SMART AND SUSTAINABLE OPERATIONS AND SUPPLY CHAIN MANAGEMENT

Smart and Sustainable Operations and Supply Chain Management in Industry 4.0

EDITED BY

Turan Paksoy and Muhammet Deveci

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Smart and Sustainable Operations and Supply Chain Management in Industry 4.0

Smart applications are transforming the conventional supply chains into digital ones. In order to compete in today's competitive market, organizations must utilize the merits of the Fourth Industrial Revolution while being sustainable, lean, and eco-conscious. Smart and Sustainable Operations and Supply Chain Management in Industry 4.0 closes the gap and provides novel ideas, research, and applications.

This book discusses smart and sustainable supply chain management concepts that will be analyzed within the Industry 4.0 perspective. It also analyzes green systems and smart applications within an Industry 4.0 setting. The book presents the latest technological developments, including disruptive technologies and their impact on smart and sustainable supply chains in accordance with the triple bottom line approach. For easy reader comprehension, each chapter will include a case study, a related problem, or a numerical example, as well as the solution.

This book is written for academicians, practitioners, PhD students, and researchers involved in this area.

Smart and Sustainable Operations and Supply Chain Management

Series Editor:
Turan Paksoy

This new book series will focus on smart applications of Industry 4.0 and how that involves operations and supply chain management and the triple-bottom line approach of: 1) Economic impact; by increasing productivity and achieving operational excellence; 2) Social Impact; by generating human-centric workplaces; 3) Environment impact; by eliminating waste and reducing material usage and applying recycling and reuse in the product design process. The series will include topics such as product price, quality, cooperation, reliability, on time delivery, lean production, corporate social responsibility, green production, green transportation and green packaging for smart and sustainable operations/supply chain management.

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Contents

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1 Fundamental Concepts of Smart and Sustainable Operations and Supply Chain Management

Sercan Demir and Turan Paksoy

CONTENTS

1.1 INTRODUCTION

1.1.1 FUNDAMENTALS OF PRODUCTION AND SECTORS OF ECONOMY

Production is a process of combining various material inputs and immaterial inputs (plans, know-how) in order to make something for consumption (output). It is the act of creating an output, a good or service that has value and contributes to the utility of individuals (Wikipedia 2020). Buffa (1977) defines "production" as the "creation of goods and services through productive systems."

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According to Kumar and Suresh (2006, p. 3), "production" is defined as "the step-by-step conversion of one form of material into another form through a chemical or mechanical process to create or enhance the utility of the product to the user." Sickles and Zelenyuk (2019) state that "a production process can be viewed as a process whereby some technology transforms inputs (x) into outputs (y)."

Production processes transform raw materials (or data) into valuable finished goods (or information) by means of technology. Value is added to the produced goods or services at each stage throughout the transformation processes of production. This value addition is only possible by transforming inputs (e.g., labor, capital, material, energy, and know-how) into outputs (finished goods and services). Figure 1.1 shows the transformation process of production.

This transformation might not always create tangible products; for instance, the created value is intangible in the service sector (e.g., hospitals, courier services, and the entertainment industry). The output of the value creation process depends on the sectors of the economy. Table 1.1 describes the four sectors of the economy and the related outputs.

The primary sector of the economy is about obtaining raw materials and directly using natural resources. This sector's field of activity includes, but is not limited to,

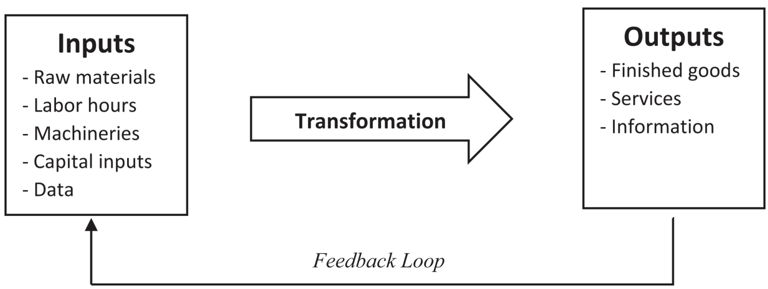

FIGURE 1.1 Transformation process of production.

TABLE 1.1
The Main Sectors of the Economy

Sectors of Economy	Description	Outputs
Primary	Extraction or production of raw materials	Mining (coal, iron, extracting of petroleum), agriculture (corn, sugarcane), forestry (wood), livestock, and fishing
Secondary	Producing finished goods	Manufacturing (car, clothing, processed food), utility companies (electricity, gas), and construction industry
Tertiary	Supplying services to individuals or businesses	Retail, financial services, travel and leisure, real estate, and the healthcare industry
Quaternary	Knowledge-based industries that generate advanced technologies	Information and Communications Technology (ICT) and research and development (R&D) advisory services

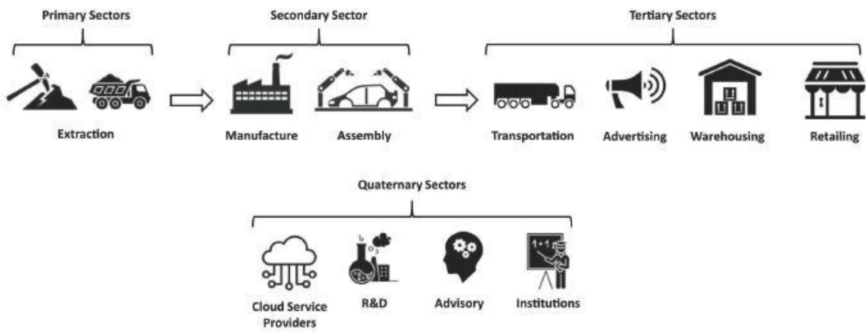

FIGURE 1.2 An illustration of the primary, secondary, tertiary, and quaternary sectors of the economy.

coal and iron mining, extraction of oil and gas, agriculture, forestry, and fishing. The primary sector of the economy is the supplier of the secondary and tertiary sectors of the economy. The secondary sector of the economy produces finished usable goods by using the outputs of the primary sector. Some examples of the secondary sector's outputs are consumer goods, such as cars, apparel, convenience foods, and residential and business buildings. The tertiary sector of the economy refers to the service sector concerned with the production of services (e.g., intangible goods) instead of finished goods. The tertiary industry can be categorized into two groups. The first one is commercial services to make money, such as financial markets and institutions, insurance companies, transport companies, and advertising agencies. The second group consists of the non-profit segment of the service sector, such as public education, safety, and health. The tertiary sector supports the primary and secondary sectors of the economy through some of its service operations, such as transport, warehousing, advertising, and insurance. Figure 1.2 illustrates the relation between the four sectors of the economy.

The fourth sector of the economy, the quaternary sector, is relatively new, and it consists of intellectual industries, such as information-based service providers. Some examples of businesses that operate in the quaternary sector are cloud computing service providers, Information and Communication Technology (ICT) companies, advisory services, R&D service firms, and institutions. Quaternary services can be outsourced since information-based services are not tightly restricted to resources, raw materials, or local suppliers. Many companies outsource IT services in order to cut operation costs and focus on their core businesses. Figure 1.3 depicts the rate of employment based on each sector of the economy during the pre-industrial, industrial, and post-industrial ages in the UK.

The change in the employment distribution among the sectors of the economy in the UK has been affected by the various stages of Industrial Revolutions. During the pre-industrial ages, the agrarian society prevailed, and cultivating the land was the primary source of income. Hence, most people were employed in the primary sector before the Industrial Revolution. As the Industrial Revolution took place, the labor force moved toward the secondary sector since more workers were needed in

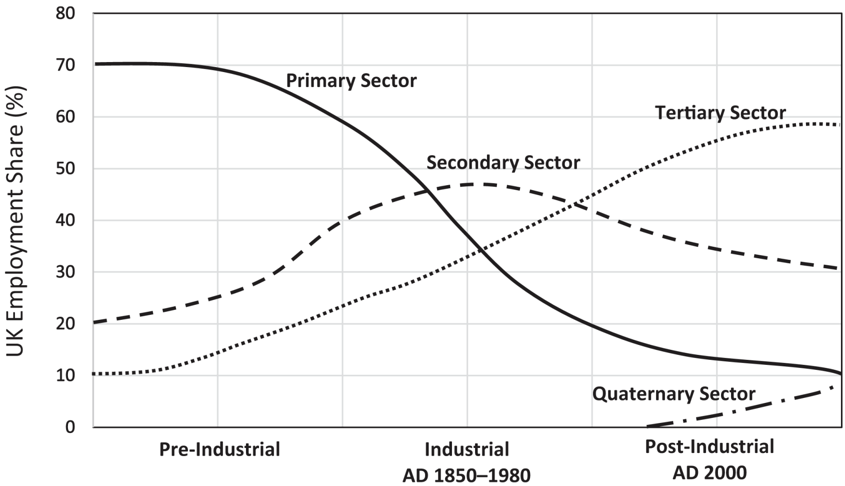

FIGURE 1.3 Distribution of employment based on sectors of the economy from 1800 to 2000 in the UK. (Adapted from BBC Bitesize 2020)

the factory system (e.g., steel and textile production). During this period, the use of external energy resources and technology increased the scale and rate of production dramatically (e.g., mass production). Additionally, the use of mechanization in agriculture brought about the need for fewer workers in the fields. Nearly half of the workers were employed in the secondary sector at the beginning of the 1900s in the UK. As people moved from rural areas to cities, the demand for education, healthcare, retail, and real estate increased substantially. This population growth led to the rapid rise of the tertiary sector. More than half of the workforce in the UK is employed in the tertiary sector today, and this sector has surpassed the primary and secondary sectors in terms of the size of the labor force since the beginning of the 2000s. The quaternary sector has recently emerged and is also known as the sector of information. The efforts of industries in this sector (e.g., ICT, R&D, advisory) make use of the latest technology; hence, the quaternary sector exists in the most economically advanced countries. Over the last decades, advances in Information and Communications Technology have accelerated and led this sector to proliferate. As a result of the rapid decline in the primary and secondary sectors, the tertiary and quaternary sectors constitute almost 75% of the labor force in the UK.

Originally introduced by Hayes and Wheelwright (1979), the Process-Product Matrix (aka Hayes and Wheelwright Matrix) classifies manufacturing methods based on product variety and production volume. Alternative production types are depicted on the vertical axis, while the production volume and product characteristics are on the horizontal axis. A replica of the Hayes and Wheelwright Process-Product Matrix is given in Figure 1.4.

The Process-Product Matrix is a useful tool to determine the relationship between product structure and alternative manufacturing processes. The horizontal axis, the

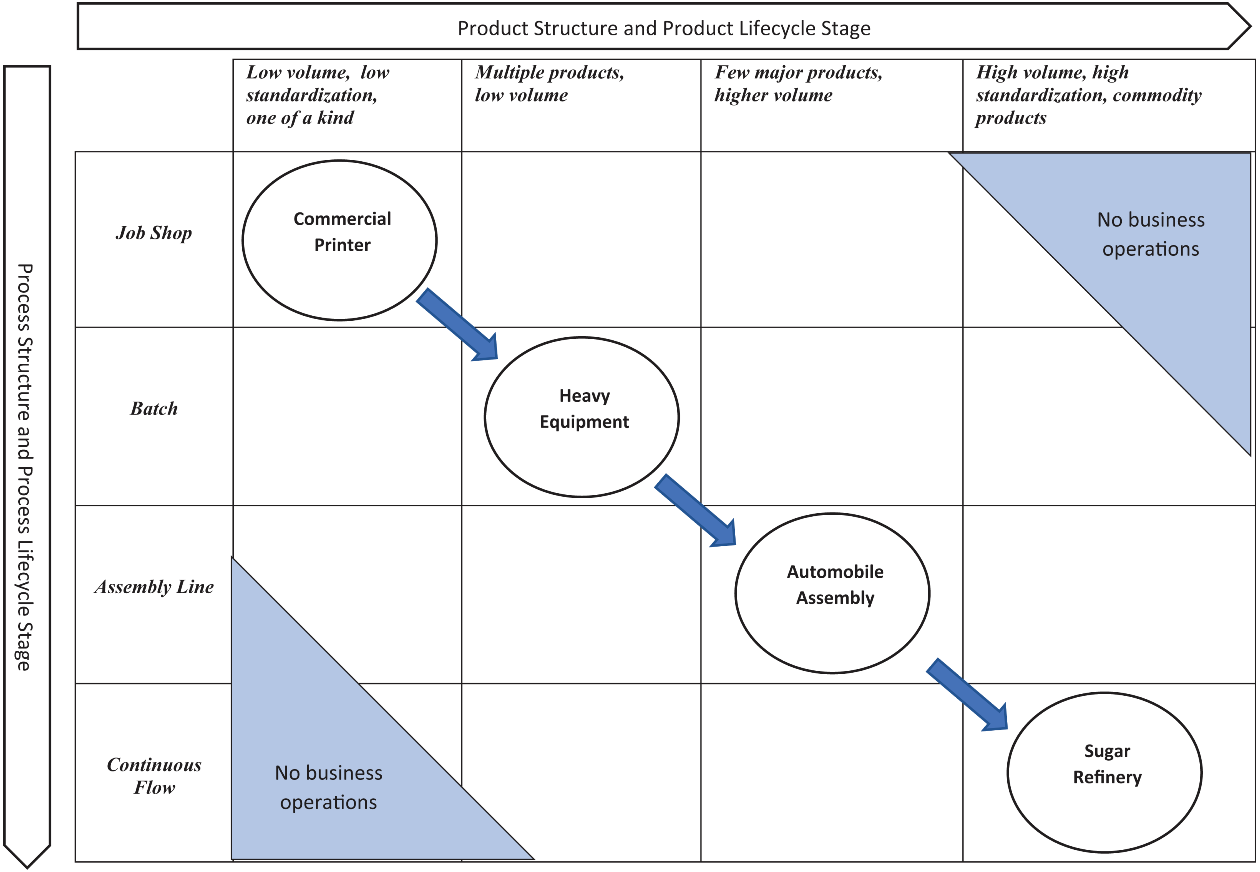

FIGURE 1.4 An illustration of the Process-Product Matrix. (Adapted from Hayes & Wheelwright 1979)

product lifecycle stage, ranges from highly customized products with low volumes to highly standardized products with high volumes. The vertical axis, the process lifecycle stage, ranges from hand-operated processes with high unit costs (e.g., job shop) to highly automated processes with low unit costs (e.g., continuous flow) (Wikivisually 2020).

1.1.2 Evolution of Production and Operations Management

One of the famous quotes about change is this: "The only thing that does not change is change itself." As new technologies, devices, practices, and procedures are being introduced every day, change in the way production is done is inevitable. The Industrial Revolution was a global phenomenon that dramatically accelerated this manufacturing transformation. The methods and applications used in manufacturing have been continuously evolving since the beginning of the Industrial Revolution. These changes push companies to adapt their operations, processes, and culture to the new phenomena to remain competitive in the market by improving their operational efficiency.

Every Industrial Revolution is characterized by the paradigm shift caused by the range of new technologies it brought about. For instance, the First Industrial Revolution started in the 18th century through the use of water and steam power in production. Later, the invention of the stationary steam engine led to the mechanization of production. The second half of the 19th century witnessed the use of electricity in manufacturing systems, while this new power source replaced steam power from the former Industrial Revolution. The invention and the rapid expansion of electricity have altered our lives irreversibly. The widespread implementation of electricity for industrial use dates back to the end of the 19th century. The installation of assembly lines powered by electricity in Henry Ford's Ford Motor Company caused a dramatic increase in productivity and popularized mass production worldwide in the 1920s. Figure 1.5 depicts the evolution of production during Industrial Revolutions.

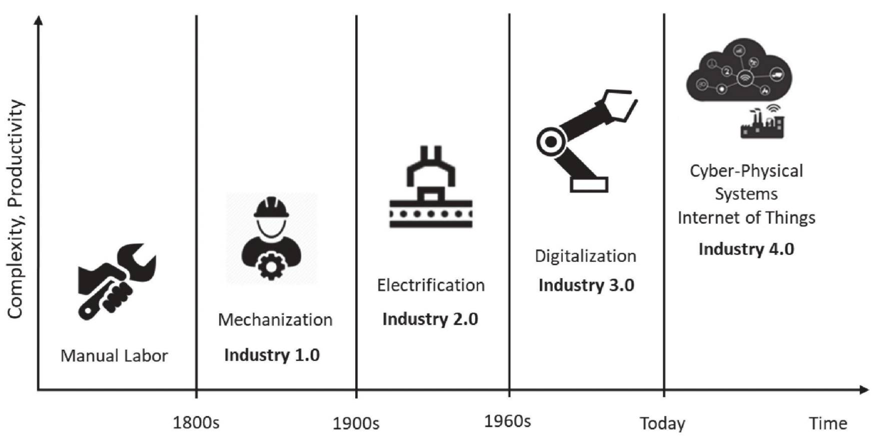

FIGURE 1.5 Evolution of production during the Industrial Revolutions. (Adapted from Demir et al. 2020)

The Third Industrial Revolution, namely the Digital Revolution, was a transition period in which the shift from mechanical production to computerized manufacturing occurred. Repetitive, consistent, and controlled manufacturing processes were expanded throughout the industry as a result of the introduction of the first programmable logic controller in 1969. As we learned how to command computers via PLCs to perform a specific task, industrial robots replaced human labor, resulting in dramatic manufacturing capacity expansion. The reduction in the cost of computing power encouraged industries to employ electronics and ICT to automate their production and paved the way for the upcoming Industrial Revolution.

The Fourth Industrial Revolution is being built upon the third one, which started in the mid-1960s. Digital technologies have transformed industrial manufacturing processes and global supply chains for decades. This transformation continues at an unprecedented speed due to the rapid advancements in digital technologies. The enabling technologies of the Industry 4.0 paradigm include, but are not limited to, the Internet of Things (IoT), advanced robotics, artificial intelligence (AI), big data analytics, cloud computing, virtual reality (VR), augmented reality (AR), cyber-physical systems, and additive manufacturing (3D printers). Smart manufacturing systems, namely smart factories, represent manufacturing environments that adopt and make the most of these emerging technologies. Smart factories are considered one of the most important outcomes of Industry 4.0. Figure 1.6 illustrates transformative technologies reshaping industrial production and are also considered the building blocks of the Industry 4.0 paradigm.

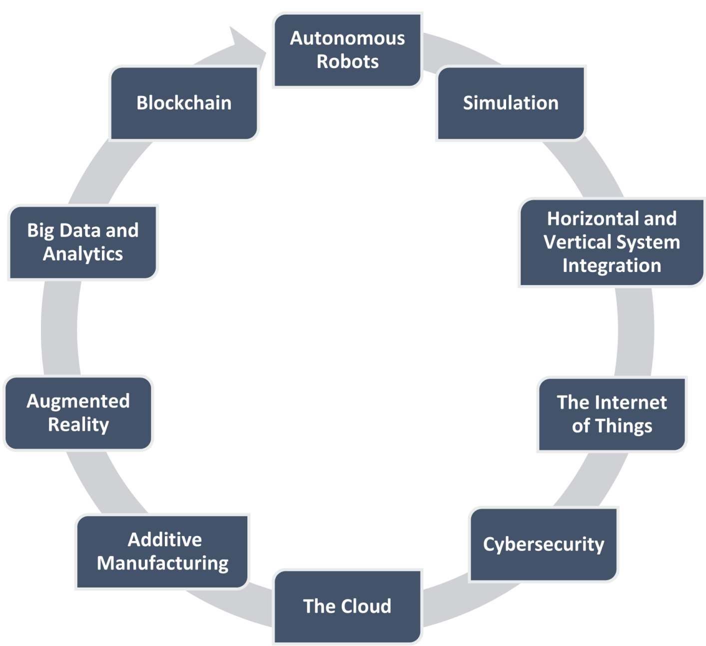

FIGURE 1.6 Ten building block technologies of the Fourth Industrial Revolution.

Heizer et al. (2017) define "operations management" as follows: "Operations management (OM) is the set of activities that creates value in the form of goods and services by transforming inputs into outputs." OM deals with the design, operation, and improvement of manufacturing and service systems (Chase et al. 2006), and it oversees the acquisition, development, and utilization of resources that are essential for a firm to continue its operations (Knowles 2019).

Various activities are performed in manufacturing or service systems, while a set of inputs are transformed into useful outputs through the transformation process. These inputs and outputs can be tangible (e.g., raw materials and physical products) and intangible (e.g., information and service). Operations management addresses critical issues and challenges in the revenue-generating transformation processes (Mahadevan 2015).

The key objectives of OM can be categorized into two main branches: customer service and resource utilization. Customer service is directly related to the satisfaction of customer needs. The output of an operating system must comply with customers' requirements in terms of cost and delivery time. Hence, the first objective of OM can be fulfilled by providing the right product at the right price at the right time. Effective utilization of resources to meet customers' expectations is the second key objective of OM. Efficient resource utilization can be achieved by obtaining maximum utility from the resources or eliminating resource losses, underutilization, and manufacturing waste (Kumar & Suresh 2006). The history of OM can be investigated under the scope of the four Industrial Revolution eras. Figure 1.7 illustrates significant events and pioneers in the history of operations management.

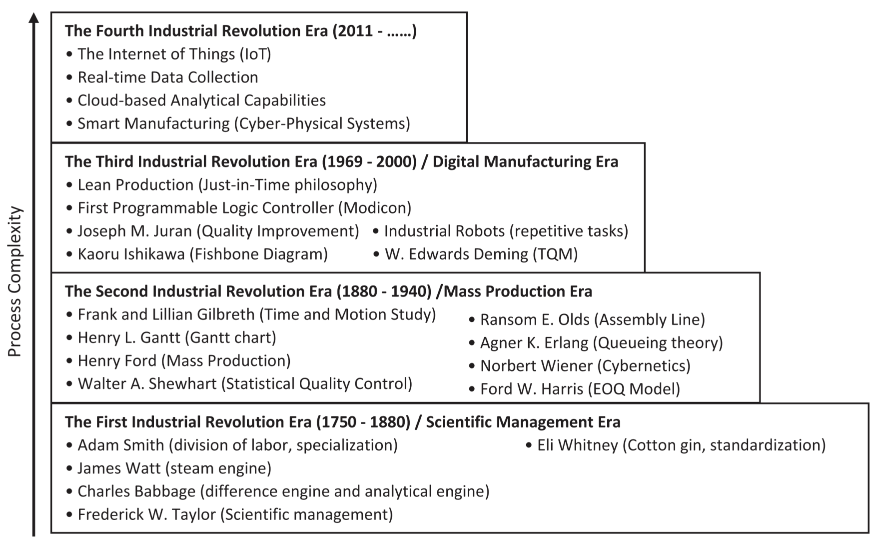

FIGURE 1.7 Milestones and pioneers in operations management.

1.1.3 Smart and Sustainable Manufacturing

Ever-shifting global markets and increasing competition put pressure on companies to look for better ways of manufacturing to sustain their competitive edge in harsh business environments. The manufacturing industry experienced many paradigm shifts throughout the Industrial Revolutions. Each Industrial Revolution left its own footprint on manufacturing, and every invention during these periods took the manufacturing industry one step forward. For instance, the First Industrial Revolution brought about the scientific management theory, known as Taylorism, and decision-makers started to utilize the scientific management approach to solve the operational problems of organizations. Mass production was one of the most important breakthroughs in the period of the Second Industrial Revolution. The industry has experienced an unprecedented productivity increase by implementing mass production methods in manufacturing. The Third Industrial Revolution started with the development of semiconductors and programmable logic controllers in the second half of the 20th century. The Third Industrial Revolution is also known as the digital manufacturing era, and the digitization of manufacturing is considered the most significant event in this period. Today, we are in the Fourth Industrial Revolution era, initiated with the propagation of the Internet in the manufacturing industry since the beginning of the 21st century. Smart factories are one of the most prominent outcomes of Industry 4.0, and this paradigm is considered the future of manufacturing. Smart factories integrate ground-breaking technological innovations, such as cyber-physical systems, autonomous robots, and real-time data collection, into manufacturing processes.

The National Institute of Standards and Technology (NIST) defines "smart manufacturing systems" as "fully-integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory, in the supply network, and customer needs" (NIST 2018). Smart factories in Industry 4.0 manufacturing environment can autonomously adapt, configure, and optimize to realize flexible and adaptive manufacturing systems. The main goal of a smart manufacturing system is to reach the desired level of production and quality performance by improving the current manufacturing systems. Creating flexible manufacturing systems will enable a company to produce customized products with small lot sizes and increase productivity (Chien et al. 2017). The increase in manufacturing process flexibility and resource usage efficiency are the main advantages of smart manufacturing. Smart products and smart factories are considered the backbones of smart manufacturing. Smart factories are highly adaptable and flexible enough to produce a large variety of products, and these products are smart enough to control their manufacturing processes. Component variation and flexibility in the manufacturing processes of smart factories are vital factors in setting up automated systems that require no or little human intervention (Dhungana et al. 2015).

Ante et al. (2018) state that companies should adopt reliable, sustainable, flexible, and productive manufacturing systems to remain competitive, and their survival in the market depends on this competitive edge.

The United States Environmental Protection Agency (EPA) defines "sustainable manufacturing" as "the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources" (EPA 2020).

According to Watanabe et al. (2016), a sustainable manufacturing system covers all production phases and the product lifecycle, from the procurement of raw materials to the sales of finished goods to customers. The authors depict sustainable manufacturing as a product-oriented system that consists of economic, environmental, and social dimensions. These dimensions are called the triple bottom line (TBL) and were introduced by Elkington (1998).

Sustainability will be the dominant issue and the driving force of the manufacturing industry in the 21st century. Sustainable production establishes a foundation for the manufacturing industry to meet society's demand to generate wealth and bolster sustainable economic development at the same time.

Even though every industrial sector constitutes a different sustainable manufacturing system, the characteristics of these systems are in common. For instance, environmental awareness should become a company culture, sustainability issues must be included in the product and process design, the use of recycled materials must become a company-wide practical implementation, and the manufacturing system should embrace the product lifecycle concept. Radical changes are needed in the design of products and manufacturing processes to maintain the inclusion of recycled components and materials in manufacturing (O'Brien 1999). Figure 1.8 illustrates the role of recycling industries in manufacturing.

Companies can improve business performance cost-efficiently by adopting sustainable manufacturing practices. This performance improvement must include economic, environmental, and social dimensions of sustainability. Cautious use of natural resources is the primary necessity of sustainability. Non-renewable resources should be used efficiently, and alternative manufacturing methods should be taken into consideration to replace renewable resources with non-renewable resources (Pusavec et al. 2010).

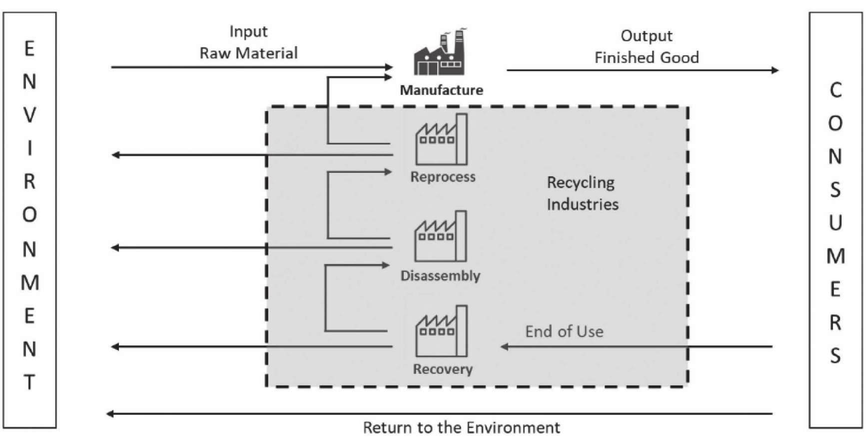

FIGURE 1.8 Recycling industries in manufacturing. (Adapted from O'Brien 1999)

Environmental challenges on a global scale result from the imprudent consumption of natural resources and the pollution caused by the contaminants released into the environment. Firms should adopt sustainable practices to minimize the negative environmental consequences of large-scale manufacturing.

1.2 SUPPLY CHAIN

A supply chain is a network of all entities and activities, from raw material providers to the final consumers who are willing to pay money for the finished goods. This network consists of suppliers, manufacturers, distributors, retailers, and customers. There are three main flows in a supply chain. Materials flow from suppliers to customers, money flows from customers to suppliers, and information flows both ways. A typical supply chain structure and the main flows of a supply chain are illustrated in Figure 1.9.

The manufacturing industry creates wealth by adding value and selling finished goods to customers. Controlling the flow of materials from the suppliers to the customers is the main concern of all manufacturers (Stevens 1989). Heizer et al. (2017) describe "supply chain management (SCM)" as "the coordination of all supply chain activities, starting with raw materials and ending with a satisfied customer." SCM combines essential business practices across different supply chain entities to organize the smooth flow of information, products, and services (Reefke & Trocchi 2013).

Mentzer et al. (2001) highlight the following characteristics of SCM:

1. The supply chain should be viewed as a whole, and the flow of goods from suppliers to the final customers should be managed under the systems approach.
2. A strategic approach should be established to build operational and strategic capabilities as a unified whole within firms and among enterprises.
3. Customer focus should be the main concern to meet unique and customized customer needs, which leads to achieving customer satisfaction.

1.2.1 Smart and Sustainable Supply Chain

The rise of smart manufacturing and sustainability concerns incites companies to intercalate smart tools and sustainability indicators into their supply chains. Increasing digitalization in the logistics processes and the necessity to reduce CO_2 emissions led companies to take an irreversible path. The adaptation of Industry

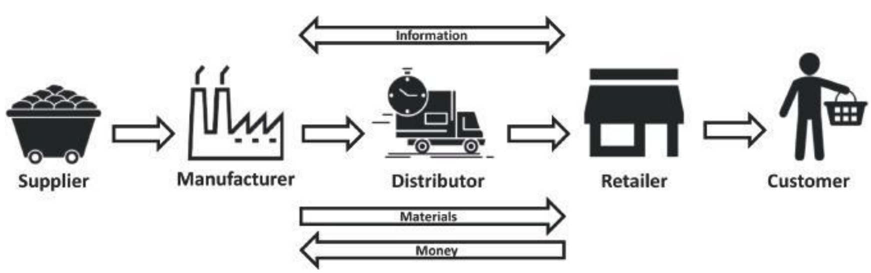

FIGURE 1.9 Structure and flows of a supply chain.

4.0 tools and green supply chain practices is necessary to achieve productive, energy-efficient, environmentally friendly, and flexible supply chains in which optimized decisions are taken quickly and decentralized. Supply chains create value by transforming raw materials or semi-finished products into finished goods through some manufacturing processes. As supply chains become smart and sustainable, manufacturing costs will be lowered as these processes utilize the limited resources prudently, customer satisfaction will increase due to a high degree of automation and shop-floor optimization, and the transformative technologies will form flexible, agile, and resilient logistics processes.

In sustainable supply chains, economic value is created by highly efficient manufacturing and distribution processes that improve productivity by minimizing the consumption of scarce resources. Collecting, sorting, and recycling waste materials or products during production, distribution, and consumer usage stages are essential for sustainability. Sustainable supply chains can be described with three Ps: profit, people, and the planet. Profit is the generation of economic value through efficiently utilizing scarce resources. The people dimension indicates customer value generation by offering products and services while considering the environmental effects of manufacturing, delivery, and returns. The planet dimension signifies the minimization of natural resource consumption and the elimination environmental impact of industrial waste (Nunen et al. 2005).

Green supply chain management (GSCM) is a new concept gaining attention from academics and practitioners in recent years. Even though sustainable supply chains are built on social, economic, and environmental dimensions, the term "green supply chain" refers to the subset of sustainable supply chains concerned with building eco-friendly supply networks. Green supply chains also deal with the financial results of supply chain activities while focusing on environmental issues. According to Cahyono et al. (2020), GSCM requires the envisioning and unification of every subset of a supply chain from a green perspective. Hence, GSCM merges green concepts, such as green purchasing, green materials and manufacturing, green distribution and marketing, and green reverse logistics. The authors further state that GSCM integrates environmental consciousness into the supply chain operations, such as product design, procurement planning, production, product distribution, and returns.

GSCM activities are classified into green procurement, green manufacturing, green distribution, and reverse logistics. Green procurement is an eco-friendly purchasing activity that reduces, reuses, and recycles materials during the purchasing period. Green manufacturing is the production method that uses eco-friendly materials and releases little or no waste to the environment. Green distribution covers all green packaging and green logistics operations. Reverse logistics is the backward flow of products from the end users and consists of collection, recovery, disassembly, reprocessing, and disposal stages (Ninlawan et al. 2010).

As supply chains become geographically dispersed and run global operations, their rate of exposure to disruptions dramatically increases. Disruption is an unexpected event that interrupts supply chain operations. According to Demir (2017), disruptions are inherent to supply chains, and natural disasters, labor disputes, supplier breakdown, wars, and terrorism interrupt and impose a high risk on supply chain operations. Besides these, an epidemic that starts in a region can spread over multiple countries and continents, and become a global pandemic, such as COVID-19, and impact the supply chains globally. These examples can be proliferated. Supply chains must integrate smart technologies into their operations to mitigate these supply chain disruption risks. Smart manufacturing enablers, such as IoT, cloud computing, autonomous robots and vehicles, AR, and cybersecurity, establish agile, robust, flexible, secure, and resilient supply chains.

Smart supply chain applications offer unique business solutions even with the complexity they possess inherently. These applications collect huge amounts of real-time data to be used to make improved business decisions. Having the ability to make better decisions result in higher system efficiency and reduced response time. Smart supply chains can remove many inefficiencies that are inherent to conventional supply chains and detect and fix system issues. Conventional supply chains need to be transformed into smart supply chains to achieve performance improvements. As the implementation cost of smart technologies lower, more and more supply chains will be part of this transformation (Wu et al. 2016).

According to Butner (2010), supply chains face five major challenges: cost containment, supply chain visibility, risk management, increasing customer demands, and globalization. The author states that building efficient, demand-driven, and transparent supply chains is essential but not sufficient to meet today's challenging business objectives and mitigate supply chain risk efficiently. Besides these, supply chains must be smart. De Giovanni (2020) investigates the impacts of smart applications and artificial intelligence systems on supply chains. The author concludes that AI systems significantly improve the decision-making process by eliminating errors and effectively synchronizing production planning and demand forecast capabilities. According to Scherbakov and Silkina (2019), smart supply chains are progressing together with Industry 4.0 and becoming an inseparable part of smart digital production by bringing about speed, adaptability, and accuracy. Smart supply chains have many advantages compared to conventional supply chains. Table 1.2 compares the traditional and the smart supply chains.

TABLE 1.2
Comparison of Traditional and Smart Supply Chains

	Traditional Supply Chains	Smart Supply Chains
Transparency	Transparency is limited	Smart tools ensure full transparency
Data Collection	Data might be lost or distorted as it moves through the chain	Real-time data can be collected with sensors and IoT devices
Responsiveness	Response to the market is slow	Quick response to customer requests or any changes is one of the main strengths
Traceability	Traceability is limited and costly	Intelligent systems can trace all operations in the supply chain
Adaptability	Traditional supply chains are vulnerable to unexpected changes	Adaptive supply chains are capable of responding to sudden changes in the market
Feedback	The feedback system is slow and exposed to delays	Real-time feedback at all stages of the chain can quickly be received and evaluated

1.3 PRODUCTIVITY: BASIC DEFINITIONS

1.3.1 Productivity

As discussed in the first section, production is the creation of finished goods and services by changing resources in a transformation process. Figure 1.1 indicates the inputs and outputs sides of this transformation process. The concept of productivity is related to the number of inputs and generated outputs, and the transformation process directly affects productivity.

Schreyer and Pilat (2001) define "productivity" as "the relationship between output and the inputs that are required to generate that output." In other sources, it is described as "a ratio of a volume measure of output to a volume measure of input use" (OECD 2001) or "the ratio of outputs (goods and services) divided by the inputs (resources, such as labor and capital)" (Heizer et al. 2017).

Productivity improvement can be made by either reducing inputs while keeping outputs at a fixed level or increasing output while keeping inputs constant. Inputs are the resources integrated into a production system, such as labor hours, capital, raw material, and information. Outputs of a production system are finished goods and services. A high production rate insinuates the involvement of many people in production activities, which implies a low unemployment rate; however, this situation does not necessarily mean high productivity. Productivity measurement facilitates the evaluation of a country's living standard. The improvement of these standards is possible by increasing productivity (Heizer et al. 2017).

Productivity can be measured in many different methods, and the selection of the measurement method is usually based on the purpose and the available data. Generally, productivity measures can be classified as single-factor productivity measurements and multifactor productivity measurements. Single-factor productivity measurement is the ratio of output to a single input, while multifactor productivity is the ratio of output to a bundle of inputs. Another productivity measurement classification is based on the type of output measure: the ratio of gross output to one or several inputs or the ratio of value-added output to one or several inputs (OECD 2001). The comparison of the main productivity measures is given in Table 1.3.

The most commonly used formulas for productivity measurement are given subsequently. Single-factor productivity formula uses one resource (input) to measure productivity.

$$\text{Single Factor Productivity} = \frac{\text{Output}\left(\text{Units Produced}\right)}{\text{Resource}\left(\text{Input Used}\right)} \tag{1.1}$$

The multifactor productivity formula included all resources (input) to measure productivity.

$$\text{Multifactor Productivity} = \frac{\text{Output}\left(\text{Units Produced}\right)}{\text{Resources}\begin{pmatrix}\text{Labor} + \text{Material} + \\ \text{Energy} + \text{Capital} + \text{others}\end{pmatrix}} \tag{1.2}$$

TABLE 1.3
Overview of Main Productivity Measures

Type of Output Measure	Type of Input Measure			
	Labor	**Capital**	**Capital and Labor**	**Capital, Labor, and Intermediate Inputs (Energy, Materials, Services)**
Gross Output	Labor productivity (based on gross output)	Capital productivity (based on gross output)	Capital-labor MFP (based on gross output)	KLEMS multifactor productivity
Value Added	Labor productivity (based on value added)	Capital productivity (based on value added)	Capital-labor MFP (based on value added)	——
	Single-factor productivity measures		**Multifactor productivity (MFP) measures**	

(OECD 2001)

1.3.2 Efficiency

Efficiency is the ability to produce goods or services without wasting materials, time, or energy. An efficient company can meet its business goals by manufacturing finished goods and offering services with the minimum expense, waste, and effort. Hence, efficient firms can maximize outputs from given inputs and minimize their costs. Efficiency is about making the best possible use of limited resources, and it is expressed by a percentage between 0% and 100%. In manufacturing, efficiency is the ratio of actual output to expected or desired output.

$$\text{Efficiency} = \frac{\text{Actual Output}}{\text{Expected Output}} \tag{1.3}$$

1.3.3 Efficacy (Effectiveness)

Efficacy is the ability to perform a task to a satisfactory or expected degree (Wikipedia 2021). The words “efficacy” and “effectiveness” can be used interchangeably, and they imply the capacity for producing a desired result or effect. While efficiency is directly related to resource utilization, efficacy is related to manufacturing performance.

$$\text{Efficacy} = \frac{\text{Achieved}}{\text{Desired}} \tag{1.4}$$

1.3.4 OEE (Overall Equipment Effectiveness)

The capacity utilization rate might be fairly low for many reasons in the manufacturing industry (Ljungberg 1998). OEE can be explained as the ratio of the actual equipment output to the maximum equipment output under the best performance condition. One of the major goals of OEE is to minimize or totally eliminate the "six big losses" that are reasons for efficiency loss in manufacturing (Almeanazel 2010).

Nakajima (1988) defines "OEE" as "a bottom-up approach where an integrated workforce strives to achieve overall equipment effectiveness by eliminating the six big losses."

These six big losses are defined by Nakajima (1988) as follows:

a. Downtime:
   1. Equipment failure
   2. Setup and adjustment
b. Speed losses:
   3. Idling and minor stoppages
   4. Reduced speed
c. Defect:
   5. Process defects
   6. Reduced yield

The six large losses are measured by OEE, and it is a function of availability (A), performance rate (P), and quality rate (Q). Therefore, OEE is quantified as follows:

$$OEE = A\,x\,P\,x\,Q \tag{1.5}$$

where,

- $A = [\text{Actual Production Time / Potential Production time}] \times 100$
- $P = [\text{Actual Output / Theoretical Output}] \times 100$
- $Q = [\text{Good Product Output / Actual Output}] \times 100$

1.3.5 A Numerical Example

ABC Co., a producer of wooden toys, wants to evaluate its single-factor and multifactor productivity. The company has 750 labor hours per day and pays $10 for each labor hour. Besides, the company incurred $3,000 for materials used, $1,000 for energy expenses, and $500 for miscellaneous costs. Given that the company produces 1,500 toys a day:

$$\text{Single Factor Productivity}\left(\text{labor hour}\right) = \frac{1500}{750} = 2 \text{ toys per labor hour}$$

$$\text{Multifactor Productivity} = \frac{1500}{\left(750 \times 10 + 3000 + 1000 + 500\right)} = 0.125 \text{ toys per dollar}$$

Given that the company's production capacity is 1,875 toys per day, however, it can only produce 1,500 toys a day for various reasons:

$$\text{Efficiency} = \frac{1500}{1875} = 0.80$$

Given the following table:

Availability	Actual Production Time	9 hours	$A = \frac{9}{10} = 0.90$
	Potential Production Time	10 hours	
Performance Rate	Actual Output	1,500 toys	$P = \frac{1500}{1875} = 0.90$
	Theoretical Output	1,875 toys	
Quality Rate	Good Product Output	1,482 toys	$Q = \frac{1482}{1500} = 0.988$
	Actual Output	1,500 toys	

$$OEE = 0.90 \times 0.80 \times 0.988 = 0.71136$$

1.4 CASE STUDY: SMART AND SUSTAINABLE APPLICATIONS AT KAREL ELECTRONICS

1.4.1 Company Profile

Karel created the electronic telephone exchange market in Turkey in 1986 with its original designs, provided PBX products to this market, and pioneered Turkey's transition from electromechanical systems to electronic systems in communications. Established with 100% domestic capital, Karel has the most advanced R&D department in Turkey in the communication electronics field today, and its facilities are compliant with international standards. Today, Karel is the market leader in Turkey for exporting products and technologies to more than 30 countries and is among the top 15 manufacturers globally.

According to the reports of all international and national research institutes, Karel is the market leader in PBXs by far in Turkey. Today, more than 700,000 businesses are using Karel PBXs. Over 50% of the business communication traffic is performed via Karel systems in Turkey. Karel is positioned amongst the top 500 industrial organizations in Turkey.

Karel develops and produces wired or wireless communication systems with different technologies, features, and capacities in its main field, namely telecommunications. Major products consist of special PBXs with small, middle, and large capacities and peripherals to these PBXs, IP call centers, and so on, in the superstructure class, and rural PBXs and interconnection PBXs in the infrastructure class. Following the advancements in technology closely and being a pioneer in technology, Karel has reinforced this position with Unified Communication Solutions. Consequently, Karel also operates in the visual communication and security systems field and performs sales and project-based applications for the intruder alarm systems market. Karel sells its products via its distribution network of Karel authorized dealers domestically and via distributors abroad. Karel also imports some complementary products covering its activities in the telecommunications field. Karel also collaborates with foreign companies to carry out turnkey projects for public and private sector organizations. As an electronic systems manufacturer, Karel mainly operates in the household appliances electronics design and production field.

1.4.2 R&D and Technology Infrastructure

Karel, the most prominent company without a foreign partner in the communications electronics sector in Turkey, is an independent company in terms of licenses and know-how. Karel places a great emphasis on research and development (R&D) activities, and it has one of the most advanced, most systematic R&D centers with the highest level of know-how in its sector in Turkey.

Product development activities are performed at the R&D premises located in Bilkent Cyberpark. Long-term competitiveness in the sector depends on the potential and competence in the incorporation of new technologies and integration of these technologies into the product systems. Developing rational technologies, translating these to marketable products, and presenting them to the market are vital in this day and age when technology advances rapidly. Therefore, having powerful R&D capabilities has always been Karel's first priority since its establishment.

Karel has been reserving 10% of its consolidated sales turnover generated by the production to R&D investments for many years. This ratio is much over the average in Turkey. Karel R&D center, employing 187 employees, has a well-deserved position in Turkey in terms of communications electronics and industrial electronics. Karel strengthens this experience in knowledge and equipment by selling designs and projects to companies such as Aselsan and Arçelik.

1.4.3 Production

Karel is placed amongst the strongest companies in terms of production capabilities and capacities. Karel's world-class production facilities, spreading over a covered area of 32,000 m^2, are located in the Ankara Industrial Zone. Production planning, purchasing, production, and control services are performed in these facilities.

The manufacturing chain between suppliers and customers is supervised via the ERP system integrated on the basis of the company. Plain Six Sigma techniques are applied in production to improve productivity and quality. Applying procedures conforming with the ISO 9001:2008 certificate and CMMI Level 3 certificate obtained by the R&D department, besides the strong production experience, Karel designs and produces electronic boards complying with international standards for both domestic and foreign major manufacturers besides its own products.

Under continuous development and assessment, the placement and test machines with state-of-the-art technology are employed in the production line. Leaded and/or lead-free placement is possible using horizontal, vertical, and surface installation technologies in the automatic assembly process. The total automated component placement rate is 300,000 components per hour. Placement, soldering, optical inspection, ICT, and functional test procedures are performed serially in fully automatic lines. It is possible to perform full automated conformal coating to protect the electronic boards from environmental influences. In-line and stand-alone optical inspection devices, advanced X-ray devices, heat test cabinets, and vibration testers used for inspection and testing operation increase the quality and reliability of the production.

1.4.4 Exports and International Activities

Karel, heading for foreign markets since 1990, is exporting products and technology to more than 30 countries all over the world with the Karel brand. Karel, employing a product range especially suitable for developing markets, is indicated as one of the 15 biggest manufacturers in the world by international research institutes, as in the recent MZA report. Over 12 million people in the world communicate by using Karel systems. Karel, with a global understanding, has set growing in foreign markets with its own brands and products as one of its prioritized objectives and places great importance on investments in foreign markets in this context.

1.4.5 Smart and Sustainable Operations at Karel

Karel Electronics produce high-tech products and industry solutions. The company output can be classified into four categories: communication solutions and products, security systems, cloud solutions, and IoT solutions.

Products and Solutions	Details
Communication Solutions and products	- PBX phone systems: small-, medium-, and large-scale businesses - Call center: IP-based call center systems and contact center solutions - Phones: IP phones, analog phones, wall phones, and so on - Convergence and integrations: conference, GSM terminals, wireless - DECT systems, VoIP, and network products
Security systems	- Security camera systems - Intruder alarm systems - Intercom systems
Cloud solutions	- The new generation of Internet applications assists businesses in maintaining economic, productive, and flexible operations
IoT solutions	- Energy productivity, indoor navigation, and vehicle tracking system

Visibility of the entire manufacturing system is a crucial activity in smart manufacturing systems. Karel Electronics diligently track the system's status while manufacturing high-tech products and services. To track productivity, the company collects OEE data from the manufacturing lines and sends these data to the Andon monitors in real time. The assembly process in a workshop using Andon monitors is given later.

The data acquisition system comprises some high-tech and conventional modules connected to computers to collect real-time information from the manufacturing and assembly lines. In Figure 1.10A, these off-the-shelf acquisition modules are given. Some of these modules can collect data automatically without human intervention. For example, when the label given to an electronic board is automatically sensed by the sensors/PLC, the whereabouts of this electronic board are exactly known in the production line. Furthermore, precise and accurate information about what action, by whom, and when it is performed can be received on this electronic board. In another process, a different sensing technique is used. In the testing area or the production line, where human intervention is really necessary, the operators input data by means of a data acquisition terminal or intelligent test equipment (Figure 1.10B). Hence, the required data can be collected from the field in real time with high precision and accuracy.

The collected data are sent to a database through Wi-Fi networks.

All data are stored in a structural and central database system to evaluate the measures required to monitor OEE in real time. A correct calculation of OEE is highly dependent on how well three factors are measured: performance, quality, and availability. These factors are a good measure to assess the efficiency level of an operation completely while it is progressing. The required data to calculate these three factors are exported from the database and processed automatically in standardized procedures on a timeslice-by-timeslice basis. For example, as explained in Chapter 1.3, availability is a ratio of actual production time to potential production time defined in percentage form. Therefore, the actual and potential production times are calculated

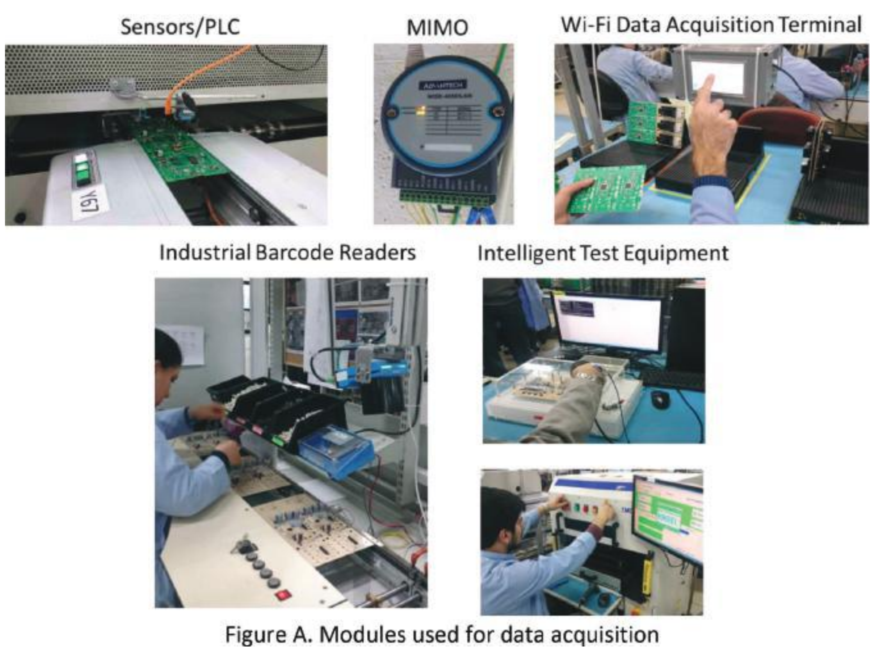

FIGURE 1.10A Modules used for data acquisition.

FIGURE 1.10B A scene from the manual assembly line.

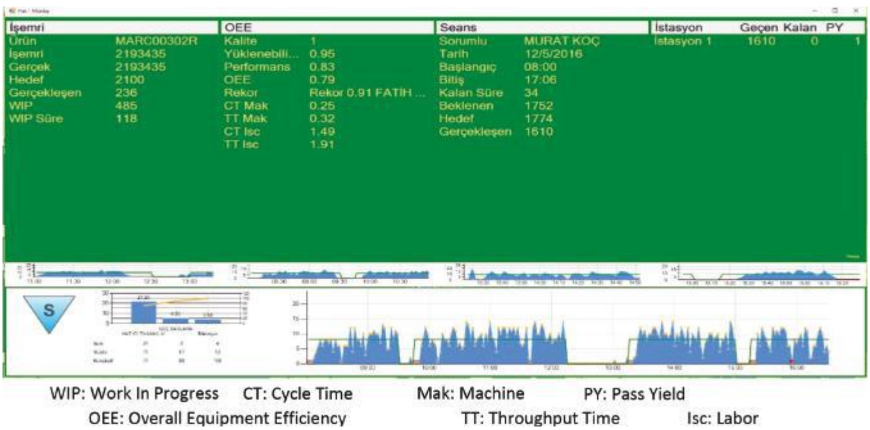

FIGURE 1.10C A screen to monitor the performance of an assembly station.

based on the data collected from the field within a specified timeframe. Similarly, the other metrics are also calculated within the same timeframe to obtain the quality rate and performance rate of the operation of interest. Finally, the OEE of this operation is quantified by using the values of these factors and is displayed on the screen, as shown in Figure 1.10A. Figure 1.10C, Figure 1.10D, and Figure 1.10E illustrate the information monitoring system for the manufacturing, assembly, and test lines, respectively. At some stations, operator performance has a direct impact on station performance. To develop suitable treatment processes for operators with poor performance, the production rate can be tracked on an operator basis. In addition, there is another monitoring system specially designed for only managers to enable them to

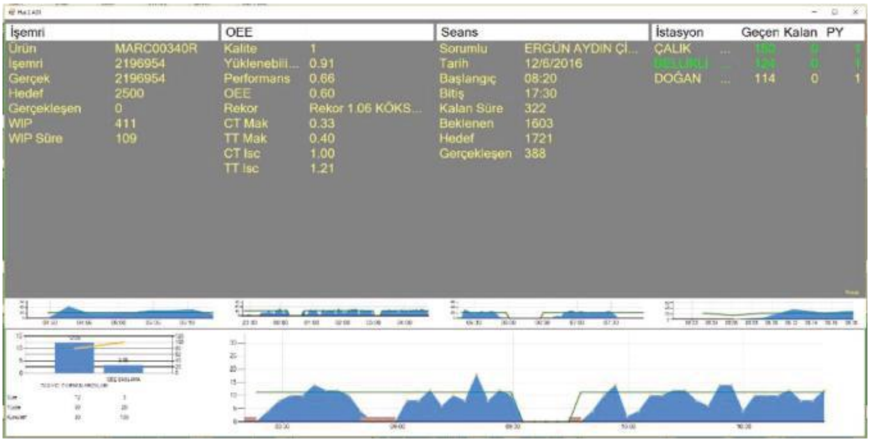

FIGURE 1.10D A screen to monitor the performance of an Automated Optical Inspection (AOI) station.

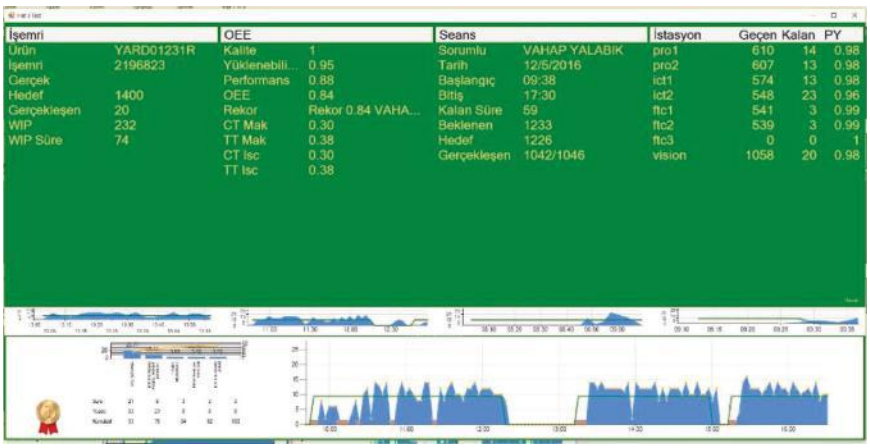

FIGURE 1.10E A screen to monitor the performance of a test station.

check the status of all operations in progress and the performance of all employees (Figure 1.10F).

Hakan Mert Saraçoğlu, Karel's quality manager (Figure 1.10G), summarized the project as follows: Thanks to the digital transformation we have carried out in our company, a real-time electronic data collection and monitoring system has been established in the production lines. Based on this Manufacturing Execution System, a digital performance measurement system supported by sensors, barcode readers, and IoT devices; an electronic kanban system for real-time inventory control reinforced by e-mails and Andon dashboards; and a digitalized 5S and visual management system using electronic forms have been developed. Thanks to these electronic forms that the company employees can easily access, a green production data management

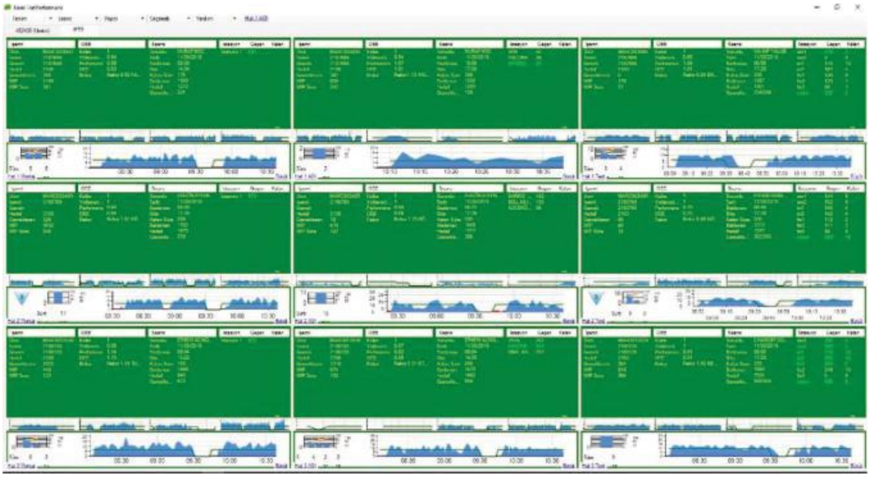

FIGURE 1.10F A multiscreen for managers to monitor the performance of all stations.

FIGURE 1.10G Karel's quality manager.

system has been created instantly and without wasting paper. This system also helped us to carry out the full traceability of the PCBAs, analyze historical data, and take measures accordingly.

All these digitalization efforts support sustainability by eliminating waste (material, labor, quality losses, etc.) in the company in accordance with lean production principles and enabling more and better-quality production by using less input/material. Moreover, paper wastage has disappeared with the digitization of the document/data management system. Therefore, Karel can be an excellent example because digitalization supports sustainability with the effective use of materials and information management.

1.5 CONCLUSION

This chapter presents a comprehensive review of the basic concepts of smart and sustainable operations and supply chain management. The past Industrial Revolution fundamentally impacted the production process, and this transformation has been continuing for decades. The Fourth Industrial Revolution brought about its technologies and paradigms and led to the beginning of a new era in the transformation of production and service sectors. Each day, more companies are adopting smart and sustainable paradigms due to factors such as increasing global competition, increasing diversity in consumer demands, and a highly moving technological growth rate. Emerging technologies of Industry 4.0 have already started to be part of the manufacturing process in various sectors. These technologies provide a flexible, agile, customer-centric, and cost-conscious manufacturing system. Besides, sustainability is another dimension that companies should consider an indispensable part of their production system. Smart tools help enterprises control, monitor, and quickly intervene in the manufacturing process while strengthening the sustainability dimension of the business processes. Enterprises must integrate smart and sustainable practices to gain a competitive advantage in today's harsh market environment.

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2 Operations Strategy

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CONTENTS

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2.1 INTRODUCTION TO OPERATIONS STRATEGY

Among the areas of operations management (OM) research, the results of work done to identify which themes are the most prevalent in this particular area point to operations strategy (OS) as the most prominent theme (Figure 2.1). This result was obtained through a bibliometric study that started with an analysis of the co-citations of authors who have produced articles on OM-related themes. Based on their exploration of how OS had been formulated, Adam Jr. and Swamidass (1989) concluded that new terms were created without expanding knowledge about the theme. Also, the consistency of actions from one strategy to another (business and operations), between operations and other strategic functional areas, and between the operations mission and its infrastructure is considered. A company's operations strategy outlines how its operational functions will complement its corporate strategy to achieve its long-term objectives. In fact, operations strategy often dictates the corporate objectives of a company. This does not imply that operations strategy needs to take a passive, reactive role.

Trading tactics are divided into two categories (not necessarily mutually exclusive). The first operational strategy is concerned with process design and the infrastructure required to support it. Technology selection, process capabilities, process location, and design all factor into process design considerations. Developing planning and control systems, quality management systems, and the organization of OM operations are all infrastructure considerations. Another operational plan is the company's competitive strategy, including operations. Operational strategies include activity-based strategies, skills-based strategies, and time-based capabilities (TBC).

Operations strategy is the collective tangible movements decided, ordered, or inspired utilizing the corporate approach. Of course, the operations function is responsible for this. With the aid of linking organization policies, programs, and systems, this operations approach binds the various operations selections and

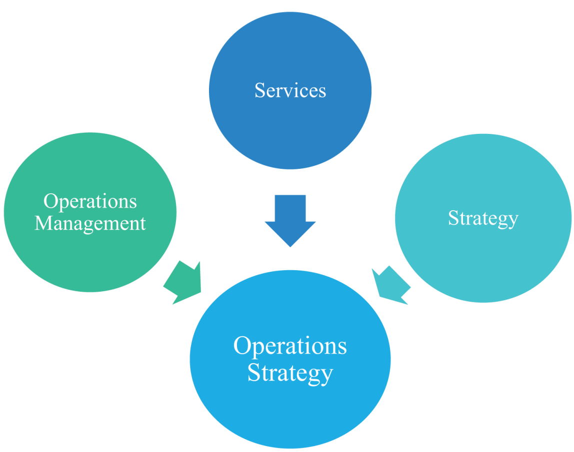

FIGURE 2.1 Operations strategies pillars. (Taghavi 2022)

moves right into a cohesive, regular reaction to aggressive forces, and moves into a scientific reaction to the aggressive priorities selected and communicated with the aid of the company or enterprise strategy. In simpler terms, the operations plan outlines how the company will use its operations capabilities to support its business strategy.

Long-term issues exist concerning operational strategies for properly identifying and developing the company's primary operational resources and ensuring a high level of compatibility between these resources and the business plan. It provides solutions to various queries concerning how essential resources should be structured to meet a company's business objectives. Challenges are related to long-term decisions concerning capacity, location, procedures, technology, and scheduling. Operations must be connected with other corporate competencies to reach world-class status via operations. Two important functions underpin a company's entire strategy. One alternative is establishing a method that gives the company a distinct competitive edge. Marketing benefits are delivered through obvious and distinctive technology advances in processes unrivaled by rivals. Some scholars express the general notion of operational strategy in simple words.

Booz et al. (1982) use the concept of production task. They describe their mission as a way to source, manufacture, and distribute products. The assignment should also specify the level of process flexibility, product configuration, customer service, product quality, product cost, productivity, and other production requirements. Shimeld et al. (1989) propose a strategic production approach that emphasizes the essential requirement of linking marketing and production perspectives to determine the best strategy for the entire company. Hill's manufacturing strategy approach provides business goals, marketing strategies, and manufacturing facilities and infrastructure by assessing whether different products (existing and planned) can win, certify, or lose orders in the market.

2.1.1 Key Concepts in Operations Strategy

The world we live in is in a period of great change. The challenges of the 21st century cover every aspect of our lives: social, technical, economic, political, and ecological, including terrestrial climate change. Abnormality is not evolution itself. However, the rate of change that accompanies it is high. As an active player in this formidable rapid change, the burden of running a business becomes heavier, finding sustainable ways to survive and compete effectively. Although the company operates in major global markets, environment variables are characterized by greater uncertainty, volatility, complexity, and ambiguity. The main pillars of the operations strategy are as follows:

2.2.1.1 Operational Efficiency

Operational efficiency refers to a company's capacity to manufacture and deliver products and services in the most cost-effective way possible (Case et al. 1982). Companies must guarantee that their products and services satisfy the highest quality standards while attempting to create the most cost-effectively feasible. Businesses can improve operational efficiency by streamlining their fundamental business operations to adapt to changing market conditions more effectively. Reducing redundancy and waste, harnessing the resources that contribute to success, and recruiting the best staff available in a business are the most effective ways to improve operational efficiency.

2.2.1.2 Operational Effectiveness

The component of an organization's performance that entails having a well-functioning function is referred to as performance. In order to properly implement an organization's plan, these traits must function together. This comprises many methods that assist businesses in the following:

i. Make better use of their free resources and reduce costs
ii. Improve business processes
iii. Accomplish their tasks and objectives

Like Michael E. Porter, many management professionals have acknowledged that an organization's success depends on its performance and strategy. Performance refers to an organization's ability to improve its functional performance. Managers do this by coordinating and monitoring functional performance, assessing and enhancing managed processes, and utilizing these advancements to boost functional efficiency.

2.2.1.3 Operational Strategy

Operational strategy is one of the essential topics in operations management. Every company must develop and implement an appropriate plan to achieve successful operations. The organization's important resources will be wasted if the proper plan is not implemented. A business's operational strategy is a way to achieve its objectives. By adopting the correct operational strategy, businesses may build and implement effective and efficient methods for using resources, people, and workflow. The operational strategy is linked to the company's functional organization. They are an element of the business plan for the organization. Managers are cautious about including a section on operational strategy in their business plans. These strategies describe the company's operations and how each process is performed to achieve the overall business goals. An effective presentation of operational strategies in a business plan provides a solid and reliable basis for the financial goals set in the business plan.

2.2.1.4 Operational Sustainability

Operational sustainability determines if a business can continue to operate without jeopardizing future resources (Glynos & Howarth 2007). Operational sustainability covers various topics, including ecological, social, and economic resources. Each of these resources is described in full further later. From an ecological point of view, corporate sustainability refers to a company's ability to use natural resources at its current pace without depleting the resources it depends on. From a social perspective, operational sustainability refers to the ability of every individual in a company or every company in a region to access the same or the same resources.

From an economic point of view, the sustainability of a business refers to the impact of a company's activities on other organizations operating in the region and its ability to continue and thrive.

2.2.1.5 Quality

In order for customers to like the products of a for-profit company, care must be taken to ensure that the products sold are considered to be of high quality. They are often defined as the non-inferiority of a product or service in the market. Some regulatory experts also define it as the suitability of a product for a particular application. Consumers often focus on the quality of their specifications. This shows how a product/service is compared to other competitors.

However, manufacturers often focus on compliance quality, which refers to how a product or service is properly manufactured. Often, consumers do not judge a company's products for themselves. They tend to compare their products with those of competitors in the market. So the leaders in my organization are constantly trying to compare our products with those of the competitors in the market and stay ahead of them.

2.2.1.6 Six Sigma

Six Sigma has become the most significant operational management concept. Keeping clients in the business requires maintaining product quality. Several methods and procedures have been created to monitor and maintain the quality of an organization's products/services. Six Sigma is a collection of tools and approaches for improving processes. By finding and closing gaps in the manufacturing process, Six Sigma aims to enhance process output quality.

Bill Smith was the first to introduce it to Motorola in 1986. When Six Sigma was initially launched, Japanese corporations like Toyota were the first to implement it. Many firms all around the world are using Six Sigma nowadays. Many organizations have dramatically improved the quality of their goods by implementing Six Sigma's principles, tools, and strategies. Aside from many large corporations using Six Sigma, many small- and medium-sized businesses also do (Kwak & Anbari 2006).

2.1.2 Operations Strategy vs. Operations Management

One of the biggest mistakes businesses can make is to confuse "operations" with "operational." The meaning of "operational" is the opposite of strategy. It means detailed, localized, short term, and daily. Moreover, operations management is very similar to that. However, "the management of resources and processes for producing and delivering goods and services" must also be considered a strategic and long-term issue. More importantly, it should be seen as potentially having important strategic implications. Hence, the answer is, "What is the difference between operational strategy and operational management?". On a superficial level, it is "a strategic vision of the functioning of resources and processes." However, this omits some important implications. The operational strategy is long term. Operations management is primarily concerned with short- and medium-term time horizons, and operational strategies address long-term issues:

- Operational strategies involve higher levels of analysis. Operations management is primarily about managing resources within and between smaller operations (e.g., departments, work units), while operational strategy

TABLE 2.1
Operations Management vs. Operations Strategy

Difference	Operations Management Example	Operations Strategy Example
Longer timescale	What demand fluctuations do we have to deal with?	When should we plan to add additional capacity?
Higher level of analysis	Where should we position each product category within our store?	How many stores should we have? Where should we locate them?
Higher level of aggregation	How do we provide tax advice to the small business sector?	What is our overall business advice capability compared with our partners?
Higher level of abstraction	How do we improve our purchasing?	Should we develop a strategic alliance with our suppliers?

(Yan et al. 2022)

is about decisions that affect many resources, the organization of more resources, and the network of suppliers.

- Operational strategies require a higher degree of integration. Operations management deals with the details of how products and services are produced. Each set of resources is managed individually, in the same way as the components of an operation. However, operational strategies combine these details into a series of problems.
- Operational strategies use a higher level of abstraction. Much of the operational management is immediately recognizable and related to tangible things. Operational strategy generally deals with more abstract and invisible issues.

2.1.3 Approaches to Operations Strategy

The literature enthusiastically supports the idea that operations should be managed from a strategic perspective and used as a competitive advantage for the company. This view of Skinner (1969) was first introduced in the article "Missing Links" and was later developed, extended, and repeated by many others. Skinner (1969) suggested that production was left to professionals such as industrial engineers and computer scientists. At the time, Skinner believed that "executives tend to shy away from participating in production policy-making, and production managers are unaware of business strategy and valuable features."

2.1.3.1 Core Operational Strategy Areas

Different sources use different terms to describe strategic areas. Core strategies can be categorized in the following ways:

- Company's overall strategy: Direction of the company's mission and interrelated departments' customer orientation.

- Customer-driven: Operational strategies to meet the needs of a targeted customer segment.
- Core competencies: Strategies to develop the company's key strengths and resources.
- Competitive priorities: Strategies that differentiate the company in the market to better provide a desired product or service.
- Product or service development: Product design, value, and innovation strategies.

A company's key success factors (KSFs) pertain to competitiveness, such as a company's attributes, resources, capabilities, and competencies. By identifying these, a company can focus on the issues that matter most and measure them with key performance indicators (KPIs).

2.1.3.2 Operations Strategy Examples

With the rapid development of the market in recent years, many companies have become prominent due to aggressive business strategies. Here are some examples: Amazon: Formerly known for books, Amazon is now known as the go-to platform for people to buy any product online. Its distribution network is widely publicized and includes drone delivery testing. Apple Computers: Apple has long been recognized by the OE for its operational excellence and supply chain management. Walmart: This retail giant has beaten many competitors in terms of price and product diversity. FedEx: FedEx has made the speed of delivery a business card and achieved it through operational excellence. IKEA: The world's largest furniture retailer is offering many household items.

2.1.3.3 Four Perspectives on Operations Strategy

Just as there is no consensus on what "strategy" means, there is no consensus on how to explain "strategy works." Different authors have slightly different opinions and definitions on this topic. Among them, four opinions have emerged on the subject:

1. An operational strategy is a top-down reflection of what a group or company wants to achieve.
2. Investment strategy is a bottom-up activity that accumulates improvements in strategy formulation.
3. The investment strategy is to translate market demands into operational decisions.
4. The investment strategy is to take advantage of the ability of investment resources in the selected market.

2.2 OPERATIONS STRATEGY FORMULATION

Strategy formulation refers to the process of selecting the most appropriate course of action to achieve an organization's goals and objectives, and achieve the organization's vision. There are six main steps in the strategy-building process. These steps do not follow a strict timeline, but they are still very logical and easy to do in that order.

2.2.1 Step 1. Setting Organizational Goals

An important element of a strategic statement is setting long-term goals for an organization. It is well known that strategies are generally a means to achieve the goals of an organization. Goals focus on existing conditions, and strategies emphasize the process of achieving those goals. The strategy includes the definition of objectives and the means used to achieve them. Therefore, strategy is a broader term, and it is related to how resources are used to achieve business goals. When defining the objectives of an organization, it is essential to analyze the factors that influence the choice of objectives.

2.2.2 Step 2. Assessing the Organizational Environment

The next step is to assess the general economic and industrial environment in which the organization operates. This includes considering the competitiveness of the organization. It is imperative to perform a qualitative and quantitative assessment of an organization's existing product line. This chapter aims to identify the essential factors for a business's competitive edge in the market. The management should identify a company's strengths and weaknesses, and the strengths and weaknesses of its competitors. After identifying their strengths and weaknesses, organizations need to monitor the behavior and behavior of their competitors to identify potential threats and opportunities.

2.2.3 Step 3. Defining Quantitative Goals

The organization needs to establish quantitative goals for several goals at this stage. The basic idea is to serve customers for many years and evaluate the contributions made by the various areas of activity of a product or service.

2.2.4 Step 4. Targeting in the Context of Service Planning

In this phase, the contributions of each service and service or product type within the organization are identified, and strategic planning is carried out for each sub-unit accordingly. This requires a thorough analysis of macroeconomic trends.

2.2.5 Step 5. Doing Performance Analysis

Performance analysis involves detecting and analyzing deviations between expected or desired performance. The organization should critically evaluate its past performance, current status, and desired future status. This critical appraisal identifies the extent of persistent disparities between actual reality and an organization's long-term aspirations. If the current trend continues, the organization will attempt to estimate the expected future state.

2.2.6 Step 6. Selecting the Strategy

This is the last step in the strategy development process. The best course of action is chosen after considering the organization's goals, strengths, capabilities, limitations, and external opportunities. Companies struggle to gain and maintain a competitive edge in today's volatile business environment on how to evaluate and (re)develop strategic initiatives that implement operational capabilities to provide a new source of competitive advantage at the enterprise level.

2.2.7 Mission and Vision Statement

Schuler et al. (2001) provide one of the best definitions of organizations' different types of strategies. They talk about the strategic pyramid. The authors claim that strategies exist on many different levels. The top of the strategic pyramid is the business strategy, the next part is the business strategy, the next part is the functional strategy, and the bottom of the pyramid is the operational strategy.

Figure 2.2 depicts the strategy pyramid in a diversified company. Each level has its own goals, stakeholders, and scope. Business strategies can be applied to many companies with multiple departments or business units. A business strategy is a comprehensive strategy that includes all the business units of a company, as all departments are brought together into one company. A business strategy is a high-level game plan for a business. This includes management at the top level (executive level). This is because business units should have the highest priority in terms of resource allocation and investment, and how to improve the competitiveness and profitability of their various business units is one such area.

The business approach is primarily targeted at organizations with long-term market competitiveness. The business plan considers "competitiveness, economic trends, technological advancement, buyer needs and demography, new laws and management requirements," action and reaction plans, and the influence and profitability of the management company's activities. It is another essential external issue to consider. The business plan and business strategy are the same for single proprietorships.

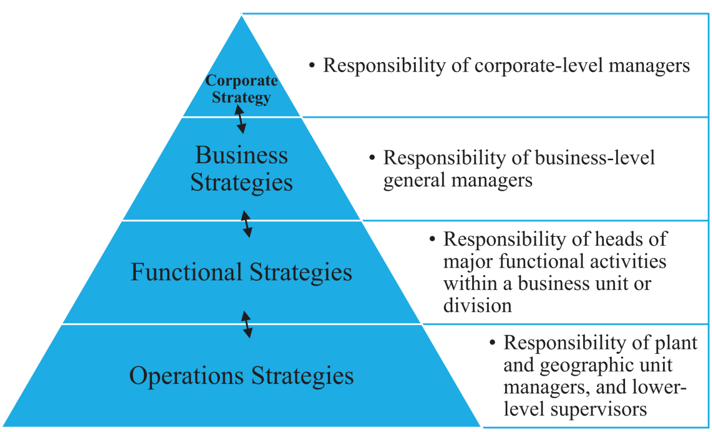

FIGURE 2.2 Strategy pyramid in a diversified company. (Galpin 2019)

Functional strategies, such as production, marketing, finance, and human resources, are developed at the divisional level. It may also relate to critical corporate activities, such as creating new products.

Functional strategies are created to meet the aims and objectives of a department. Like a business-level plan, a functional-level strategy must complement the company's overall business and business strategy. Finally, the operational strategy is the base of the strategic pyramid. The operational strategy follows two main areas:

1. Organized operational units: Factories, warehouses, and distribution hubs are examples of organized operational units. Each must have its own approach to keeping track of its activities. This plan should be used in conjunction with the entity's functional strategy and the organization's overarching business strategy.
2. Operational tasks: Purchase of raw materials, inventory management, transportation management, and customer returns handling are all operational tasks. Each of these duties necessitates a distinct technique.

2.2.7.1 Developing a Mission Statement

The first step in determining a strategic direction is to write a mission statement. The present scope of the company's activities is described in the mission statement. Figure out "who they are" and "what they are up to." The company's mission statement describes its goods and services, the sorts of clients it serves, and its technological and business skills. The company's current operations are described in the mission statement. A company's mission statement can be used to determine its future direction. Customer needs, customer happiness, and the company's capabilities are all included in a well-defined mission statement.

A mission statement that incorporates all three of the previous parts is a complete mission statement. Determine the items and services a corporation and its various client segments now provide. The major duties of a mission statement are depicted in Figure 2.3.

2.2.7.2 Developing a Business Vision Statement

The organization's vision statement comes next. The vision statement essentially identifies the organizational orientation. This offers the business a long-term perspective. A strategic instrument, the vision statement, is critical. The vision statement usually considers the company's position and status over the next five years. Its goal is to provide answers to important questions like the following:

- Where do you want your firm to be in five years?
- What are the new goods and services that a business should offer?
- What kind of position would a company prefer to have in this industry?
- What changes in target consumers must be addressed to focus on the new target customer group?

The establishment of the vision statement is the premise for setting meaningful goals and milestones. This is a vision statement that defines the company's strategic goals

FIGURE 2.3 Main tasks in the mission statement. (Bowen 2018)

and objectives. The strategic vision reflects the intentions and objectives of management for the organization's future. This reflects how management thinks about the future of the company. Establishing a vision statement requires an analysis of the internal and external business environment. It aims to shape a company's direction and path for the next five years. It also aims to understand how the current needs of businesses will evolve in the coming years.

2.2.8 Internal and External Environment Assessment

Modern business theory will play an important role in studying the external environment to ensure the success and stability of an organization. Experts point out that the formation of a competitive market environment and its evaluation from the position of the external environment are closely related to the search for effective methods of business management based on the improvement and optimization of existing business processes. It is possible to provide the latest management results strategy used.

The external environment is outside the organization and is a set of factors that influence the organization's effectiveness. The initial conditions faced by entrepreneurs in every economy. Regardless of an organization's sector, the external environment affects companies seeking to be strategically competitive (Hitt et al. 2011). An organization's external environment is a dynamically evolving aggregate function that goes beyond corporate control and imposes restrictions on the activities of an organization, including a set of social, technical, economic, political, and legal factors. The survival and success of an organization depend on the skillful interaction of company management with the external environment and the rapid response to this change in the environment, analyzing and interpreting its impact on organizations and businesses in general.

2.2.8.1 PESTEL Analysis for Internal and External Assessment

A PESTEL study, also known as a PESTLE analysis or PEST analysis, is a framework or method for analyzing and monitoring macro-environmental elements that can significantly influence an organization's performance. This tool is beneficial when launching a new firm or entering a foreign market. It is frequently used with other analytical business tools like the SWOT analysis and Porter's Five Forces to comprehend a scenario and related internal and external aspects. Political, economic, social, technological, environmental, and legal elements are abbreviated as PESTEL.

Political factors concern how and to what extent the government intervenes in the economy or a particular business. This is where the government's effect on corporations may be categorized. Economic considerations influence how well a country's economy performs. Economic growth, currency rates, inflation rates, interest rates, consumer disposable income, and unemployment rates are considered.

The general environment dimension represents the demographic traits, norms, customs, and values of the organization's population. Social factors are how it is defined. Technological factors are technological advancements that may positively or negatively impact industry and market operations.

Environmental variables have just lately gained prominence. Due to rising raw material shortages, government pollution standards, and carbon footprint requirements, they have become required. These laws include discrimination laws, antitrust laws, employment laws, consumer protection laws, copyright and patent laws, and health and safety regulations.

2.2.9 Competitive Advantage

Faced with intensifying competition, manufacturers need to develop effective operational strategies to outperform their competitors. According to the Resource-Based Vision (RBV), resource-based operational strategies have been promoted and presented as a lasting and competitive weapon that allows companies to gain a competitive advantage (Terziovski 2010).

However, little is known about how companies evaluate and develop strategies to achieve the goals of competitive strategies. Furthermore, given the uncertain environmental dynamics and the evolution of the company over time, it is unlikely that the company will be able to rely on its original business strategy. Previous studies have suggested that companies need to develop adaptive systems to develop dynamic functions that respond quickly to customer needs and market changes (Gonçalves-Coelho & Mourao 2007).

Adaptive manufacturing and agile behaviors have been widely regarded as the core belief for manufacturers to gain sustainable competitive advantage (SCA). In particular, sentiment and feedback (SandR) as a methodology for a post-industrial society is receiving increasing attention. SandR skills are often seen as the key to building flexible strategies and dynamic capabilities for companies to achieve different strategic goals.

A competitive analysis strategy is a strategy in which a company competes by analyzing and imitating the success of other companies. Companies with nuclear reactor strategies do not have a consistent strategic approach to competition. The reactor strategy is not the recommended competitive strategy for achieving the SCA of the four strategies. Therefore, we recommend that the study focuses on only three other strategic groups for strategy analysis: seekers, advocates, and analysts (Hambrick 1983). As markets become increasingly integrated and new forms of technology and competition emerge, companies struggle to develop competitive strategies to help achieve SCA.

Previous research has shown that the operational role is more important than simply developing a good strategy. Active competitive strategies are considered the engines of a successful offensive or defensive strategy. Many researchers argue that operational excellence improves a company's existing competitiveness and, more importantly, relies on operational resources and capabilities integrated into the company's processes.

2.2.10 Core Competencies and Outsourcing

Outsourcing is an option based on a company policy and business strategy, as it changes a company's boundaries as a legal entity and often involves senior management decision-makers. Outsourcing decisions affect enterprise-wide resource allocation policies and resource management practices that often involve multiple parts of a large and diverse company, such as operational IT outsourcing. Outsourcing is an activity that includes the transfer of transactions previously handled by an external supplier through a long-term contract and the transfer of personnel to the tier supplier.

ALIBABA OUTSOURCING

Without outsourcing its website design and development work, Alibaba, popularly known as "China's eBay," would not have gotten very far. For a variety of reasons, Alibaba founder Jack Ma outsourced development to a US business. For starters, China had a dearth of development talent at the time. Ma also sought advice on how to build an e-commerce infrastructure that would be able to function past China's stringent Internet regulations. Ma was able to develop sustainable infrastructure, demonstrate its promise, and get finance for further expansion by working with the outsourcer.

Alibaba's $25 billion initial public offering (IPO) was the biggest in history in 2014. The company's many platforms are now among the largest and most popular online markets in the world.

Source: Ee and Yazdanifard 2015

Outsourcing tends to continue. Although long considered a means of reducing costs, cost reduction can only be achieved under certain conditions. External suppliers must have access to economies of scale that subcontractors cannot. In short, internal restructuring is better for achieving this goal, especially when outsourcing reduces the costs of performing the same task, especially since administrators often find that cost reduction is not quite the case. They are reached by outsourcing companies. The variable costs of switching to external suppliers are high, including costs associated with supplier selection, negotiation, reorganization, and monitoring. Indeed, outsourcing is not just about improving operational efficiency. In fact, it is not limited to peripheral operations, such as catering and gardening, but is increasingly accompanied by a great contribution to the activities and functions of the company, especially the added value of the company. The concept of outsourcing strategy was introduced by De Quinn (2000). However, suppose the majority of companies in the same sector choose the same type of solution, such as outsourcing. In that case, the strategic benefit will be negated because they all converge on the same economic model (Porter 1996). To be considered a strategic option, outsourcing must be characteristic of a particular company in the industry.

2.2.11 Scenario Planning and Foresight

Changes in the business environment force organizations and businesses to constantly adapt to new realities, new concepts, new products, and new technologies. Identifying future trends and anticipating market changes are key factors for an organization's competitiveness. Furthermore, the company's ability to cope with uncertainty and adapt quickly to major changes is a key success factor and a major problem for managers. Therefore, managers and organizations have tried to develop methods and strategies to understand the business environment better. However, traditional strategic approaches may not be enough in these uncertain, focused, complex, competitive markets.

According to Acar and Druckenmiller (2006), in such circumstances, the traditional approach replaces "competition at the periphery" and turns into a temporary competitive advantage. Fast, high-quality, and widely supported strategic decision-making is essential to a company's success. Furthermore, Adam and Moodley (1993) found that traditional strategic planning methods provide information on how organizations can anticipate and respond to change generally in political, environmental, economic, and/or social aspects. The planning of scenarios is a strategic approach centered on processes, unlike traditional approaches often considered rational, which involves the search for optimal or scalable strategies. Scenario planning is increasingly being promoted to improve decision-making and help small businesses manage uncertainty. The scenario assumes that the business world is unpredictable, but certain events are predetermined. No scenario can give an exact explanation for the future. Their role is to help managers recognize, consider, and reflect on the uncertainties they may encounter. By identifying trends and uncertainties, managers can build scenarios for overcoming common mistakes in decision-making: excessive self-confidence and tunnel vision. Scenario planning leverages the participation of many people, such as network experts, strategists, and managers, to create surrogate representations of the future. Therefore, "scenario planning" is defined by Anderson and Rothstein (2004) as a network process that challenges the strategic paradigm and forces companies to rethink their internal and external boundaries.

Figure 2.4 shows how Daheim and Uerz (2008) plot their four foresight approaches along the axes of scope and level of connectedness of the foresight tasks and the size

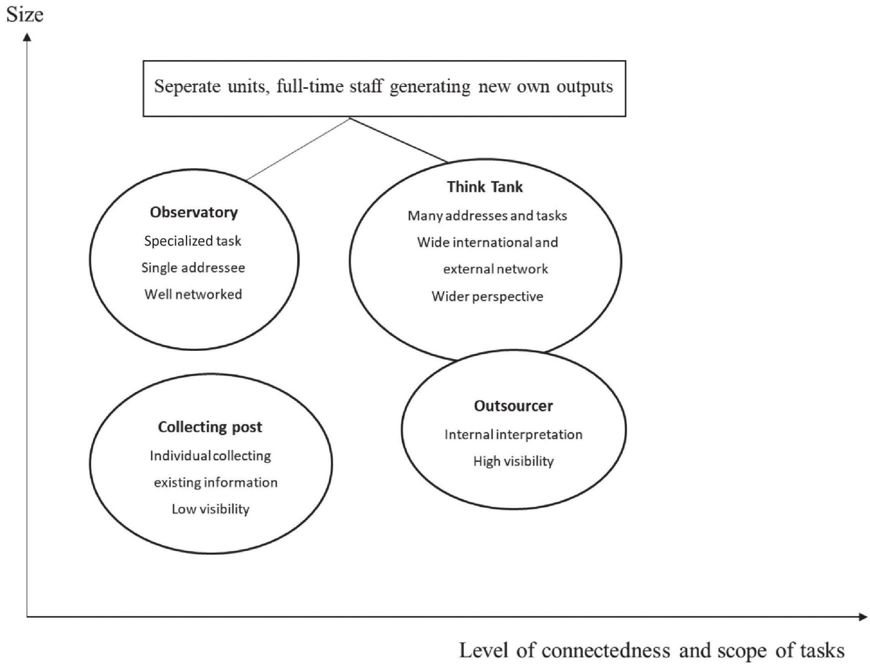

FIGURE 2.4 The manner of organizing foresight research. (Adapted from Daheim & Uerz 2008)

of the teams. This graph mirrors the Cuhls and Johnston graph, implying that as foresight teams are more change-oriented, the scope of their tasks and their networking with other resources and teams become greater.

Strategic foresight requires an increasingly broader view of the environment and conscious attention to the organization's vision and foresight scenarios in the environment.

Strategic foresight encourages organizations to learn more effectively, be more creative in developing strategies and initiatives, pursue their vision, and deliver results more effectively. To achieve this effect, strategic foresight forces organizations to look further into the future than is usual in strategic planning (five to ten years). Strategic foresight should also consider the organization's vision in the context of the environment. Scenarios allow organizations to look into the future (typically 10 to 50 years) and envision potential and foresight. A scenario is a parallel story about how the future unfolds. Scenarios can take different forms depending on 1) the purpose of the scenario, 2) the resources of the organization focused on the efforts of the scenario, 3) the culture and planning style of the organization, and 4) the psychological preferences of the public. The final plot format can range from tiled or cartoon images of the same scene to stories and report text, and even live or virtual/visual thumbnails. Scenarios can also be primarily qualitative or quantitative, depending on the organization's processes and resources (Bezold 2010).

2.3 OPERATIONS STRATEGY IMPLEMENTATION

2.3.1 Approaches to Operations Strategy Implementation

Newkirk et al. (2008) define "strategy" as "the direction and scope of an organization over the long term, which achieves advantage in a changing environment through its configuration of resources and competencies to fulfill stakeholder expectations." Strategic management differs from operations management in terms of the complexity and organizational impact of the decisions. Table 2.2 depicts various organizational levels at which strategic decisions can be made.

According to Heizer et al. (2017), businesses have six main reasons that compel them to move their operations to the international level. These are as follows:

1. Improve the supply chain.
2. Reduce costs and exchange rate risk.
3. Improve operations.
4. Understand markets.
5. Improve products.
6. Attract and retain global talent.

2.4 STRATEGIC DECISION IN OPERATIONAL PERFORMANCE

It is generally accepted that operations can provide a company with a competitive advantage when operational decisions are made to support the business and corporation (Wheelwright 1978). These operational and strategic decisions have been classified in the OM literature as structural and infrastructural. Structural operational decisions (factory capacity and location, vertical integration, product and process technology) involve brick-and-mortar and are, therefore, considered long-term significance. Infrastructure-related decisions relate to operational policies and have been defined as an organization, workforce management, quality management, and planning and control systems. Infrastructure decisions are generally considered more fluid because they do not require the large and costly physical changes that structural decisions require. However, combined infrastructure decisions are described as having a strategic impact on a firm's competitive position. Over the past decade or so, with

TABLE 2.2
Strategic Decisions Levels

Strategy Levels	Business Functions
Corporate level strategy	Strategies that cover an organization's overall purpose and scope
Business level strategy	Strategies that help to successfully compete in a market
Operational strategy	Strategies that organize resources, processes, and people to deliver corporate- and business-level strategies effectively

(Newkirk et al. 2008)

the quality management movement's focus on these areas, it has increasingly been recognized that infrastructure changes are critical to the organization's functioning and much more challenging to change than previously thought. In practice, infrastructure decisions are critical in professional services organizations because the customer determines service delivery location and why capacity decisions are made.

Strategic factors are the things an organization or business unit must do well to succeed with key stakeholders (e.g., customers, suppliers, employees, owners, and any other stakeholders). Any other organization, business unit, or individual depends on that for success. Stakeholders use these criteria to judge organizational success.

Strategic factors as a common currency: Strategic elements provide the path to success and the common currency that links how strategic planning and performance measurement is performed. Keywords are the strategic elements that form this link.

Strategic factors for business units: Strategic elements are also used to move from business to service, from organization to business unit. Because they apply equally well to an entity's relationship with key stakeholders, they facilitate the link between the entity's strategic plan and the organization's plan. Finally, the strategic elements provide us with a system for streamlining strategy development and measurement, a system for connecting different strategic concepts and activities. We call it the system of strategic elements. Table 2.3 shows the results obtained from employing strategic factors for business units.

TABLE 2.3
Results of Employing Strategic Factors

Without Strategic Factors	With Strategic Factors
Connecting strategic analysis and strategy formulation	
Connecting strategic analysis and strategy formulation is poor to almost disconnected	Connection is clear and streamlined
Defining competitive advantage	
Gets mixed up with internal capabilities	Defined outside-in, not inside-out
Conducting competitive assessments and assessing competitive advantage	
Lack of focus on external factors	Focuses on external factors
Establishing clear and quantified objectives	
Generally, a jumble of statements	Clear statements built around measurable outcomes
Writing a clear and focused strategy	
Lacks focus as methods are confused	Clearly focused as methods are clear
Developing strategy for key stakeholders	
Tends to focus on customers to the exclusion of other key stakeholders	Encompasses all key stakeholders
Defining value	
Mixed cost with value added	Value clearly defined

(Kenny 2012)

2.4.1 Strategic Operational Performance Assessment

Measuring and monitoring performance is a challenging task, but it is one of the most important aspects of managing change and gaining a competitive edge. Today's organizations are under growing pressure to adopt efficient performance management systems and increase operational efficiency while staying focused on their goals.

As a result, the importance of performance management systems for strategic, administrative, and development purposes (Hayes et al. 2001) in an organization cannot be overestimated. Organizations (e.g., United Parcel Services (UPS) 1999; Mobil 2000; Hilton Hotel Corporation 2000; Spirit of Consuelo 2002; NASA 2000) have developed and implemented various evaluation models based on this strategic role, not only as a source of information but also as an improvement to strategic and operational management decisions. For-profit and non-profit companies may accomplish their long-term strategic objectives by executing and constructing strategies linked to unitary and individual goals by understanding how these diverse valuation models can be employed in organizations such as strategic management systems.

An assessment is a research that is developed and carried out to assist audiences in determining the worth of a thing (Stufflebeam 2001). "The information needed to develop and protect a program's value and merits by continuously providing managers with the information they need to plan, direct, control, and report on their programs or areas of responsibility," according to evaluation models like the decision/accountability approach to assessment.

Many evaluation models have been utilized to aid stakeholders' strategic decision-making, planning, and monitoring to establish and implement strategic performance evaluations. "The core of strategy," as Kaplan and Norton (2015) put it, "is to establish desired objectives and identify the assets (tangible and intangible) and actions necessary to attain them."

Assessment models are also effective instruments for assessing organizations since they provide managers with data on "process and work/staff performance, Performance, measuring performance, questions to ask about performance biases, and actions to alter performance."

Another application of organizational assessment models is to assist organizations in focusing not only on traditional performance areas, such as financial, operational, or functional performance, but also on non-traditional measures, such as entity markets, stakeholders, strategy execution, and resource management, which tend to involve intangible assets. Non-traditional measurements, in theory, are often predictive. Organizations struggle to analyze effectiveness and efficiency because information focuses solely on financial metrics (Kaplan 2009). When data is available, it is usually confined to financial measures. "Financial measures are not equipped to direct and analyze the trajectory of enterprises through competitive contexts," according to (Kaplan & Norton 1996). They are lagging indicators that fail to capture much of the organizations' value generated or lost. They are trailing indicators that do not reflect much of the value generated or destroyed by management during the most recent accounting period. Financial metrics "convey some, but not all, of the tales of previous activities and do not give full direction for actions made today and tomorrow to produce future financial value."

2.5 CASE STUDY: COVENTRY UNIVERSITY OPERATIONS STRATEGY

2.5.1 History of the Coventry University

The Coventry University's roots (Figure 2.5A) go as far back as the Coventry College of Design in 1843. The Coventry College of Art merged with Lanchester College of Technology and Rugby College of Engineering Technology in 1970. After that, the institution was named Lanchester Polytechnic: "Lanchester," after the Midlands automotive industry pioneer Dr. Frederick Lanchester, and "Polytechnic," meaning "skilled in many sciences and arts" (Figure 2.5B).

The name of the university was changed to Coventry Polytechnic and Coventry University in 1987 and 1992, respectively. The Lanchester name has been preserved in the title of the university's art gallery, the Lanchester Gallery, as well as in the Lanchester Library (Coventry University 2022a).

The "Group Strategy 2030 report" published by the university states that societal advancement is achieved through powerful education. The mission of

FIGURE 2.5A A quick look at the history of Coventry University (Coventry University 2022b)

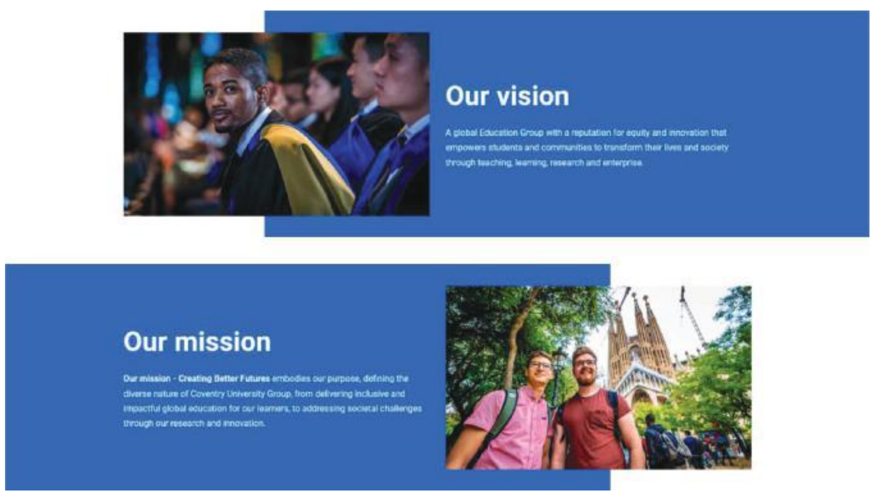

FIGURE 2.5B Vision and mission statements of the Coventry University (Coventry University 2022b)

the university, creating better futures, expresses this purpose and defines the diverse nature of the Coventry University group, from delivering an inclusive and impactful global education for our learners to our research and innovation focus on societal and economic needs and addressing real-world challenges (Coventry University 2022b).

The report affirms that the 2030 strategy of Coventry University contributes to the continuity of the university's objective of maintaining high-quality, inclusive, and empowering global education. It is stated that individuals are empowered to grow and advance in society through education. Besides, the report focuses on the need for continuous innovation, transformation, and sustainable investment that leads to delivering high-quality teaching, learning, and research to meet ever-changing societal needs. The university sets its strategic themes in the "Group Strategy 2030 report" and states these themes possess crucial importance for the goals and success. These strategic themes are evaluated by a group of key performance indicators and

TABLE 2.4
Coventry University Group Strategy 2030

Core Themes	Key Priorities	Specific Aims
Education and student experience	- Access, participation, and inclusion - Learning pathways and student engagement - Curriculum framework - Student experience and learning environment - Employability, skills, and employer engagement - Future teaching and learning environment	- Ensure our students have equal and wide opportunities to access, succeed, and progress in education and into purposeful roles in society - Evolve our teaching and learning approaches and curriculum to reflect societal and economic needs and expectations to deliver an inclusive and engaging learning experience that reflects cultural and global perspectives - Enrich teaching and learning by integrating research within the curriculum and embedding knowledge of international economic and societal research and innovation challenges - Evolve and adapt our use of educational technologies to enable innovation and democratize access to learning - Provide a holistic approach to student and graduate employment support, combining employability skills development, employer engagement, and careers advice and guidance - Establish long-term relationships with our students and learners, empowering them to take control of their learning journey

Core Themes	Key Priorities	Specific Aims
Research and impact	- Challenge-led research institutes - High-performing research teams - Future research leaders - Research environment - Strategic partnerships - Innovation and knowledge exchange	- Increase our research power, moving the Coventry University research into the top quartile nationally - Address global research, innovation, economic, and societal challenges, delivering local, national, and international outcomes and impact - Deliver high-quality transdisciplinary and challenge-led research - Enrich teaching and learning by integrating research within the curriculum and embedding knowledge of international economic and societal research and innovation challenges - Deliver solutions to enterprises and innovation challenges, develop future technologies, and address wider global societal and economic challenges - Build high-performing transdisciplinary research teams to deliver excellence with impact - Support our current and future research students and early career researchers to become our future research leaders - Provide our researchers with creative and inspiring spaces and facilities to enable them to deliver high-quality research - Build strategic international partnerships and alliances to address global challenges with local impact
Enterprise and innovation	- Strategic partnerships - Innovation ecosystem - Creativity, enterprise, and entrepreneurship - Knowledge exchange - Commercialization of research and innovation - Professional development	- Expand our enterprise, innovation, and knowledge exchange activities across our campuses and delivery locations - Underpin our civic and anchor institution role in supporting enterprise development, local growth, and regeneration - Develop our ecosystem to provide a dynamic enterprise and innovation environment for our students, staff, communities, and businesses - Establish the group as a sector leader in the provision of professional development programs - Improve the commercialization of our research and knowledge to reflect its quality and enhance its impact

(*Continued*)

TABLE 2.4 (Continued)

Core Themes	Key Priorities	Specific Aims
Global university	- Global mobility - Global employability - Global profile and reputation - Global intelligence - Global presence - Global learning	- Continue to enhance our knowledge and understanding of global challenges and cultures to inform our actions and activities and to pursue our mission - Develop our intelligence capacity and capability to enhance our insight and in-depth understanding of academic opportunities and challenges in key areas - Develop a sophisticated and strategic approach to the development of opportunities focused on the drivers of student and stakeholder objectives - Deliver an inclusive and engaging curriculum that reflects cultural perspectives - Deliver a strategic and sustainable approach to the delivery of mobility and collaborative online international learning experiences - Deliver a sustainable activity-led approach to our in-country presence in key markets focused on education, research, enterprise, and innovation - Better articulate the unique global contribution of Coventry in education, research, and knowledge transfer - Deliver excellence with impact on a global scale across all dimensions of our activity

(Coventry University 2022b)

operational measures. The qualitative goals of the 2030 strategy set by the university are as follows (Coventry University 2022b):

- Be a leading education group recognized for our educational pathways and delivery at scale of innovative approaches to learning
- Be recognized internationally for our focus on challenge-led research and for the excellence of our research institutes
- Be recognized internationally for the scale and impact of our innovation ecosystem
- Be recognized internationally for our global presence, profile, and reputation

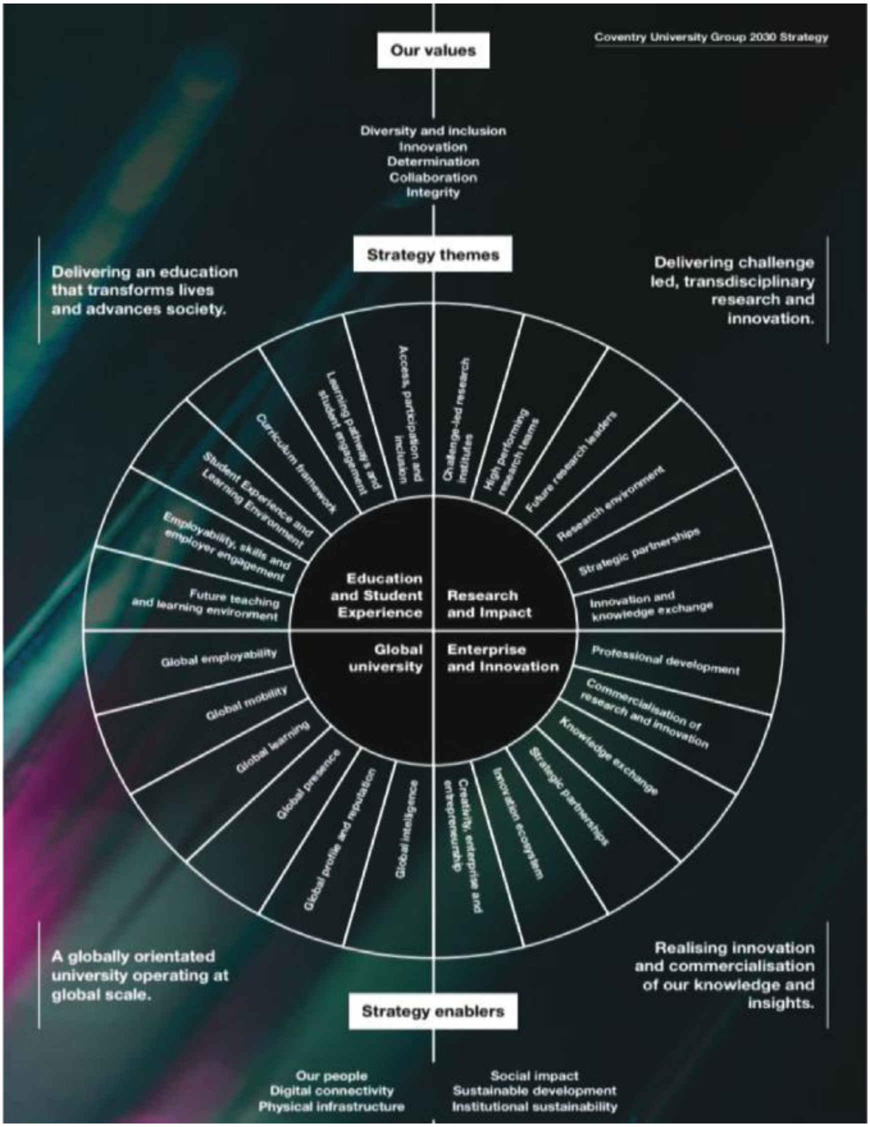

FIGURE 2.5C Coventry University Group 2030 strategy. (Coventry University 2022b)

The university develops its strategic themes (Figure 2.5C) based on its mission, vision, values, and principles of continuity, innovation, excellence, and growth. Four core themes are defined as follows:

1. Education and student experience: Delivering an education that transforms lives and advances society

2. Research and impact: Delivering challenge-led, transdisciplinary research and innovation
3. Enterprise and innovation: Realizing innovation and commercialization of our knowledge and insights
4. Global university: A globally orientated university delivering at a global scale

2.6 CONCLUSION

This chapter provided a generic and systematic overview of key principles of operations strategy and operations management and how they can be implemented. Production, quality control, and service creation are all part of operations. Banking systems, hospitals, and enterprises dealing with suppliers and consumers, and leveraging technology are all examples of operations management. Along with supply chains, marketing, finance, and human resources, operations are some of the most important jobs in a company. The operations department is responsible for overseeing both the strategic and daily production of goods and services. In the settings of production, manufacturing, or service supply, operations management is largely concerned with planning, coordinating, and overseeing. It is concerned with the whole management of a production or service system, which is the process of converting inputs (raw materials, labor, customers, and energy) into outputs (goods and/or services for consumers). The systematic direction and control of processes that change resources (inputs) into completed goods or services for consumers or clients is known as operations management (outputs).

Operations management (OM) has seen a profusion of innovative management methods packaged under topics such as total quality management and lean manufacturing during the last three decades. These new practices have taken on a strong prescriptive tone, and they are frequently promoted as universally applicable to businesses and their operations. This tendency is part of the creation of a new paradigm in OM, the best practice paradigm, which is founded on the notion that adopting best (world-class) practice in a wide variety of domains leads to greater performance. This paradigm emphasizes the continual creation of best practices in all aspects of an organization, and it is backed up by research that shows a correlation between best practice adoption and enhanced performance.

Despite the fact that strategy and structure in organizations are distinct, they are strongly connected, particularly in operations management. Indeed, operations strategy can be defined as the interaction between a firm's strategic direction (while we use the term "firm," the unit of analysis could be a business unit, a not-for-profit organization, etc.) and the organization of its resources for developing, producing, and delivering goods and services. Consider that *Organization Science*'s domain statement includes "the domains of strategy, management, and organisation theory" as more proof of their tight relationship. Similarly, the *Strategic Management Journal*'s goals and scope cover "important themes such as strategic resource allocation, organisational structure, and" clearly, management journals regard strategy to be an important component of their subject, and vice versa.

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3 Project Management

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CONTENTS

3.1 IMPORTANCE OF PROJECT MANAGEMENT

Your boss calls you one morning and says the following:

> You have been put in charge of marketing a new product. It will be a total team effort: design, production, advertising, and sales. We will meet in the boardroom at 13:30 to review your preparation plan for building this team. As you know, the success of this project can be crucial to your career.

Project management is needed in cases where this and similar extensive, complex work require more than one coordination to be carried out and where specific time and cost limitations are in question. Project management is the function of scheduling, organizing, and managing resources, such as individuals, devices, and materials, to comprehend the project, most actually taking into account limited period, cost, and technical conditions. A successfully executed project is supplied on time, fulfills

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the promised functions, and is realized within the planned budget. In order to achieve a successful project, the project must have a good project coordinator as well as coordinated work and good planning. A good project manager (PM) should be able to define the objectives and the vital plans to accomplish these aims; coordinate people, ideas, and resources effectively; comprehend the extent of the project and its significance in the success of the company; and convey this to entire project team associates, eliminating intra-group disagreements and personal conflicts. They should be able to motivate them to conclude the project in a way that is appropriate, distribute the authority and responsibilities appropriately, and take corrective actions if necessary to monitor the progress of the project within the framework of the plans.

The primary stages for a project are initiation, planning, execution, control, and closure. The initiation phase contains the official beginning of the project and the coverage statement. In this stage, a document that contains the objectives based on the aim of the project and the desired result in detail is prepared. Then what can be done in the project is analyzed. The PM determines the best strategy to achieve the project objectives during the planning phase. The PM selects team members as well as solicits the necessary resources. The timeline of the project is determined at this stage. During the execution phase, the PM supervises all activities to achieve the outcome as delineated in the project plan. This phase takes the most duration, resources, and power. In the control stage, performance and inspections are carried out at the same time. The PM observes the crew from the planning stage to ensure that the anticipated performance is achieved. Finally, the PM presents the resulting project in the closing stage. The achievement of the project management team and the project team is evaluated.

Project management has many benefits. First, it enables the effective use of people, tools, materials, money, and information, and the timely achievement of the company's goals. Second, project management provides performance and customer satisfaction at an affordable cost, on time, and at the desired level. Third, project management helps protect the business against changing social, economic, political, and technical constraints.

3.2 WHAT DOES A PROJECT MEAN?

A project is a complicated, one-time, non-routine action restricted by duration, performance specifications, funding, and resources to meet customer needs (Kurstedt and Kurstedt 2005).

A project is a temporary effort to construct a service, unique product, or outcome. Like many corporate endeavors, the primary purpose of a project is to meet a customer's demand. However, beyond this basic resemblance, the features of a project help distinguish it from other corporate efforts. The significant attributes of a project are as follows:

1. The project must serve a specific objective.
2. The project must have a certain life with a beginning and an end.
3. Generally, the project should be carried out with the coordinated work of several departments and experts.

4. Typically, the project to be done should be one that has never been done before.
5. The project needs a budget, exact time, and performance needs.

3.3 WHAT ARE THE CHARACTERISTICS OF A PROJECT?

The project is the team's goal to find a resolution to an issue or capture an emerging chance using a set of resources within a limited duration and limited budget provided that manages probable risks while taking into account client pleasure and quality within a restricted scope. The project includes the processes of initiating, executing, controlling, and finalizing a unique plan in line with its goals and objectives. Many different project definitions can be given, but there are some common concepts in each description. The features that a project should have are as follows (Gray and Larson 2021):

- The project to be done should be different from other projects and be unique.
- The project to be done must change a process.
- Each project should have a specific objective.
- Each project has a specific life with a beginning and an end.
- Each project has a budget, duration, and performance conditions.

3.4 WHAT IS THE LIFECYCLE OF A PROJECT?

Projects involve a certain amount of uncertainty because they are unique transactions. As a result, organizations that produce projects often divide them into phases to increase control over projects and establish links with ongoing work. This combination of phases is named the lifecycle of a project. The merging of stages forms the project lifecycle, sometimes in series and sometimes in intertwined states. The managers determine the number and names of these phases. While deciding, criteria, such as the number of controls required, the structure of the project, and its application area, are adequate. Projects vary widely in size and complexity. But no matter how big or complex the project, it has to go through the following cycles (Gray and Larson 2021):

- Defining
- Planning
- Executing
- Closure

Defining: The defining phase refers to when the project is still in the idea phase. At this stage, the project owner makes a series of explanations and presentations about how the project will contribute to the company or institution. The proposed project may be the production of a new product or may be in the form of a solution to an existing problem. The project idea can come from the company's managers as well as from the technical workers operating in various roles within the organization. At this phase, a sequence of panels and discussions are initiated to comprehend whether the offered project has the potential to supply benefits. The fact that most people agree on the project at this preliminary stage and that it will indeed provide the claimed benefits also confirms the project's transition to the next stage. Goals, specifications, tasks, and responsibilities are determined at this stage.

Planning: Creation and scheduling are carried out in the project's second phase, which was accepted and approved at the defining stage. This is perhaps the essential stage of the project. Because errors or unseen issues in the planning may cause substantial disturbances in the implementation of the project and possibly guide to the project's collapse, experts should be included in every subject during the project lifecycle. In addition, experts from outside the institution should be included in the project when necessary. Particular attention should be paid to the budget and time planning of the project because the emergence of additional costs during the execution of the project causes the company to encounter expenses that are not in the account. Not estimating the project's completion date or leaving the end open may lead to the prolongation of the project and the occurrence of a series of damages due to this. Therefore, the design and planning phase should be carefully considered. This stage includes schedules, budgets, resources, risks, and staffing planning.

Executing: After planning the project, it is necessary to select a project crew that can successfully execute this plan. It is vital to have an expert on every topic related to the project in the project team. One of the essential issues is the PM, who will be put in charge of the project squad. Even if the team is composed of experts, the manager's lack of expertise or inability to adapt to the crew may cause the project to be interrupted. Therefore, it is required to appoint a PM who is both informed and wise, and able to perform cohesively. In this phase, the execution of the project, which was prepared during the design and planning stage, starts.

Monitoring and controls in the project lifecycle measure how well the project's progress is in line with the plan. These measurements are made from many different angles. For example, the distinction between the planned duration and the current duration is measured, the budget allocated for the project is compared with the budget used, and the project is evaluated in many other ways. This is crucial in preventing the project from getting out of control during the management phase and achieving the desired result with minor deviation. This stage contains situation statements, modifications, quality, and predictions.

Closure: The declarations prepared both at the project chasing and controlling phase and the finishing stage are used to carry out the closure process. When a project is finished, it is supposed to be reviewed, and lessons are to be realized from mistakes and failures. The circumstances that guided the project's achievement had better also be highlighted, and these characteristics had better be improved and utilized in forthcoming projects. This phase contains educating clients, transferring records, unleashing resources, assessing, and comprehending lectures.

3.5 WHAT DOES PROJECT MANAGEMENT MEAN?

Project management is a collection of plans made to meet customer expectations, such as early delivery, striking design, and low cost within the budget, workforce, performance, and time constraints of a project. Project management is carried out in three stages:

- Planning: Setting goals, defining the project, and defining the organization
- Scheduling: Relating activities to the demands for labor, money, and time
- Control: Controlling and arranging activities to meet time and cost demands

PMs use the project plan to ensure that their schedules are complete and of high quality. The project schedule, also called the project management strategy, answers the what, who, when, why, how, and where questions of the project. The project plan is more than a Gantt chart with duties and expected finish dates. A project plan aims to guide in executing and controlling project phases. A project program is able to be reworded in six steps:

1. Describe the stakeholders of the project, quality baseline, scope, outputs, achievement criteria, and needs, and develop a project alliance, work breakdown, and declaration of work.
2. Determine risks, allocate tasks to team associates with duties to be performed, and observe the associated risks.
3. Define your project crew roles and responsibilities.
4. List the resources needed for this project, such as how many days, workers, salaries, and materials, and then estimate how much it will cost on average.
5. Develop change management procedures and forms for any situation that may occur.
6. Develop a communication plan, timeline, budget, and roadmap for the project.

Project planning will clarify what you need to achieve and help you gain insights into moving the project plan forward by solving the processes you need to get there. However, cost overruns and excessive tardiness can occur due to inadequate scheduling and controls. For this reason, the planning step of the project is of tremendous importance for the project to satisfy the expectations.

After the project is planned, collaborative work and scheduling are needed to complete the project on time. After the work is determined, task assignments should be made in line with the project's timeline baseline. If the PM deems it necessary after the project schedule is created, changes can be made to the schedule so that the project is able to be achieved.

The control function and definition of the project in line with the determined performance and support of the intended targets are among the main tasks of project control. During project control, various mechanisms are used according to the characteristics of the project. These are investment, cost trend, risk profile, benefit-value, turning trend, cost-benefit analysis, expert surveys, additional expense calculations, target/actual comparison, and simulation accounts.

Project control over project execution takes various forms. In general, this control depends on the project's size, nature, and complexity. In addition, the knowledge, skills, and control policy of the PMs also play an essential role in controlling them (Vanhoucke 2017).

3.6 WHO IS A PROJECT MANAGER, AND WHAT ARE THE DUTIES OF A PROJECT MANAGER?

The PM is the head of the project, coordinating activities and team members within budget, resource, and time constraints. The PM reports directly to top management. A good PM does the following:

- Makes a fair price and time offer according to the planning information.
- Does material planning in line with customer expectations and budget.
- Ensures that the project meets customer needs and expectations.
- Organizes team members as a good coach and communicator.
- Follows the current workflow and checks that the work is done correctly and in accordance with the workflow.
- Takes action against current and planned workflow differences.

3.7 WHAT ARE THE TOOLS OF PROJECT MANAGEMENT?

Since the teams are small in the early days of the startups, there are not many problems while carrying out projects and works, but with the growth of the teams, it becomes challenging to follow up on these work projects. In addition, companies often overgrow, so project management becomes difficult for managers to follow. Project management tools reduce this complexity and facilitate the follow-up of project management. In addition, project management tools are very effective for regularly ensuring the division of labor and tracking the work done. Some of the project management tools used are as follows:

1. Scope of the Project
2. Requirements of the Project
3. Task List
4. Work Breakdown Structure
5. Responsibility Matrix
6. Project Scheduling
7. Probability of Project Completion
8. Cost-Time Trade-Offs and Project Crashing

3.7.1 Scope of the Project

The success of a project is measured by the extent to which customer requests and expectations are met by the results of the project. For this reason, a project should first be started by determining what the client's expectations are. A responsible individual, called the PM, should be assigned to the project to make evaluations about the success rate achieved as an outcome of the project. The Scope of the Project (SoP) aims to determine the expectations, responsibilities, and accountability of a project. Knowing what is expected and intended for a project makes it easier to meet customer expectations.

In determining the scope, the customer and the PM should evaluate the tasks of the PM. SoP provides the advantage of looking at the project from a broad perspective.

The primary purpose of the SoP is to delegate responsibility to the PM by expressing customer expectations. SoP obtains general details about the project by providing the following information:

- Identify the customer and PM
- Identify the tasks or expectations of the project
- Describe the responsibilities of the customer and PM
- Describe the provided services
- Describe the project needs
- Identify the funding and budget
- Describe the supporting information

The customer and PM sign the SoP and publish it to the whole project associates. PMs responsible for only a minor project are able to schedule project duties without much proper projection and knowledge. However, when the PM has to handle a few smaller projects or one enormous, complicated project, a verge is rapidly arrived where the PM can no longer come through the details.

Defining the SoP molds the phase for improving a project schedule. The SoP describes the outcome or task of a service or product project for clients. The prime aim is to determine outputs for the end user as clearly as possible and focus on the project plans. However essential and necessary the scope definition may seem, it is often unnoticed by PMs of well-managed, gigantic corporations. The SoP guides the focus on the project goal all along with the project's life for the client and project participants (Berkun 2005). The PM is responsible for ensuring an agreement with the project owner on issues such as project objectives, deliverables at each stage of the project, and technical requirements. The SoP describes what is expected to be delivered to customers when the project is complete. Also, the SoP should describe the results to be achieved in specific, concrete, and measurable terms.

The SoP defines the overall goal and key outputs to meet customers' needs (i.e., expected outcomes over the project's life). PM and customers should define the boundaries of the project. Otherwise, it can lead to false expectations and wasted resources and time on the wrong problems. Within the SoP, the parties must agree on all issues, and it must be signed. With the SoP, it is concluded that the customer's expectations will be met at the end of the project; the performance requirements, such as the budget and the duration of the project, are defined; and the constraints of the project are determined. The SoP should be as short but complete as possible; it should not exceed one or two pages. If the SoP needs to change, it is essential to have a robust change control process that records and keeps track of all project changes.

The ultimate achievement and quality of a project have conventionally been determined as meeting or surpassing the anticipations of the client or top administration in terms of performance (scope), time (schedule), and cost (budget) of the project. The mutual relationship among these criteria differs. For instance, occasionally, it is required to compromise the scope and performance of the project to achieve the task quickly or more cheaply. Generally, the longer a project takes, the pricier it becomes. Nevertheless, the optimistic correlation between program and cost may not invariably be accurate. At different times, the costs of projects can be decreased by utilizing more affordable, undersized efficient work power or tools that expand the project period. Similarly, PMs often have to accelerate certain key activities by adding a workforce, thus increasing the project's original cost. One of the primary tasks of a PM is to control the trade-offs between cost, time, and performance. To do this, PMs are supposed to identify and comprehend the essence of the project's precedence.

3.7.2 Requirements of the Project

The Requirements of the Project (RoP) aims to clarify the customer's needs and expectations. The RoP focuses on the outcome and output of the project. The RoP shapes the solution space the PM will use to reach the result according to customer expectations and needs. If the RoP is prepared incorrectly, the project output will not meet customer expectations.

In the preparation process of the RoP, sentences should be formed with an active structure. Furthermore, the requirements should be written using the shall expression. Requirement statements should be accurate, complete, consistent, testable, and clear.

3.7.3 Task List

The Task List aims to define the tasks required to accomplish the project and the estimated duration by considering the SoP and RoP. The SoP and RoP identify the expectations about the project. In the Task List, all required operations in the project are listed in order (Tocqueville 2007).

3.7.4 Responsibility Matrix

The Responsibility Matrix (RM) aims to pair the tasks and the project member who is responsible, is a participant, or is an acceptor:

- It reveals the importance of human management.
- The bigger the team, the more challenging it is to control.
- The responsibility of all project members involved in an activity is not the same.
- The PM should coordinate the tasks.
- The RM is the most effective way to inform project members of their responsibilities.

RM outlines the duties to be completed and who is accountable for what on a project. An RM comprises a chart listing all project tasks and the parties accountable for each task in its most straightforward form. In this matrix, R is used to determine the committee associate accountable for coordinating the actions of other team associates assigned to the duty and ensuring the duty is completed. S is used to determine the associates of the five-person crew who will support or assist the accountable person. More complicated RMs not only represent personal obligations but also describe essential interfaces between crews and people that need coordination. RM supplies a means for all parties in a project to see their obligations and decide on their duties (Wysocki 2019). Additionally, RM assists in defining the scope or variety of authority wielded by each party when performing a task with overlapping participation of two or more parties. By utilizing an RM and limiting authority, accountability, and contact within it, the connection between various organizational units and the enterprise context of the project is clarified. In this context, an RM has personnel with the following authorities: i. be responsible, ii. support, iii. consult, iv. notify, and v. approve.

3.7.5 Work Breakdown Structure

Once the scope and instructions are determined, the project's work can be divided into smaller work items, and the hierarchical structure formed by this division is called the Work Breakdown Structure (WBS). WBS helps PMs ensure that all products and work items are defined, integrate the project with the existing organization, and provide a basis for control. Consider the project as one gigantic work package consecutively split into smaller packages; the whole project is the sum of all smaller work packages. This gradual structure facilitates the evaluation of budget, duration, and technical performance at entire levels in the organization throughout the project lifecycle. Time and cost estimates are required for each item in the WBS. This knowledge makes it possible to schedule, plan, and budget projects with WBS. WBS also serves as a structure for monitoring cost and companies' performance, and as it is improved, corporate units and individuals are given accountability for managing work packages. WBS allows the collection of the funding and exact costs of more small packages into more oversized work items so organizational units and business success can measure that performance.

The most inferior level of WBS, called work packages, are short-term tasks with a specific beginning and endpoint, resource spending, and cost illustration. Practices suggest that a work package had better not extend ten workdays or one reporting period. In addition, each work package of the WBS had better be separated as much as possible from other project packages.

The following four steps should be considered when constructing work packages:

1. Define the task.
2. Determine the time required to complete a work package.
3. Set a time-phased budget to complete a work package.
4. Identify the resources needed to complete a work package.

3.7.6 Project Scheduling

At this stage, how long each activity will take is decided, and the project team calculates the resources needed at each stage of the project (Meredith J.R. and Scott M.S. 2021). In some cases, PMs may plan personnel and material needs in separate programs according to their abilities. The Gantt chart is one of the most popular project scheduling approaches. The Gantt chart is a low-cost project scheduling tool that helps project members ensure that activities are planned and sequenced. The Gantt chart is very effortless to understand as it shows project activities with horizontal bars across a timeline. For uncomplicated projects, the Gantt chart allows project members to monitor the progress of activities and identify problem areas. However, the Gantt chart is insufficient when showing the relationships between activities and resources. Project scheduling techniques are capable of closing the gap that Gantt charts cannot provide since they take into account the dependencies and priority relations of activities. Project scheduling techniques aim at these objectives: i. show how each activity relates to others, ii. define the priority relations between the activities, and iii. identify the bottlenecks in the project and ensure better use of resources.

3.7.6.1 Project Scheduling Techniques

Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are two scheduling techniques developed to enable project teams to schedule and manage enormous and complicated projects. CPM was developed at DuPont in the 1950s to assist in constructing and maintaining a chemical plant. Meanwhile, PERT was developed for the US Navy in 1958. PERT and CPM techniques use the following common primary six steps:

1. Describe the project and design the WBS.
2. Determine the priority interrelationship of the activities.
3. Sketch project networks (PN) linking all activities.
4. Define the times for the activities.
5. Compute the lengthiest path on the PN (the critical path).
6. Utilize the PN to schedule and manage the project.

The fifth step is the essential part of managing a project. If tasks in the critical path are not completed on time, these activities represent activities that are going to delay the whole project. The flexibility required to achieve essential tasks can be provided by adjusting non-critical activities to avoid this situation (Table 3.1).

PERT and CPM are important project scheduling techniques, as they can answer the following questions: i. When will the whole project be finished?, ii. What are the

TABLE 3.1
Activities and Their Predecessors

Activity	Predecessor Activities
A	-
B	A
C	-
D	B, C
E	A
F	A
G	E, D

vital and non-vital tasks in the project?, and iii. Is the project on, behind, or ahead of schedule? The most significant difference between CPM and PERT is that PERT uses three different time estimations for a particular activity task time.

Two different approaches have been developed to draw the link that connects the activities, the third step of PERT and CPM: i. nodes determine activities (Activity on Node (AON)) and ii. arrows indicate activities (Activity on Arc (AOA)). Although both PN diagram techniques are famous, most software packages use AON.

The PN plan was created, as given in Figure 3.1, by using the activities and the predecessor relationships of the activities shown in Table 3.1. After the PN is drawn, the project plan should be determined. Let's assume that the estimated times for each activity are given in Table 3.2.

According to Table 3.2, the total duration of all activities is 26 weeks, but some activities can be done simultaneously. Therefore, the time required to complete the project is less than 26 weeks. A Critical Path Analysis should be performed to determine how many weeks the project will take. The critical path is found by calculating two different start and finish times:

- Earliest start (ES): The earliest time an activity can begin when all the pioneers are complete.
- Earliest finish (EF): The earliest time an activity can be finished.
- Latest start (LS): The latest time an activity can start so as not to delay the project.
- Latest finish (LF): The latest time an activity should finish so as not to delay the project.

A two-pass process, one forward and one back pass, is used in the PN to set these timelines for each activity. The forward transition period determines ES and EF times, and LS and LF times are defined in the backward transition period. Figure 3.1 shows how transit times are calculated on the PN. In Table 3.3, the ST, ES, EF, LS, and LF values of activities required to find the critical path are calculated. There are some rules that we should pay attention to before calculating the durations:

- Earliest start time rule: All predecessors must be completed before an activity can start.
  - If an activity has only one predecessor, its ES is equal to the EF of the previous activity.
  - If an activity has more than one predecessor, its ES is equal to the maximum of its EFs.
- Earliest finish time rule: The EF of an activity is equal to the sum of the activity's ES and the duration.
- With the forward pass, the project completion time can be calculated, but the project's critical path cannot be determined. Therefore, the LS and LF for each activity must be calculated to determine the critical path.
- In the backward transition process, first, the LF and then the LS of the activities are calculated.

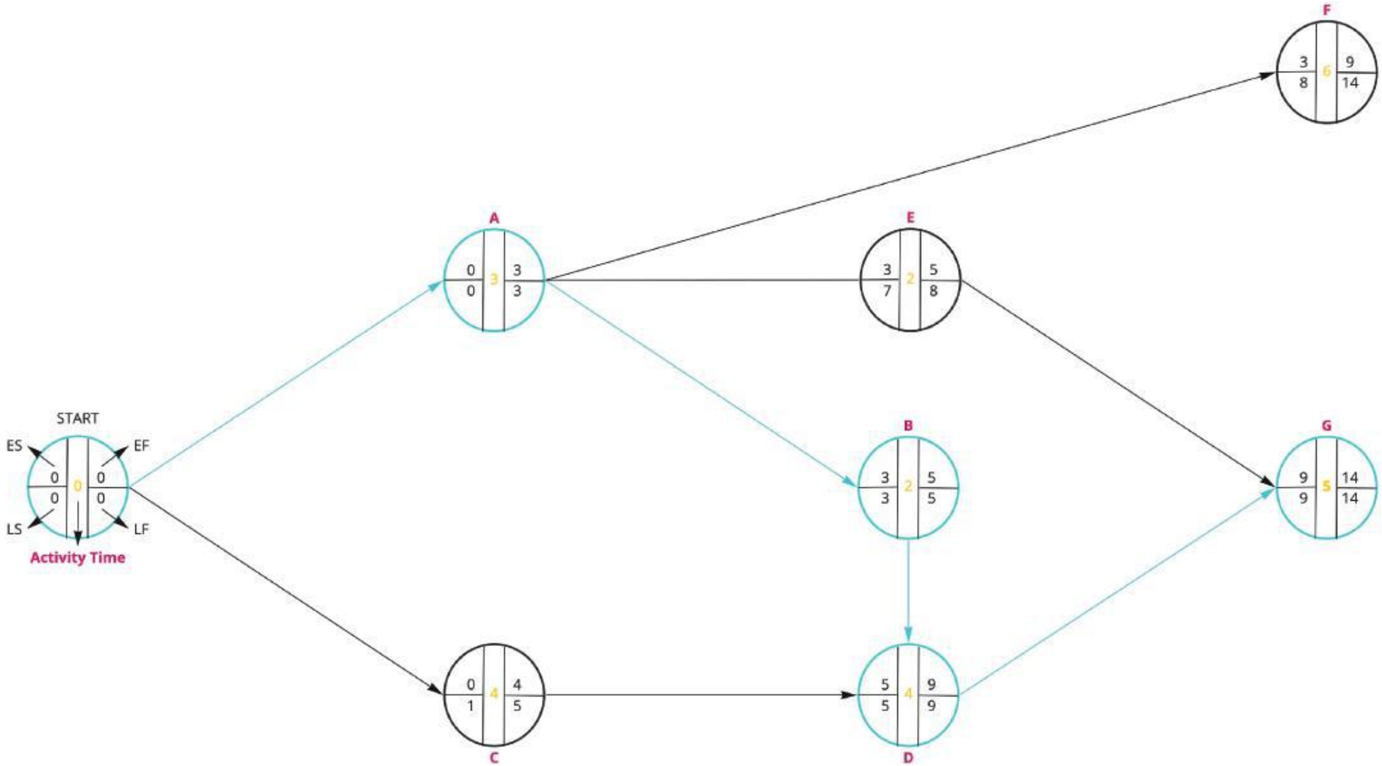

FIGURE 3.1 Example 1: AON project network.

TABLE 3.2
Time Required to Perform Activities

Activity	Required Time (Week)
A	3
B	2
C	4
D	4
E	2
F	6
G	5

TABLE 3.3
Early-Late Start and End Times of the PN

Activity	Time	ES	EF	LS	LF	ST
A	3	0	3	0	3	0
B	2	3	5	3	5	0
C	4	0	4	1	5	1
D	4	5	9	5	9	0
E	2	3	5	7	9	4
F	6	3	9	8	14	5
G	5	9	14	9	14	0

- Latest finish time rule: It is based on the principle that all predecessors must be completed before an activity can begin.
  - If an activity is a predecessor for a single activity, its LF is equal to the LS of the following activity.
  - If an activity is a predecessor to more than one activity, its LF is equal to the minimum of the LS of the following activities.
- Latest start time rule: The LS of an activity is equal to the difference between its LF and the time of the activity.
- After calculating the earliest and latest times for all activities, each activity's slack time (ST) should be calculated. ST is the time an activity can be delayed without delaying the project and can be calculated as LS – ES or LF – EF. Activities with zero ST are critical activities and are on the critical path.
- The critical path includes each critical activity, starting with the first activity and finishing with the last activity.

3.7.6.2 Advantages of PERT

PMs sometimes minimize or evade their efforts to estimate project duration and cost due to the pressure of starting a task on the project. This manner is a significant error and is pricey. There are critical reasons to take into account the cost of struggle and assessment for projects. Incorrect forecasts lead to wrong expectations and client dissatisfaction. PN, a tool for planning, scheduling, and monitoring project progress, was developed from the information gathered for the WBS and is the graphical flowchart of the project work plan. PNs are enhanced with the support of WBS. A PN is a graphical flowchart of the order, dependencies, and relationships of all tasks that must be performed to terminate the project. These activities are time-consuming elements of the project. The PN forms the framework of the project information system that PMs will use to make decisions regarding project duration, cost, and performance. The PN is easily understood by others, as it provides a graphical display of the workflow and sequence throughout the project. In addition, once developed, it is straightforward to modify or change when unexpected events occur as the project progresses.

The PN provides the basis for programming workforce and equipment. It provides an estimated project duration rather than randomly choosing a project finish date from someone's preferred date. It gives the times when activities can start and finish and when they can be postponed. It determines which activities are critical and should not be delayed if the project is completed as planned. It highlights activities to consider whether the project needs to be compressed to meet the deadline. PNs minimize surprises by getting the plan out early and allowing for corrective feedback.

3.7.7 Probability of Project Completion

The critical path analysis method allows us to calculate the expected completion time of a project. We made our transactions by assuming that the duration of the activities in the PN we have created is certain. However, there may be significant differences in the expected time estimates of the activities. Such differences cause concern to the PMs. In order to avoid this situation in PERT, probability distributions according to three time estimates can be used:

- Optimistic time (*a*): The time needed to perform the activity if all goes well as planned.
- Pessimistic time (*b*): The time needed for the activity to be carried out if everything goes very negatively.
- Most likely time (*m*): The most realistic time an activity needs to be performed.

While using PERT, it can be assumed that the activity time estimates are realized by the beta probability distribution. These three time estimates can be calculated using equation 3.1 to find the expected duration of activity with the beta distribution:

$$t = \frac{(a + 4m + b)}{6} \tag{3.1}$$

The variance of the completion time of the activity can be calculated using equation 3.2:

$$\text{Variance} = \sigma^2 = \left[\frac{(b-a)}{6}\right]^2 \tag{3.2}$$

The total variance of the project is calculated by adding the variances of the critical activities, as shown in equation 3.3:

$$\text{Project Variance} = \sigma_p^2 = \sum \text{Variances of critical activities} \tag{3.3}$$

According to PERT, project completion times follow the normal probability distribution, and activity times are statistically independent. The probability that a project will be completed in how many weeks is calculated as shown in equation 3.4 and equation 3.5:

$$Z = \frac{(\text{Due Date} - \text{Expected Date of Completion})}{\sigma_p} \tag{3.4}$$

$$\text{Normal Distribution}(Z) = \text{Probability of Completion} \tag{3.5}$$

Later, the activities of a project and the duration are given in Table 3.4. In addition, the precedence relations of the project activities are shown in Figure 3.2. Finally, the due date of the project was determined as 20 weeks. In light of this information, the possibility of achieving this project on time is calculated as follows from equation 3.6 to equation 3.10.

$$t_A = \frac{(5+4*6+13)}{6} = 7, t_B = \frac{(2+4*2+2)}{6} = 2, \cdots, t_G = \frac{(2+4*3+10)}{6} = 4 \tag{3.6}$$

$$\sigma_A^2 = \left[\frac{(13-5)}{6}\right]^2 = 1.78, \sigma_B^2 = \left[\frac{(2-2)}{6}\right]^2 = 0, \cdots, \sigma_C^2 = \left[\frac{(10-2)}{6}\right]^2 = 1.78 \tag{3.7}$$

TABLE 3.4
Time Estimates (in Weeks) for Activities

Activities	Optimistic	Most Likely	Pessimistic	Expected Time $t = \frac{(a+4m+b)}{6}$	Variance $\text{Variance} = \left[\frac{(b-a)}{6}\right]^2$
A	5	6	13	7	1.78
B	2	2	2	2	0
C	2	5	8	5	1
D	6	8	10	8	0.44
E	3	5	7	5	0.44
F	1	3	5	3	0.44
G	2	3	10	4	1.78

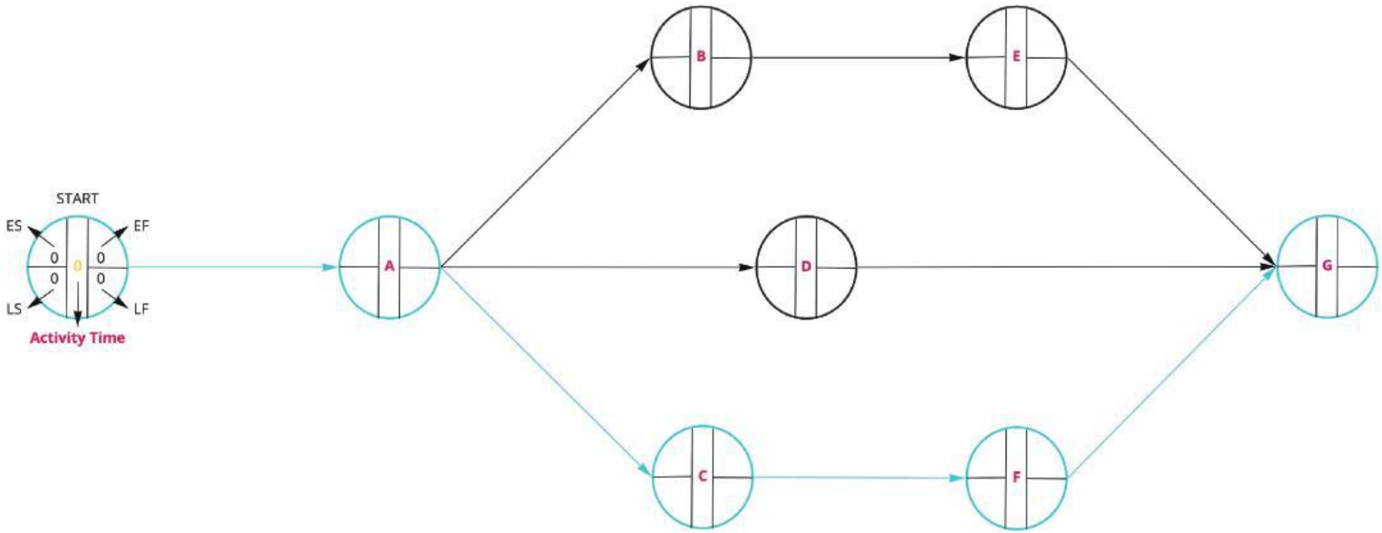

FIGURE 3.2 Example 2: AON project network.

$$\sigma_p^2 = \sum \text{Variances of critical activities} = 1.78 + 1 + 0.44 + 1.78 = 5 \tag{3.8}$$

$$Z = \frac{(20-19)}{\sqrt{5}} = 0.4464 \tag{3.9}$$

$$\text{Normal Distribution}\,(Z < 0.4464) = 67.36\% \tag{3.10}$$

According to the results obtained, the project can be completed in 19 weeks. Therefore, the probability of completion before 20 weeks was determined as 67.36%.

3.7.8 Cost-Time Trade-Offs and Project Crashing

It is not uncommon for a PM to come across situations such as the project being behind schedule or the planned project completion time being pushed forward. In either case, some or all remaining activities need to be expedited by adding the necessary resources to complete the project by the expected deadline. The period in which a project can be shortened as cheaply as possible is called project crashing (Table 3.5).

CPM is a technique where activities used in calculations have a standard time. Each activity has an expected cost calculated over a standard time. The shortest time required to complete activities is called Crash Time (CT). Every activity with CT has a Cost of Crash (CM). Extra resources are often needed to complete activities in less time than expected. Therefore, the CM of an activity is more than its standard cost. The amount of time an activity can be shortened depends on the type of activity. For this reason, some activities can be shortened significantly, while others cannot be shortened at all. Similarly, the CM of an activity depends on the nature of the activity. Shortening a project consists of four steps (Heizer, Render and Munson 2020):

1. If the shortening cost is linear in time: Crash Cost per Project (CCPP) = (CM – Normal Cost) / (Normal Time – CT)

TABLE 3.5
Normal and Crash Data for Activities

Activities	Time (Weeks)		Cost ($)		CCPP	Critical Path
	Normal	Crash	Normal	Crash		
A	6	4	5,000	10,000	2,500	Yes
B	3	1	2,000	6,000	4,000	No
C	5	4	1,000	3,000	2,000	Yes
D	8	6	2,000	4,000	1,000	No
E	5	3	4,000	8,000	2,000	No
F	4	3	3,000	9,000	6,000	Yes
G	3	3	10,000	10,000	—	Yes

2. Identify critical activities.
3. If there is only one critical path, select the activity on that path that can still be shortened and has the lowest CM per period.
4. Update all activity times and stop if desired time is reached; otherwise, return to Step 2.

In light of the information in Table 3.5, when the calculations are made using standard times, knowing that the critical path of this project is the A-C-F-G path, we see that the project was completed in 18 weeks for $27,000. In order to shorten the completion time of the project by one week, it is necessary to compress one of the activities A, C, F, and G on the critical path. Among these activities, the activity with the smallest CCPP is activity C, with $2,000. If activity C is compressed into one week, the project will be able to be completed in 17 weeks, but the cost to complete will be $27,000 + $2,000 = $29,000. When the project is rescheduled after a week's compression of activity C, two different critical paths will emerge, A-C-F-G and A-D-G. The minimum project crashing values obtained by continuing the processes are shown in Table 3.6.

After this step, all three pathways, A-C-F-G, A-D-G, and A-B-E-G, become critical. However, since all activities in the A-C-F-G path are non-crashing, the project cannot be shortened further. The cost duration chart for this project can be correlated, as shown in Figure 3.3. Conversely, the cost of the project increases as the duration of the project decreases.

3.8 CASE STUDY

A metropolitan municipality in Turkey carries out many studies to serve its citizens. The municipality, which wants to provide better services to the citizens in the face of the increasing population over time, has increased the number of vehicles in its body in line with the needs. The increase in the number of vehicles necessitated the follow-up of these vehicles and the vehicle fleet. The metropolitan municipality

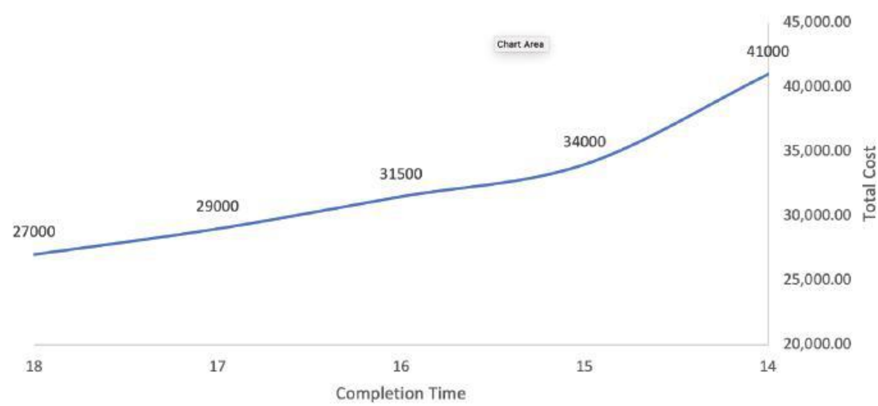

FIGURE 3.3 The cost duration chart.

TABLE 3.6
Results of Project Crashing

Step	Critical Path	Crashing Activity	Activity Time	Additional Cost	Total Cost	Completion Time	Non-Crashing Activities
0	A-C-F-G	-	-	-	27,000	18	G
1	A-C-F-G	C	4	2,000	29,000	17	G, C
2	A-C-F-G A-D-G	A	5	2,500	31,500	16	G, C
3	A-C-F-G A-D-G	A	4	2,500	34,000	15	G, C, A
4	A-C-F-G A-D-G	F D	3 7	6,000 1,000	41,000	14	G, C, A, F

has decided to implement a vehicle tracking and fleet management system project by taking advantage of the developing technologies. Thanks to the satellite tracking system, this project requests that the vehicles serving the municipality be tracked online and have necessary controls (speed, where and how long they stop, which roads they follow, etc.), thanks to the satellite tracking system. In addition, the aim is for it to work in an integrated way with the fleet management software to help the fleet be managed in the best way. With the system to be established, it is desired to direct the vehicles and their drivers in the best way and to increase the controls. The system will work with the logic of transferring the data received from the GPS satellites and sensors connected to the device to the server computers via GSM/GPRS by the devices installed on the vehicles. For example, citizens who prefer public transportation going from one place to another can see where the vehicle is and how many minutes it will take to arrive at the station with the municipality application downloaded to their phones. In addition, the car's route can be followed on the map. In this way, citizens have the opportunity to follow up on the system at which stop they should get off and whether they are on the right track. The SoP, RoP, Task List, WBS, and Gantt chart created with the project data are shown in the following figures (Figure 3.4, Figure 3.5, Figure 3.6, Figure 3.7, and Figure 3.8).

The Scope of the Project is shown in detail in Figure 3.4. In addition, the project's budget, the manager, the customer, the expectations from the project, the responsibilities of the customer, and the PM and supporting information are explained in detail.

In Figure 3.5, the Requirements of the Project are shown in detail. The project's manager, its client, the client's expectations from the project, and the PM's demands are explained in detail.

Figure 3.6 shows each task of the project. The Gantt chart of the project is shown in Figure 3.7. It is shown which task will start and end when, graphically. In Figure 3.8, the tasks and sub-tasks of the project are shown.

SCOPE OF PROJECT

Project Name: Development of Black Box and Tracking Software for Vehicles within the Metropolitan Municipality

Project Manager: Head of Transportation Dept. **Customer:** The Metropolitan Municipality

Budget: $2,355,768.80 (Two Million Three Hundred And Fifty-Five Thousand Seven Hundred And Sixty-Eight Dollars Eighty Cents)

Project Needs: The following outputs are expected from this project for the vehicles in the municipality's fleet: i. A Vehicle Telemetry software should be developed to enable the acquisition, transfer, storage, and reporting of vehicle-related data from the vehicle's telemetry systems at the desired frequency, ii. Establishing the necessary infrastructure for the correct, reliable, and economical vehicle use in line with these reports, and iii. Maintenance and repair activities must be continued throughout the contract period.

Responsibilities of Project Manager and Customer: The place of delivery of the devices is the address to be determined by the municipality. The assembly of the devices must be completed within 120 calendar days from the signing of the contract. If the municipality cannot supply the vehicles, the number of days that cannot be delivered will be added to the assembly delivery time. The project team will cover all equipment required during the installation. The project team will deliver the system in complete and working condition, with device and software compatibility and assembly completed. The guarantee of the devices will start from the delivery date of the last device and will have a five-year warranty. Defective machines will be repaired or replaced within 72 hours. The "installation and operation" training will be given face to face by the project team at the location to be determined by the municipality. After that, the system's operation will be done by the municipality.

Supporting Information: This project it is aimed to increase driving safety, reduce breakdowns and accidents, prolong the life of parts, keep the vehicles in service longer and provide fuel savings by ensuring the correct, reliable, and economical use of vehicles.

FIGURE 3.4 Scope of the Project.

REQUIREMENTS OF PROJECT

Project Name: Development of Black Box and Tracking Software for Vehicles within the Metropolitan Municipality

Project Manager: Head of Transportation Dept. **Customer:** The Metropolitan Municipality

Expectations of Customer: The Black Box must be capable of receiving data from the vehicles' telemetric network system and must support in-vehicle communication protocols. There must be at least three digital inputs, two analog inputs, and three digital outputs for additional equipment that may be requested in the future. In addition, Black Box should have the infrastructure to connect with in-vehicle signal converters. All data should be collected simultaneously. The Black Box must have a SIM card slot. The received data should be transmitted to the servers instantly over M2M lines, using GSM/GPRS. The built-in GPS receiver should be 72 channels simultaneous GNSS receiver that allows receiving up to 3 location information (GPS, Galileo, GLONASS, BeiDou) with online/offline data support. The cables used in the assembly must not be affected by the magnetic field and must be fireproof. (BLACK BOX)

The Vehicle/Driver Tracking System software interface must be in Turkish. Map, warning, and settings (speed, engine speed, idling, engine temperature, etc. violations to be determined by the administration) should be able to be adjusted and changed on a region-by-region basis. Data from the vehicles can be accessed via Internet Explorer and Google Chrome etc., by logging in with a username and password. It should be able to be monitored instantly or retrospectively from browsers and all computers and mobile devices (mobile phone and tablet computer compatible) with an internet connection and reported since the system was installed. There should be no limit to the number of users. The interface should have a list of users with all usernames, units, a list of vehicles for which they are authorized, email addresses, and phone numbers. Users and vehicles can be grouped. It should be possible to define which vehicles or vehicle groups can be monitored by users through the software. Thus, users connected to the system can only track vehicles within their authorization level. All vehicles registered in the system should be able to be displayed on the same screen on the digital map, and their movements should be monitored simultaneously. (SOFTWARE)

Demands of Project Manager: Installation of the devices will be completed within 120 calendar days following the signing of the contract. If the municipality cannot supply the vehicles, the number of days that cannot be delivered will be added to the assembly delivery time. The software will be delivered in working condition and with at least three fully authorized user accounts within five working days after signing the contract. The "installation and operation" training will be given face to face by the project team at the location to be determined by the municipality. After that, the municipality will do the operation of the system. During the warranty period (5 years), any errors that may occur in the software will be corrected free of charge by the project team. The municipality should state wholly and precisely which data to be obtained, which reports, and which warnings it wants to be generated from the appropriate tools within the municipality.

FIGURE 3.5 Requirements of the Project.

TASK LIST

Project Name: Development of Black Box and Tracking Software for Vehicles within The Metropolitan Municipality

Project Manager: Head of Transportation Department

No.	Task Name	Duration
1	Updating and Completion of Technical Specification	5 Workdays
2	The Tender Process	20 Workdays
3	Contract Process	10 Workdays
4	Device Installations Phase I	20 Workdays
5	Device Installations Phase II	20 Workdays
6	Fulfilling Additional Software Requests	40 Workdays
7	Inspection and Acceptance	5 Workdays
8	Training	5 Workdays

FIGURE 3.6 Task List of the project.

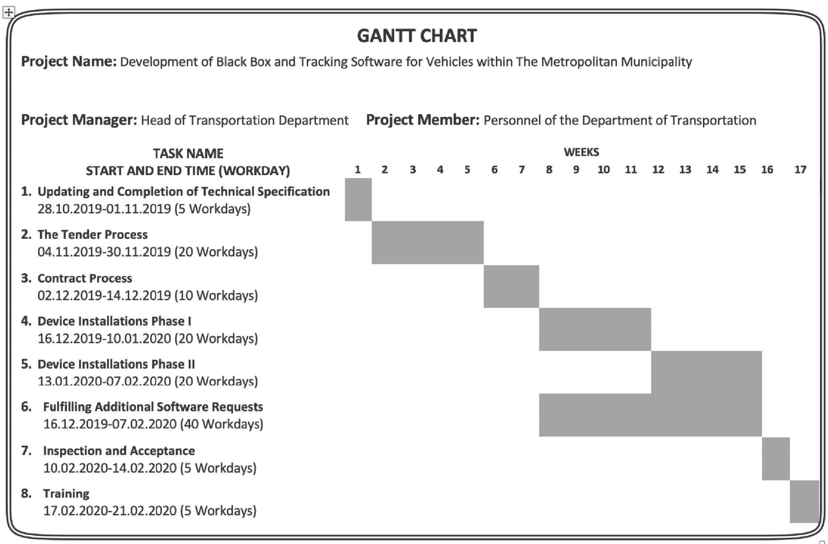

FIGURE 3.7 Gantt chart of the project.

WORK BREAKDOWN STRUCTURE

Project Name: Development of Black Box and Tracking Software for Vehicles within The Metropolitan Municipality

Project Manager: Head of Transportation Dept. **Project Member:** The Metropolitan Municipality

1. **Updating and Completion of Technical Specification**
   - **1.1.** Designing of Technical Specification
   - **1.2.** Updating of Technical Specification
2. **The Tender Process**
3. **Contract Process**
   - **3.1.** Preparation of the contract
   - **3.2.** Confirmation of the contract
4. **Device Installations Phase I**
   - **4.1.** Completing device setups
   - **4.2.** Testing device setups
5. Device Installations Phase II
   - **5.1.** Updating device setups
   - **5.2.** Confirmation device setups
6. **Fulfilling Additional Software Requests**
7. **Inspection and Acceptance**
8. **Training**

FIGURE 3.8 Work Breakdown Structure of the project.

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4 Forecasting

Yüksel Değirmencioğlu and İbrahim Zeki Akyurt

CONTENTS

4.1 INTRODUCTION

Business managers make various decisions for the future of the business every day. They make new investments without knowing how much the business income will be, carry out stock studies without knowing the sales levels, and purchase new equipment without knowing the product demands. In a world where technology is advancing and the competitive environment in the market is increasing rapidly, managers are always trying to make better evaluations despite this uncertainty (Stevenson 1993). Making good assessments is also the primary purpose of forecasting.

The ability to predict future developments is defined as 'forecasting' (Akyurt 2015). This prediction is performed via mathematical analysis of past data or by subjective methods. Sometimes both are used simultaneously, called the 'mpngixed method' (Elsayed and Boucher 1994). There is no single correct method that gives the best forecast in all cases in general terms. A specific method can be the most appropriate one for a particular firm while causing the highest error rate for another firm. The proper method can differ among different departments, even among other

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products of a single firm. Because the forecasting process and maintenance have both timely and monetary costs, borders have to be drawn appropriately in order to achieve sustainability (Tersine 1994).

Forecasts may be related to the economy, technology, or demand. Demand or sales forecasting, which is the focus of this study, means making estimates about the demand for products or services supplied to the market by a firm (Arnold, Chapman, and Clive 2004). Officials who control inventory and production operations must forecast future amounts regarding these processes. Demand forecasts will help them establish production, capacity, and scheduling systems. As an input, sales forecasting contributes to financing, marketing, and personnel planning. With successful forecasting, stocks can be reduced, costs can be reduced, effective production plans can be drawn up, and service to customers can be improved (Axsäter 2015).

Forecasting processes take into account past consumer behavior as well as current trends. This method requires not only predicting future demand but also explaining previous demand behavior and the factors influencing that behavior. As the amount of data in businesses grows, it becomes increasingly challenging to create accurate and timely predictions. For businesses that wish to maintain their competitiveness, making accurate and quick predictions is unavoidable. New technologies such as powerful artificial intelligence algorithms, cloud computing, machine learning, data mining, and simulation facilitate the classification, sorting, processing, and interpretation of data. Thus, managers can make dynamic, fast, and satisfactory forecasts.

4.2 FORECASTING TYPES AND METHODS

Forecasting means the prediction of the future; therefore, estimates are made about customer demands over a defined period. The length of a forecasting period or date directly helps us to decide the type of activity where that forecast will be used. According to the period, there are three types of forecasting (Guide 2000):

1. *Short-term forecasting:* They are forecasts limited to a future period shorter than one year. These forecasts are mostly produced actually for a period shorter than three months. They are used generally in processes such as purchasing, supply planning, work scheduling, production planning, and machine and worker assignment.
2. *Medium-term forecasting:* These forecasts are made for a period of three months to three years. In general, they are used for sales planning, production planning and budgeting, cash budgeting, and analysis of various operation plans.
3. *Long-term forecasting:* This covers forecasts for periods three years or longer. They are used for decisions about new products, capital increase, establishment of new facilities, research and development (R&D), and resource planning.

Some characteristics distinguish medium- and long-term forecasts from short-term forecasts. Medium- and long-term forecasts address broader issues related to processes, products, facilities, and business plans that are more relevant to senior management. The implementation of some facility opening decisions, such as the establishment of a new airport, may take 10–20 years from the beginning to the completion, considering regional planning, such as transportation and field use. Short-term forecasts, in contrast, mostly use mathematical techniques, such as moving average and exponential smoothing. That is, it is useful in estimating problems such as deciding whether to add a new flight line to the flight route that includes the less quantitative method. Furthermore, short-term forecasts give more accurate results than long-term forecasts, as expected. In other words, the longer the time horizon, the less accurate the prediction. As a result, sales predictions must be revised on a frequent basis. In order to obtain more accurate forecasts, the estimates should be reviewed and revised at certain time intervals (Heizer and Render 1996).

4.3 CLASSIFICATION OF FORECASTING METHODS

Some demand forecasts make use of objective or quantitative forecasts, while others make use of subjective or qualitative forecasts. Businesses may have a variety of preferred choices. While some firms prefer the first strategy, which involves mathematical procedures based on past data, others prefer the second approach, which is based on the decision-maker's intuition and personal experience. In most cases, the most convenient way is to use both methods (Blumenfeld 2001). These are the two forecasting methods:

4.3.1 Qualitative Forecasting Method

According to the qualitative analysis approach, intuitions, emotions, personal experiences, and values systems of decision-makers are included in the forecasting process. They are also called non-numerical, opinion-based, or judgment-based. The nominal group technique, Delphi technique, market research, and so on are used in this type of forecasting.

Nominal group technique: The nominal group technique is a method for the scalability and prioritization of ideas. This ensures that a large number of opinions are prioritized with joint participation, and the consensus is achieved through scoring. Businesses may prefer this technique when they need to make quick decisions.

Delphi technique: The purpose of the Delphi technique is to make predictions about the future, reveal expert opinions, and reach a consensus. The Delphi technique can be used especially when decision-making is required in political or emotional situations, or when group dynamics do not allow for effective communication (for example, time differences, distance, and personality conflicts). In general, the Delphi technique has three features: (1) participant secrecy, (2) statistical analysis of group response, and (3) controlled feedback. The use of the Delphi technique usually involves sequential questionnaires administered to experts. After each application, the application results are communicated to the participants. This process continues until an agreement is reached. The compromise achieved is the product of this process.

Market research: In this approach, companies collect various information about the market they are in. They make various predictions by evaluating the information they collect. Using these forecasts, they make plans for the future of the company. For example, as a result of its market research, Tesla has revolutionized the history of electric vehicles as an environmentally friendly electric car, with the Roadster model produced in 2011 in order to reduce natural resource consumption, increase sales, and ensure sustainability.

4.3.2 Quantitative Forecasting Method

Quantitative forecasting is based on numerical data and mathematical models. Past numerical data can be analyzed by focusing on time series or causal relationships. When there is enough sales data for a certain product, based on the assumption that the future is a function of the past, the demand structure is analyzed, a fitting time series model is detected, and the future sales are predicted by 'time-series analysis' (Wagner 1970).

As opposed to the time series analysis, which includes only one single variable, namely the time factor, the causal relationship analysis may focus on various external variables. In the absence of past sales data, correlations between various external factors (such as air temperature) and sales are looked at, and estimates are based on those relationships. After detecting those influential factors, a statistical model is developed and used for demand forecasting (Peterson and Silver 1979).

Even if some firms use either one or the other, using both of them simultaneously (i.e., mixed forecasting method) seems to be the most appropriate way in most cases.

4.4 FORECASTING STAGES

The forecast phases consist of five steps, according to Nahmias (1993):

1. *Determination of forecasting purpose:* The intended use of the forecast results should be specified explicitly.
2. *Data collection:* Incomplete or more thorough information not only raises the expense of the research but also reduces the sensitivity of the results. As a result, it is critical to obtain reliable data.
3. *Determination of the forecast period:* The length of the forecast period should be appropriate for the intended use of the forecast results. The period length should not be too short to allow for a successful forecast, nor should it be too long to diverge from the precision of producing a correct forecast.
4. *Selection of the forecast method and making the forecasting:* The features of the acquired data, such as uncertainty, sensitivity, change form, and application aims, should be considered when selecting the method to be employed. Following the selection of a suitable estimation method, implementation steps should be performed.
5. *Investigation of the validity of forecast results:* The differences (forecast errors) between the forecast made and the actual values are examined systematically.

4.5 SIMPLE LINEAR REGRESSION AND CORRELATION ANALYSIS

The demand data is supposed to be created by a linear process of form $Y_t = a_0 + a_1 X_t + e_t$ with random variation. As shown in Figure 4.1, the purpose of regression analysis is to identify the linear function $\hat{Y}_t = \hat{a}_0 + \hat{a}_1 X_t$ that best reflects the linear relationship between the independent variable X_t and the dependent variable Y_t.

The $\hat{Y}_t = \hat{a}_0 + \hat{a}_1 X_t$ line that minimizes the sum of the squares of the error terms (e_t) is called the regression line. The parameters of the linear function of $\hat{Y}_t = \hat{a}_0 + \hat{a}_1 X_t$ are $\hat{a}_0$ and $\hat{a}_1$. The parameters of the linear function are found using the least-squares method with the help of the following equations:

$$\hat{a}_0 = \frac{\sum X_t^2 \sum Y_t - \sum X_t \sum X_t Y_t}{n \sum X_t^2 - (\sum X_t)^2} \tag{4.1}$$

$$\hat{a}_1 = \frac{n \sum X_t Y_t - \sum X_t \sum Y_t}{n \sum X_t^2 - (\sum X_t)^2} \tag{4.2}$$

The correlation coefficient (r) indicates the strength and direction of the cause-effect relationship between the independent variable X_t and the dependent variable Y_t. In other words, it demonstrates how successful the factor that is thought to affect the demand is in explaining the demand. The correlation coefficient is calculated with the following equation:

$$r = \frac{n \sum X_t Y_t - \sum X_t \sum Y_t}{\sqrt{\left(n \sum X_t^2 - \left(\sum X_t\right)^2\right)\left(n \sum Y_t^2 - \left(\sum Y_t\right)^2\right)}} \tag{4.3}$$

If $0{,}9 \le r \le 1$, there is a very strong relationship between X_t and Y_t.
If $0{,}7 \le r \le 0{,}9$, there is a strong relationship between X_t and Y_t.

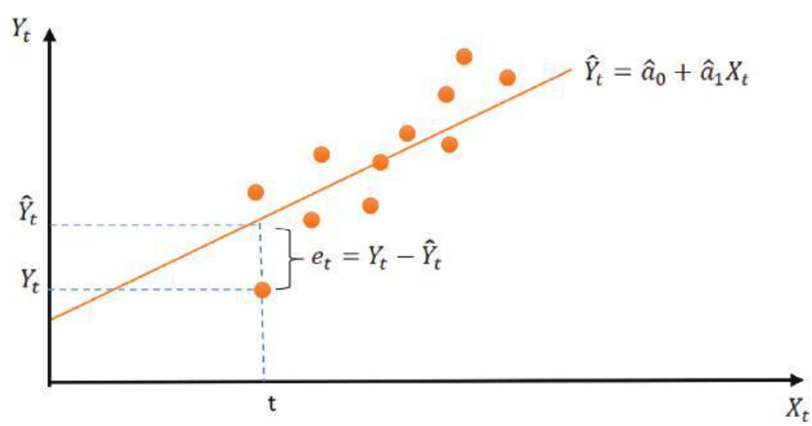

FIGURE 4.1 Simple linear regression demonstration.

If $0{,}4 \le r \le 0{,}7$, there is a moderate relationship between X_t and Y_t.
If $0{,}2 \le r \le 0{,}4$, there is a weak relationship between X_t and Y_t.
If $0 \le r \le 0{,}2$, there is a very weak relationship between X_t and Y_t.
If r is negative in the previous ranges, there is an inverse relationship.

4.6 FORECAST ERROR

In Figure 4.2, the success of the forecasting is evaluated using some criteria derived from the forecast error.

Some methods used for forecast errors are as follows:

Mean absolute deviation is the most commonly used indicator for tracking forecasts and assessing forecast success and is calculated with the following formula:

$$MAD = \sum_{t=1}^{n} \left| E_t \right| / n \tag{4.4}$$

$$E_t = D_t - F_t \tag{4.5}$$

Mean squared error is calculated by dividing the sum of the forecasting errors by the number of observations and with the following formula:

$$MSE = \sum_{t=1}^{n} \left(E_t \right)^2 / n \tag{4.6}$$

A balanced distribution of positive and negative forecast errors is a good forecast, and as a result, the cumulative sum of forecast error (CSFE) is expected to be near zero and is calculated with the following formula:

$$CSFE = \sum_{i=1}^{t} \left(E_t \right) \approx 0 \tag{4.7}$$

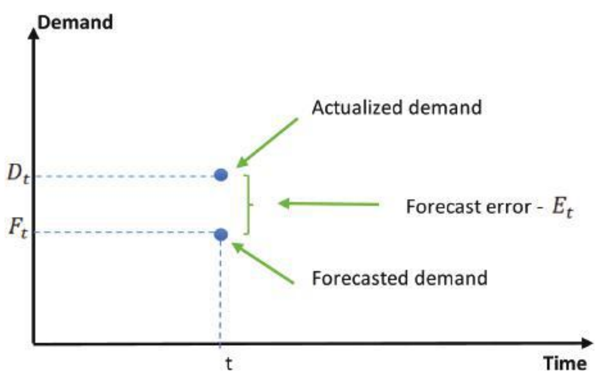

FIGURE 4.2 Forecast error demonstration.

CSFE is generally desired to be within the range of ∓ 3 mean absolute deviation. When it goes out of this range, it is concluded that the change in the forecast error is not caused by something random but may have been made by a systematic bias. As a result, forecasting needs to be revised. Forecasting precision can be raised in forecast systems where forecast errors can result in costly negative results by decreasing the ∓ 3 mean absolute deviation range (Russell and Taylor 1995).

4.7 TIME SERIES ANALYSIS

A time series is a set of values obtained by an independent variable in consecutive and equally spaced times. It is assumed that behavior in the past will continue in the future. This assumption is likened to driving by looking in the rearview mirror. The value taken by the variable in the time series is considered a function of its values in previous periods. Time series examples include the annual number of students at the Massachusetts Institute of Technology, Turkish Airlines' annual passenger counts, Apple's monthly computer sales, Versace's weekly eyeglass production, and so on (Martinich 1997).

There is a fixed level of demand data that makes up the time series. At the same time, there are four main sources of changes in the series:

1. Trend
2. Seasonality
3. Cyclical
4. Random

The first step in the analysis of a time series is to plot the data on a graph in order to examine the pattern of changes and to choose the appropriate forecasting method.

4.8 TIME SERIES ANALYSIS METHODS

There are a number of models in demand forecasting that do not need any independent variables and are easier to use. These models are called time series analysis methods. The time series analysis methods that will be examined in the following sections are as follows:

- Moving average methods
- Exponential smoothing methods
- Seasonal variation methods

4.8.1 Moving Average Methods

There are two types of moving average methods: simple moving average and trending moving average.

4.8.1.1 Simple Moving Average Method

The simple moving average (SMA) method assumes that the data in the time series has a stable level but random changes. That is, in Figure 4.3, the demand data is assumed to be generated by a process in the format $D_t = a_{0+} e_t$ with random variation.

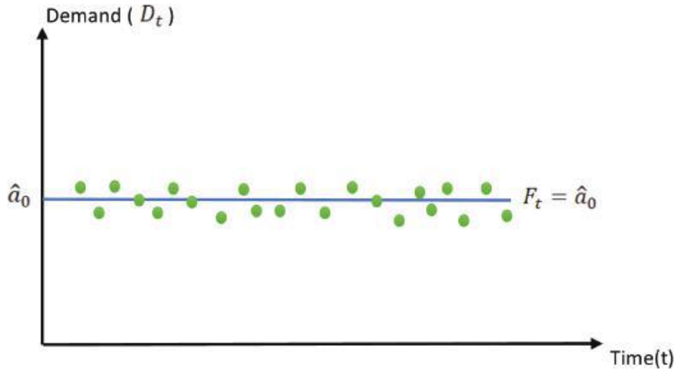

FIGURE 4.3 Simple moving average demonstration.

The optimal value of $\hat{a}_0$, which is the forecast of a_0, which is the constant level of demand, should minimize the sum of the squares of the distances of the elements of the series D_t from $\hat{a}_0$.

$$E_t = D_t - \hat{a}_0 \tag{4.8}$$

The following equation is used to calculate the sum of squares (SS) for n periods.

$$SS = \sum_{t=1}^{n} (D_t - \hat{a}_0)^2 \tag{4.9}$$

If equation 4.9 is equalized to zero by taking the derivative with respect to $\hat{a}_0$, we get the $\hat{a}_0$ value that minimizes the sum of squares as follows:

$$\hat{a}_0 = \frac{1}{n} \sum_{t=1}^{n} D_t \tag{4.10}$$

Equation 4.10 assumes that the process has not changed over the last n periods. The decision-maker may think that this assumption is unrealistic and may want to use only the observations of the last m period in the estimation of $\hat{a}_0$. In this case, the following equation applies:

$$\hat{a}_0 = \frac{1}{m} \sum_{t=n-m+1}^{n} D_t \tag{4.11}$$

As a result, the forecast with the simple moving average method can be expressed as follows:

$$F_{t,\tau} = \hat{a}_0 \tag{4.12}$$

Here:

$F_{t,\tau}$: Demand forecast for period τ at the end of period t
$\hat{a}_0$: Forecast for constant a_0 at the end of period t

Example: As seen in Table 4.1, Erikli, a water distribution company, has demand data for 12 months. Calculate the demand forecasts for January and August using the simple moving average method over the last three periods and the last five periods.

TABLE 4.1
Demand Forecast Data for the Past 12 Months

Period (t)	Demand (D_t)
January	106
February	110
March	118
April	105
May	115
June	100
July	112
August	106
September	118
October	102
November	112
December	110

Solution: The demand forecasts according to three and five periods are calculated in Table 4.2:

TABLE 4.2
Three-Period and Five-Period Simple Moving Average Values

Period (t)	Demand (D_t)	3-SMA	5-SMA
January	106	-	-
February	110	-	-
March	118	111,33	-
April	105	111,00	-
May	115	112,67	110,80
June	100	106,67	109,60
July	112	109,00	110,00
August	106	106,00	107,60
September	118	112,00	110,20
October	102	108,67	107,60
November	112	110,67	110,00
December	110	108,00	109,60

5-SMA

$F_{\text{December, January}} = 109{,}60$

$F_{\text{December, August}} = 109{,}60$

3-SMA

$F_{\text{December, January}} = 108{,}00$

$F_{\text{December, August}} = 108{,}00$

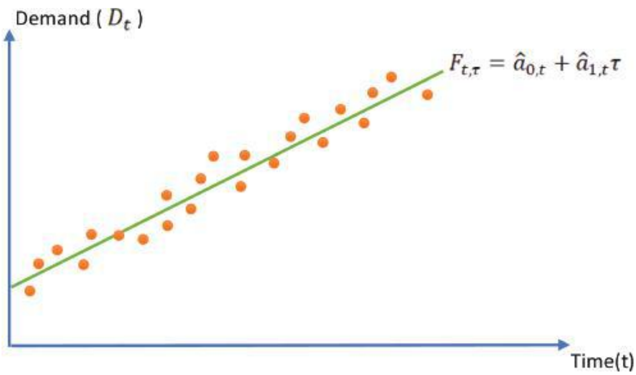

FIGURE 4.4 Trending moving average demonstration.

4.8.1.2 Trending Moving Average Method

The trended moving average method is used when a trend is observed in the data forming the time series. In Figure 4.4, the simple moving average method assumes that a_0 changes over time. Demand data is assumed to be generated by a process $D_t = a_{0,t} + a_{1,t}\tau + e_t$ in form.

Here:

$a_{0,t}$: The constant level of demand in period t, assumed to change over time
$a_{1,t}$: Slope in period t
τ: A future period whose demand is to be forecasted
$\tau - t$: Forecast horizon

In summary, forecasting with the trending moving average method is made using the following equation:

$$F_{t,\tau} = \hat{a}_{0,t} + \hat{a}_{1,t}\tau \tag{4.13}$$

Here:

$$\hat{a}_{0,t} = 2MA_t^{[1]} - MA_t^{[2]} \tag{4.14}$$

$$\hat{a}_{1,t} = \left(\frac{2}{n-1}\right)\left(MA_t^{[1]} - MA_t^{[2]}\right) \tag{4.15}$$

$MA_t^{[1]}$: Moving average for t period
$MA_t^{[2]}$: Moving average of the moving average for period t
n: The number of periods for which the moving average is calculated ($n - MA$)

Example: The demand forecast data for the past 12 months of Xiaomi phone sales are given in Table 4.3. Using the trending moving average method, compute the demand forecasts for January and August. Create the model based on the latest $n = 3$ periods.

TABLE 4.3
Demand Forecast Data for the Past 12 Months

Period (t)	Demand (D_t)
January	106
February	115
March	128
April	123
May	135
June	130
July	147
August	150
September	158
October	155
November	167
December	170

Solution: The demand forecast according to three periods is calculated in Table 4.4:

TABLE 4.4
Three-Period Trending Moving Average Forecasting Values

Period (t)	Demand (D_t)	$MA_t^{[1]}$	$MA_t^{[2]}$	$\hat{a}_{0,t}$	$\hat{a}_{1,t}$
January	106				
February	115				
March	128	116,3			
April	123	122,0			
May	135	128,7	122,3	135,1	6,4
June	130	129,3	126,7	131,9	2,6
July	147	137,3	131,8	142,8	5,5
August	150	142,3	136,3	148,3	6,0
September	158	151,7	143,8	159,6	7,9
October	155	154,3	149,4	159,2	4,9
November	167	160,0	155,3	164,7	4,7
December	170	164,0	159,4	168,6	4,6

$F_{\text{December, January}} = 168{,}6 + 4{,}6\ (1) = 173{,}2$

$F_{\text{December, August}} = 168{,}6 + 4{,}6\ (8) = 205{,}4$

4.8.2 Exponential Smoothing Methods

The exponential smoothing method is a technique based on the same principles as the n-period moving average method but requires less computation. Furthermore, it is a method that does not require past data to be stored for long periods but only uses the most recent demand data. The exponential smoothing method is particularly useful when making short-term forecasts. There are two types of exponential smoothing methods: simple exponential smoothing and double exponential smoothing (Krupp 1992).

4.8.2.1 Simple Exponential Smoothing Method

The simple exponential smoothing method is used when the data indicates a random variation around a fixed level and has no trend. The smoothing process is performed by means of a value known as the smoothing factor (α), which ranges from 0 to 1. The purpose of the smoothing factor is to give more importance to recent past data. Usually, values between 0,01 and 0,30 are used in the smoothing process. The purpose is to give more weight to the most recent data than to past data. Thus, it tries to minimize the sum of the weighted error squares. Assume that the data is generated by a process $D_t = a_{0+}e_t$ in form.

$$SS = \sum_{t=1}^{n} \beta^{n-t} (D_t - \hat{a}_0)^2, \qquad 0 < \beta < 1 \tag{4.16}$$

In β^{n-t}, t indicates the weight of the error in the period. Thus, the greatest weights are given to the forecast errors that occurred in the most recent past. Equation 4.16 is equalized to zero by taking the derivative with respect to $\hat{a}_0$. When the necessary mathematical operations are performed, is obtained the following equation is obtained:

$$\hat{\alpha}_{0,t} = (1-\beta) D_t + \beta \hat{a}_{0,t-1} \tag{4.17}$$

If $\alpha = (1 - \beta)$ is accepted, the equation becomes as follows:

$$\hat{\alpha}_{0,t} = \alpha D_t + (1-\alpha) \hat{a}_{0,t-1} \tag{4.18}$$

$$F_t = \hat{a}_{0,t-1} \tag{4.19}$$

According to equation 4.19, in order to calculate the forecasted demand value for any period, it is necessary to have a forecasted value for the previous period as well. Therefore, the forecasting made by the exponential smoothing method will have the knowledge of all past data.

In order to start the calculations, an initial value of the forecast values is needed. This value can be obtained in the following ways:

- If there is data previous to the starting period, the average of the last n periods previous to the relevant period can be obtained.
- The demand of the initial period can be considered as the forecasting value.
- If the data is not available, a subjective method can be used.

Example: As seen in Table 4.5, make use of the previous example of the water distribution company and forecast the demand for January using the simple exponential smoothing method for the smoothing factors $\alpha = 0{,}1$ and $\alpha = 0{,}3$.

TABLE 4.5
Demand Forecast Data for the Past 12 Months

Period (t)	Demand (D_t)
January	106
February	110
March	118
April	105
May	115
June	100
July	112
August	106
September	118
October	102
November	112
December	110

Solution: The demand forecast is calculated in Table 4.6:

TABLE 4.6
Simple Exponential Smoothing Forecasting Values

Period (t)	Demand (D_t)	$\alpha = 0{,}1$			$\alpha = 0{,}3$		
		αD_t	$(1-\alpha)a_{0,t-1}$	$a_{0,t}$	αD_t	$(1-\alpha)a_{0,t-1}$	$a_{0,t}$
January	106			106,0			106,0
February	110	11,0	95,4	106,4	33,0	74,2	107,2
March	118	11,8	95,8	107,6	35,4	75,0	110,4
April	105	10,5	96,8	107,3	31,5	77,3	108,8
May	115	11,5	96,6	108,1	34,5	76,2	110,7
June	100	10,0	97,3	107,3	30,0	77,5	107,5
July	112	11,2	96,5	107,7	33,6	75,2	108,8
August	106	10,6	97,0	107,6	31,8	76,2	108,0
September	118	11,8	96,8	108,6	35,4	75,6	111,0
October	102	10,2	97,7	107,9	30,6	77,7	108,3
November	112	11,2	97,2	108,4	33,6	75,8	109,4
December	110	11,0	97,5	108,5	33,0	76,6	109,6

The forecast errors obtained by the mean absolute deviation method for the forecasting are given in Table 4.7:

TABLE 4.7
Mean Absolute Deviation Estimation Error Values

Period (t)	Demand (D_t)	α = 0,1		α = 0,3	
		F_t	$F_t - D_t$	F_t	$F_t - D_t$
January	106				
February	110	106,0	–4	106,0	–4
March	118	106,4	–11,6	107,2	–10,8
April	105	107,6	2,6	110,4	5,4
May	115	107,3	–7,7	108,8	–6,2
June	100	108,1	8,1	110,7	10,7
July	112	107,3	–4,7	107,5	–4,5
August	106	107,7	1,7	108,8	2,8
September	118	107,6	–10,4	108,0	–10
October	102	108,6	6,6	111,0	9
November	112	107,9	–4,1	108,3	–3,7
December	110	108,4	–1,6	109,4	–0,6
MAD		5,74		6,15	

4.8.2.2 Double Exponential Smoothing Method

The double exponential smoothing method is used when the data forming the time series has a trend, as in the trending moving average method. In this method, it is assumed that the demand data is generated by a process $D_t = a_{0,t} + a_{1,t}\tau + e_t$ in form.

Here:

$a_{0,t}$: The constant level of demand in period t, assumed to change over time
$a_{1,t}$: Slope in period t
τ: A future period whose demand is to be forecasted
$\tau - t$: Forecast horizon

Forecasting with the double exponential smoothing method is made using the following equation:

$$F_{t,\tau} = \hat{a}_{0,t} + \hat{a}_{1,t}(\tau - t) \tag{4.20}$$

Here:

$$\hat{a}_{0,t} = 2F_t^{[1]} - F_t^{[2]} \tag{4.21}$$

$$\hat{a}_{1,t} = \left(\frac{\alpha}{1-\alpha}\right)\left(F_t^{[1]} - F_t^{[2]}\right) \tag{4.22}$$

$F_t^{[1]}$: Forecasting value obtained by simple exponential smoothing method for period t
$F_t^{[2]}$: The value obtained by applying the simple exponential smoothing method again, assuming the $F_t^{[1]}$ values for the t period as the real demand values

Example: As seen in Table 4.8, make use of the previous example of the Xiaomi phone sales and forecast the demand for January and August using the double exponential smoothing method for the smoothing (α = 0,3).

TABLE 4.8
Demand Forecast Data for the Past 12 Months

Period (t)	Demand (D_t)
January	106
February	115
March	128
April	123
May	135
June	130
July	147
August	150
September	158
October	155
November	167
December	170

Solution: The demand forecast is calculated in Table 4.9:

TABLE 4.9
Double Exponential Smoothing Forecasting Values

Period (t)	Demand (D_t)	αD_t	$(1-\alpha)F_{t-1}^{[1]}$	$F_t^{[1]}$	$\alpha F_t^{[1]}$	$(1-\alpha)\,F_{t-1}^{[2]}$	$F_t^{[2]}$	$\hat{a}_{0,t}$	$\hat{a}_{1,t}$
January	106			106,0			106,0		
February	115	34,5	74,2	108,7	32,6	74,2	106,8	110,6	0,8
March	128	38,4	76,1	114,5	34,3	74,8	109,2	119,8	2,3
April	123	36,9	80,2	117,1	35,1	76,3	111,5	122,7	2,4
May	135	40,5	82,0	122,5	36,7	78,0	114,9	130,1	3,3
June	130	39,0	85,8	124,8	37,4	80,3	117,8	131,8	3,0
July	147	44,1	87,4	131,5	39,4	82,4	122,0	141,0	4,1
August	150	45,0	92,1	137,1	41,1	85,3	126,5	147,7	4,5
September	158	47,4	96,0	143,4	43,0	88,5	131,6	155,2	5,1
October	155	46,5	100,4	146,9	44,0	92,0	136,2	157,6	4,6
November	167	50,1	102,8	152,9	45,9	95,2	141,2	164,6	5,0
December	170	51,0	107,0	158,0	47,4	98,8	146,2	169,8	5,1

$F_{\text{June, July}} = 131{,}8 + 3{,}0(1) = 134{,}8$
$F_{\text{December, January}} = 169{,}8 + 5{,}1(1) = 174{,}9$
$F_{\text{December, August}} = 169{,}8 + 5{,}1(8) = 210{,}6$

4.8.3 Seasonal Smoothing Method (Winter's Method)

The seasonal smoothing method is utilized when there is a seasonal fluctuation in demand data. Assume that the data generation model has three components: a constant level component, a trend component, and a seasonal component. Each of the mentioned components is regularly updated thanks to a correction constant applied to the previous demand and most recent forecasting values (Winston 1971).

In Figure 4.5, in the seasonal smoothing method, it is assumed that the data is produced by a process $D_t = \left(a_{0,t} + a_{1,t}\tau\right)C_t + e_t$ in form. C_t is referred to as the seasonal factor. The $a_{0,t}$, $a_{1,t}$, and C_t parameters are constantly updated thanks to an exponential smoothing process.

After the relevant parameters have been updated, the following equation is used for the forecasts:

$$F_t = (a_{0,t} + a_{1,t})C_t \tag{4.23}$$

In all exponential smoothing methods, the initial values of the parameters are required to begin the forecasting process. There are several different methods to set initial values for parameters, one of which is as follows:

Slope: A slope is calculated using two years of average sales data:

$$\bar{S}_1 = \frac{\sum_{t=1}^{N} D_t}{N} \quad \bar{S}_2 = \frac{\sum_{t=N+1}^{2N} D_t}{N} \quad a_1 = \frac{\bar{S}_2 - \bar{S}_1}{N} \tag{4.24}$$

Level: The level at the end of the *2N* period is computed using the calculated slope values of a_1 and S_2:

$$a_{0,2N} = \bar{S}_2 + a_1 \frac{N-1}{2} \tag{4.25}$$

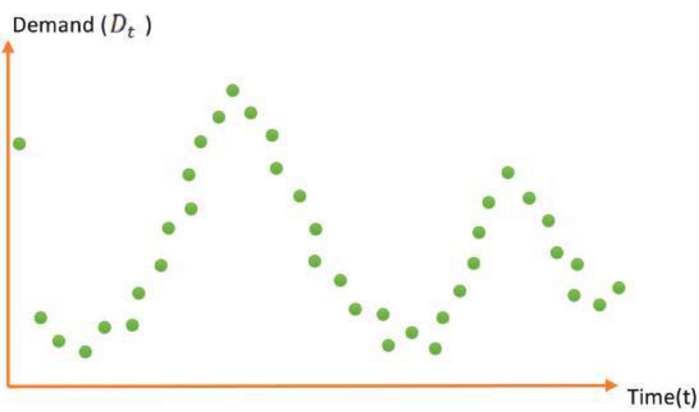

FIGURE 4.5 Seasonal smoothing demonstration.

Seasonal factor: Seasonal factors are computed with the following initial values:

$$C_t = \frac{D_t}{a_{0+}a_1 t} \tag{4.26}$$

Here, the level is at the beginning of the first period:

$$a_{0,0} = a_{0,2N} - (2N)a_1 \tag{4.27}$$

Example: Two-year data on Michelin snow wheel sales are given in Table 4.10. Calculate the January, February, and March forecasting of the third year.

Solution: First, the initial parameters are determined:

Slope:

$$S_1 = 2522 / 12 = 210{,}2$$
$$S_2 = 2817 / 12 = 234{,}8$$
$$a_1 = (234{,}8 - 210{,}2) / 12 = 2{,}05$$

Level:

$$a_{0,2N} = 234{,}8 + 2{,}05\ (11 / 2) = 246{,}08$$
$$a_{0,0} = 246{,}8 - (24)\ (2{,}05) = 196{,}88$$

TABLE 4.10
Snow Wheel Sales Data for Two Years

Period (t)	Number of Wheels Sold (D_t)	
	Year 1	Year 2
January	195	229
February	252	271
March	299	333
April	276	305
May	258	277
June	210	239
July	192	211
August	154	193
September	141	155
October	128	159
November	200	209
December	217	236
TOTAL	2522	2817

Seasonal factor:

The values obtained according to equation 4.26 are in Table 4.11:

TABLE 4.11
Seasonal Factor Calculations

t	$a'_{0\,0} + a_1 t$	C_t	t	$a'_{0\,0} + a_1 t$	C_t	$\bar{C}_t$
1	198,93	0,98	13	223,53	1,02	1,00
2	200,98	1,25	14	225,58	1,20	1,23
3	203,03	1,47	15	227,63	1,46	1,47
4	205,08	1,35	16	229,68	1,33	1,34
5	207,13	1,25	17	231,73	1,20	1,23
6	209,18	1,00	18	233,78	1,02	1,01
7	211,23	0,91	19	235,83	0,89	0,90
8	213,28	0,72	20	237,88	0,81	0,77
9	215,33	0,65	21	239,93	0,65	0,65
10	217,38	0,59	22	241,98	0,66	0,63
11	219,43	0,91	23	244,03	0,86	0,88
12	221,48	0,98	24	246,08	0,96	0,97
TOTAL						12,08

As seen in Table 4.12, after the normalization process, the seasonal factors are as follows:

TABLE 4.12
Seasonal Factors After the Normalization Process

t	Normalized C_t
1	= (1,00 × 12) / 12,08 = 0,99
2	1,22
3	1,46
4	1,33
5	1,22
6	1,00
7	0,89
8	0,76
9	0,65
10	0,63
11	0,87
12	0,96
TOTAL	12,00

$$F_t = \left(a_{0,2N} + a_1 t\right) C_t$$

$$F_{\text{January}} = [246{,}08 + (2{,}05)\,(1)]\,(0{,}99) = 245{,}64$$
$$F_{\text{February}} = [246{,}08 + (2{,}05)\,(2)]\,(1{,}22) = 305{,}21$$
$$F_{\text{March}} = [246{,}08 + (2{,}05)\,(3)]\,(1{,}46) = 368{,}25$$

4.9 FORECASTING REQUIREMENT AND SUSTAINABILITY

Today, globalization and increased production volumes have brought some environmental and ethical problems. This situation is forcing companies to undertake some preventive actions. As a result, sustainability has gained considerable attention in the business world. Each and every one of us has a role to play in achieving a more sustainable future. Scientific progress enables the creation of a sustainable future for the next generations in this sense, balancing environmental, social, and economic values through running a business (Tibben-Lembke and Rogers 2002).

In this context, forecasting methods used by firms have to be revised in terms of sustainability. New legal requirements, such as reverse logistics, have especially made forecasting more complicated. It is a sign of how crucial demand forecasting is for sustainability. In classical terms, waste management has been defined as incineration and burying. However, now, it means mostly recycling. The process of reverse logistics begins with the transfer of recyclable products from the consumption points of end users to collection and selection points. The process starts with the sale of the product and ends when the product returns to the manufacturer or distributor for recycling. Reverse logistics gained importance, especially since the increase in environmental problems (Waters and Waters 2003). Because the discipline of management deals with the normal forward flow direction of goods, until now, there have been few studies on reverse logistics. There are various types of reverse logistics, such as repair, refurbishing, remanufacturing, cannibalization, and recycling. At each step of the reverse logistics process, there are certain ambiguities that make forecasts regarding collected products difficult. The first uncertainty is related to the time and amount of the collected product, which is a result of the product's lifetime. The lifecycle and, of course, technological developments influence rates of return. The second ambiguity is balancing the returns with the demand for remanufactured goods (Seuring and Gold 2013). The equivalence between rates of return and demand is also a function of expected product lifetime and technological innovations. The firm has to maximize profit by balancing the return coming from customers and the demand for remanufactured goods. Neither inventory accumulation nor decreasing levels of service are allowed in this process.

In addition to the mentioned situation, demand for that product may not be met in time when demand changes are not predicted accurately, which is highly unfavorable for the firms. When is the firm going to need a new facility in the future? This crucial question also can only be answered with the help of forecasting (Lund and Hauser 2010). When the demand decreases on a seasonal basis, temporary manpower surplus can be cannibalized by another production. Two seasonal demand curves complementing each other can result in high productivity. During the demand forecasting process, product lifetime and lifecycle gain significance. Products are not purchased steadily at the same level. Each product has a certain lifetime. Even the most successful products pass through different episodes in their lifecycle; in other words, they join the market, increase their market share, mature, and drop in at the end. While choosing the right forecasting method and technique, the place of the product in its lifecycle has to be taken into account (Hillier and Lieberman 2010).

Factors that affect demand change from day to day. Therefore, the reliability of forecasts decreases proportionally as their term gets longer. As a result, demand forecasts have to be repeated on a regular basis at the end of every sale season (Narasimhan, Mcleavey, and Billington 2009). Here, the costs and efforts of forecasting are believed to be lower than their benefit. In order to maintain forecasting, it is expected that this situation will continue (Silver, Pyke, and Peterson 1998).

4.10 CASE STUDY

In this case, the Turkish Airlines Flight Academy, which provides integrated flight training in Turkey, will be analyzed.

Turkish Airlines Flight Academy (henceforth, TAFA), as a sub-brand of Turkish Airlines, was founded with the purpose of educating airline pilots needed by Turkish Airlines and other airlines as well as providing pilot training (ATP (A) Unified Airline Transport Pilot Training). The duration of training includes seven months of theoretical training and seven to eight months of practical training. Theoretical training covers ten different coursework, while practical training refers to the simulations and flight experience of up to 244 hours. In Figure 4.6, TAFA has been providing training in their academy facilities at Aydın Çıldır Airport since 2013 with its 25 training aircraft (12 Cessna C-172, 6 Diamond DA-40, and 7 Diamond DA-42), 3 flight simulators, 6 classrooms, and 26 instructors, including

FIGURE 4.6 TAFA trainer aircraft.

23 FI(A) and 3 TI trainers. Turkish Airlines Flight Academy has an ongoing planning system intertwined with diverse variables, such as weather conditions and human and mechanical setbacks. To overcome and manage the requirements of planning without complications, intensive mental force is called for making conducive instantaneous decisions to best suit student pilots, instructors, and aviation-related dynamic conditions.

There are pretty much factors and restrictions affecting flight hours. These factors are daylight time, weather conditions, aircraft type, regulations, maintenance hours, and pandemic impact. The result of all these effects complicates forecasts at the same time.

In TAFA, flights are scheduled between sunrise and sunset times. Thus, as the daylight time is longer in the summer periods, the planned flight hours are also higher than in the winter periods. Flights take place within the weather conditions limits specified in company procedures. These limits may vary according to the training phase of the student. Therefore, in the wintertime, the flight hours are fewer compared with the other months as the weather does not enable flying. Solo flights are scheduled with Cessna aircraft only, and Diamond aircraft are not used for this purpose.

For instruction pilots, a maximum of six hours of flight time is scheduled per day. In this period, flight crews are permitted to fly 100 hours for 28 consecutive (sequential) days and a maximum of 1.000 hours for a calendar year. The daily duty time shall not exceed 12 hours. The period of duty begins one hour before the first flight and ends one hour after the last flight of the assigned crew. The period of duty is 60 hours for 7 consecutive days, 110 hours for 14 days, and 190 hours for 28 days, and it is not allowed to exceed 2.000 hours for a calendar year. The rest time for the next day is at least 12 hours. For the instructor pilots, there shall be scheduled a minimum of 1 off day following 6 consecutive days, a minimum of 7 local days for a single calendar month, and a minimum of 96 local days for each calendar year. Off days are distributed proportionally according to the number of workdays within the month. Per civil aviation regulations, the minimum of seven local off days should be given in two halves in a calendar month, grouped as two, two, one, one, and one. For cadet pilots, solo navigation flights shall be planned for a maximum of six hours per day, while dual training flights shall be planned for a maximum of four hours. Applied limitations regulated by DGCA and EASA for instructor pilots also include cadet pilots.

Cessna-type aircraft in every 50-hour flight time and Diamonds in every 100-hour flight time have periodic technical maintenance. In addition to this maintenance, there is annual periodic technical maintenance for all types of our fleet. The flights are scheduled for all days, with the exception of New Year's Eve and religious holidays.

In unexpected and urgent circumstances, such as a pandemic, flights may be interrupted. According to the measures taken by the government authorities, the flight school was closed, and there were no flights between 15.03.2020 and 31.05.2020.

In Figure 4.7, 2022 flight hours will be forecast in this study, using past data regarding TAFA flight hours during the 2018–2021 period.

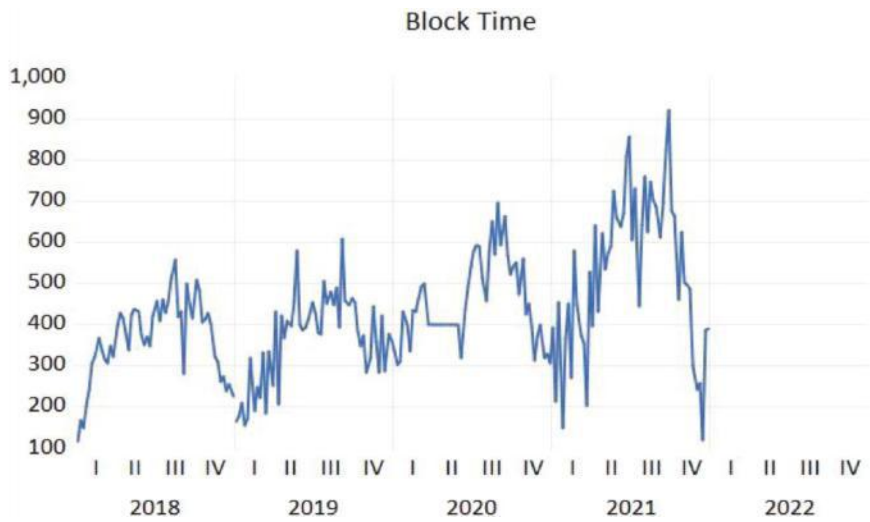

FIGURE 4.7 Actual flight hours during the 2018–2021 period.

When the flight data for the 2018–2021 period is studied, it is seen that there is a seasonal change in the data. In Figure 4.8 and as seen in Table 4.13, according to the seasonal smoothing method, the weekly forecasting values obtained for the year 2022 in the EViews 12 program are as follows:

TABLE 4.13
2022 Weekly Block Time Forecast Values

Weeks	Block Time	Weeks	Block Time	Weeks	Block Time	Weeks	Block Time
03/1/2022	274.9942	**04/4/2022**	473.4832	**04/7/2022**	584.8598	**03/10/2022**	613.3187
10/1/2022	246.3299	**11/4/2022**	464.0322	**11/7/2022**	584.8530	**10/10/2022**	581.2628
17/1/2022	306.6299	**18/4/2022**	483.5257	**18/7/2022**	534.5767	**17/10/2022**	478.1393
24/1/2022	269.6068	**25/4/2022**	495.5056	**25/7/2022**	591.8329	**24/10/2022**	548.3048
31/1/2022	329.2973	**02/5/2022**	477.3365	**01/8/2022**	593.4364	**31/10/2022**	461.61446
07/2/2022	402.2249	**09/5/2022**	510.3655	**08/8/2022**	623.9406	**07/11/2022**	469.0447
14/2/2022	349.3966	**16/5/2022**	538.6669	**15/8/2022**	673.9661	**14/11/2022**	466.0549
21/2/2022	453.4353	**23/5/2022**	607.3988	**22/8/2022**	610.2468	**21/11/2022**	369.7118
28/2/2022	413.7179	**30/5/2022**	513.3917	**29/8/2022**	612.3161	**28/11/2022**	331.2925
07/3/2022	423.8873	**06/6/2022**	475.0442	**05/9/2022**	589.8678	**05/12/2022**	391.4789
14/3/2022	378.3711	**13/6/2022**	522.4881	**12/9/2022**	649.0545	**12/12/2022**	284.6558
21/3/2022	381.4857	**20/6/2022**	566.8997	**19/9/2022**	633.4729	**19/12/2022**	382.3680
28/3/2022	417.7772	**27/6/2022**	629.0827	**26/9/2022**	637.2758	**26/12/2022**	361.4716

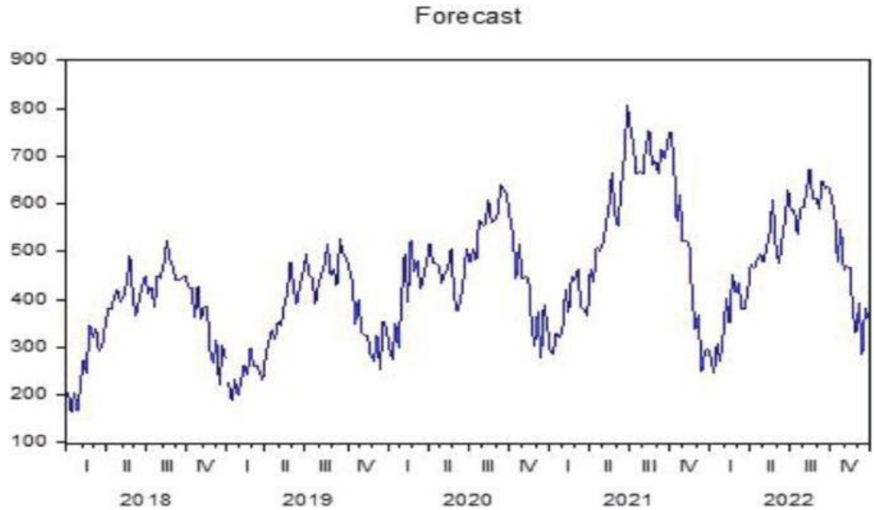

FIGURE 4.8 2022 weekly block time forecast values.

In Figure 4.9, in addition, the 2018–2021 forecast values and actual values are as follows:

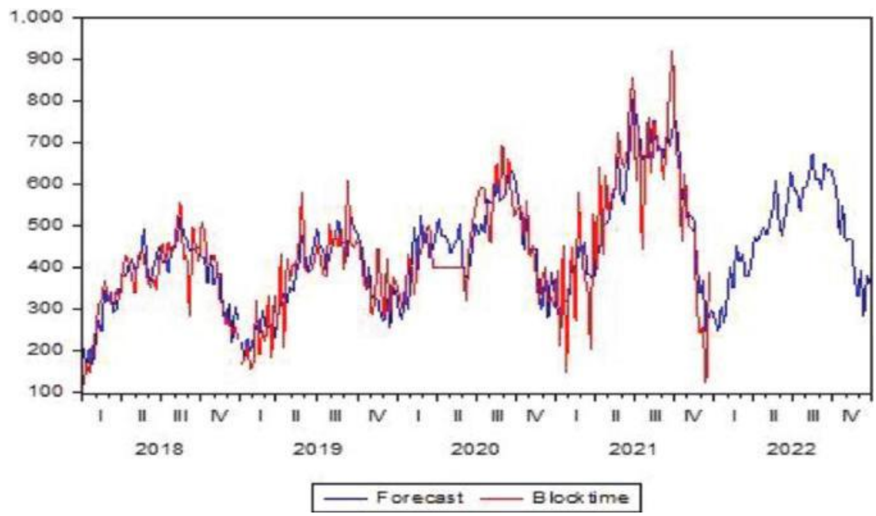

FIGURE 4.9 2018–2021 forecast values and actual values.

In this study, it is seen that realistic forecasting was obtained between the period 2018–2020. As demonstrated in this study, successful forecasts can benefit businesses in many ways. Businesses can build more effective strategies by basing what they can do in the face of future scenarios and what they require on scientific data rather than uncertainty. They will be able to take their enterprises to the next level.

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5 Design of Goods and Services

Yüksel Değirmencioğlu and Yakup Kara

CONTENTS

5.1 INTRODUCTION

Businesses that do not want to lose their competitive power should be constantly open to innovations and changes. For this reason, it is very important for businesses to design and produce new products. Businesses are designing new products by considering customer requests and needs. Product design is an activity aimed at determining the physical characteristics (size, performance, shape) and functions of the product to be produced by the enterprise (Dongmin, Yanyun, and Ye 2012). The type and some features of the product to be produced are generally revealed at the end of R&D and market research. After that, an intense exchange of information begins between the product design department, known as product engineering, and other departments of the business. Product design cooperates particularly closely with sales, marketing, process, and production planning. The product design department, which has the main responsibility for product design, is the center of all activities. Many vital decisions are made in the long journey between the design and production of a new product. According to a study conducted by DuPont on its own products, it takes an average of nine years from the R&D stage to the commercial production of a new product (Karol, Loeser, and Tait 2016). During this period, 56% of the projects were eliminated in the preliminary rounds, and 59% of the remaining ones were eliminated due to feasibility calculations or design and process constraints. With subsequent losses, only 2% of the products originally designed were able to achieve commercial production. As can be seen from this example, the creation of a new product is very difficult and requires careful planning.

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Product development does not end with the design and production of a new product. After the product goes into production, it starts to develop just like a baby. In all these development processes, the product is closely observed, and different strategies are applied at each development stage in this process, which is called the product lifecycle.

The presentation of goods and services, which are the basis of the existence of businesses, to society is possible with effective product strategies. When an effective product strategy is made, a roadmap is determined for the new product to be created by making associations with the product-related cost-effective investments, market share, and product lifecycle (Wu et al. 2014). The main purpose of planning all these and making various decisions is to enable businesses to gain competitiveness in the market. Today, businesses that integrate developing technology into their structures are one step ahead of other businesses. Especially today, applications such as augmented reality, artificial intelligence, and virtual reality, which are within the scope of Industry 4.0 technologies, provide great convenience to businesses in the design and development of products and services.

5.2 PRODUCT LIFECYCLES

No matter how well designed, the majority of products introduced to the market have a limited lifetime. Product lifecycles are becoming shorter due to the rapid development of technology, particularly in computers and other technological items and consumer goods. The following are the results of the shortening of product lifetimes (Gmelin and Seuring 2014; Wu et al. 2014):

1. Businesses that have to do product design and development have increased their expenses.
2. In order to keep up with the ever-changing product models, businesses have started to prefer flexible production systems that can be easily shifted to the production of other products.
3. The ability to develop and produce products quickly has become an important element of the production strategy. As a result, computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies have begun to be used, which allow products to be designed and produced quickly.
4. Today, companies that want to increase their competitive power have entered the race to produce both fast and as wide a variety of products as possible. Companies benefiting from developing technology benefit from various Industry 4.0 technologies, such as virtual reality, augmented reality, artificial intelligence, and cloud computing.

In Figure 5.1, a product lifecycle is the length of time from when a product is first introduced to consumers until it is removed from the market. A product's lifecycle is usually broken down into four stages: introduction, growth, maturity, and decline (Dongmin, Yanyun, and Ye 2012; Iveson and Hultman 2022).

Introduction: The introduction is the period when the product is introduced to the market, the sales amount is quite slow, and the product starts to be recognized

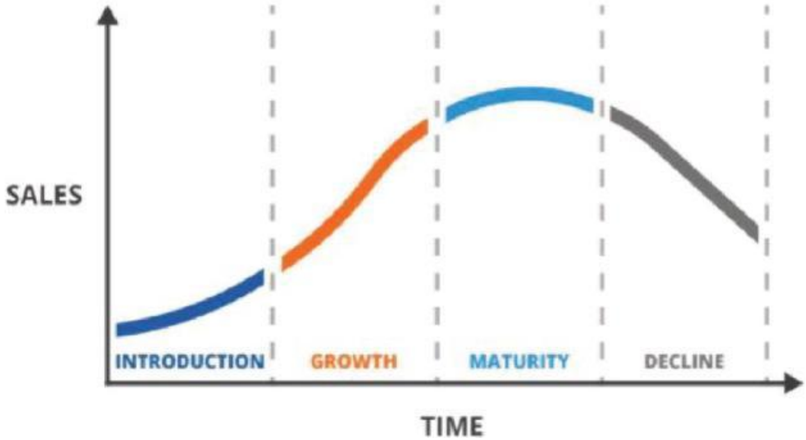


FIGURE 5.1 Product lifecycle.

by the consumer. Because design changes are frequent throughout this time, the expenditures for product design and development are significant and high. This period can be shortened by marketing studies and intensive advertising campaigns. Competition is not important for this period due to the high costs of production and distribution.

Growth: Growth is the period when the sales amount increases rapidly, and the product starts to take hold in the market. During this period, improvements are made in production and design, increasing the reliability of the product, reducing costs, and profiting from the product. Growth is the period when the product starts to compete in the market. The business is looking for ways to increase its production amount to meet the increase in demand with the increase in product sales.

Maturity: Maturity is the period when the increase in the sales amount of the product slows down, and this speed comes to a halt due to the saturation in the market. In this period, demand has reached a stable structure. The product design is standardized, and there are no design changes. All efforts are focused on increasing efficiency, reducing costs, and increasing production volume. During this period, the profit has reached its highest level.

Decline: The decline is the period when the demand for the product begins to fall, and the product begins to withdraw from the market gradually. During this period, the product begins to lose its appeal due to changes in consumer preferences and similar products filling the market. Sales, and therefore profits, begin to fall. At this point, ways, such as stopping the production of the product whose profitability has decreased and producing the product by changing some of its features, can be resorted to, or a completely new product can be introduced to the market.

Product lifecycles are used by management and marketing professionals to help determine advertising schedules, price points, expansion to new product markets, packaging redesigns, and more. These strategic methods of supporting a product are known as product lifecycle management. They can also help determine when newer products are ready to push older ones from the market.

5.2.1 Strategic Elements in the Product Lifecycle

While business managers do various studies to develop new products, they also have to develop various strategies for existing products. As shown in Figure 5.2, business managers should also consider product design and development costs, revenue from sales, and net profit when developing these strategies.

In the introduction period, the development cost of the product is quite high and is the period in which no profit is earned from the product yet. During this period, strategies such as business, make-to-order, product-based layout, and production in very small batches are used. During this period, the need for high flexibility and low investment in the enterprise arises.

The growth period is the period when the development costs of the product begin to decrease, and profits are started to be obtained from the product. During this period, the company uses production-to-order, process-based layout, and small-lot production strategies. The business needs flexibility and low investment.

Maturity is the period in which product development costs decrease compared to the previous period and profit is maximum. During this period, the company uses production-to-stock, product-based layout, and mass production strategies. While the business does not need flexibility, the need for investment arises.

The decline period is the period when the development costs of the product and the profit from the product are reduced considerably. During this period, the company uses production-to-stock, product-based layout, and mass production strategies. While the business does not need flexibility, it needs investment.

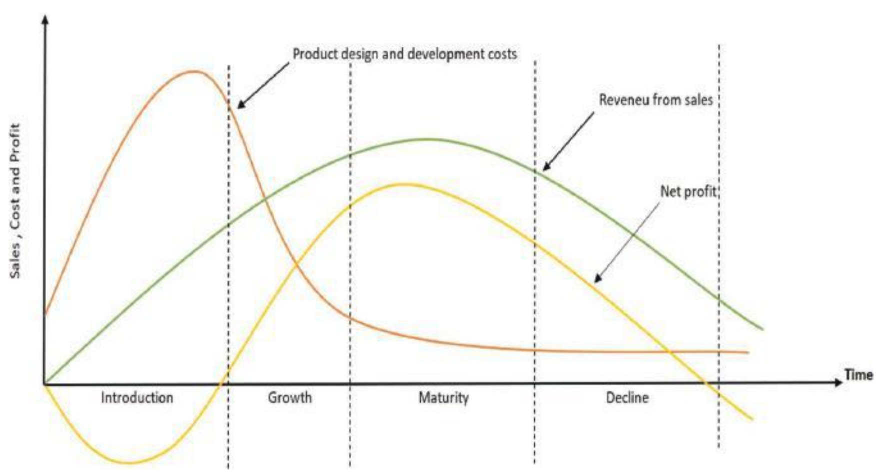


FIGURE 5.2 Product lifecycle, sales, cost, and net profit.

5.3 PRODUCT DEVELOPMENT

In today's markets, where competition has increased due to globalization, it has become imperative for companies to be in constant innovation in order to compete and to make customer-oriented production by knowing customer demands and requirements very well (Crawford 1977). In terms of being able to compete in the market, the effectiveness of the new product design process emerges as one of the most important success conditions for the organization. Planning, such as R&D studies, finance, and sales strategy in the new product design process, is very important in creating an effective product. Integration in all steps, from the design of the product to the maintenance of the product in the optimum product development process, leads the business to success. Otherwise, new products that are tried to be produced without taking into account market share, cost analysis, and customer requests lead the business to failure rather than success (Crawford 1987).

5.3.1 New Product Strategies

There are three basic strategies to follow in the development and production of a new product (Jan Hultink et al. 1998):

1. *Market-targeted strategy:* The producer follows the "produce what you can sell" philosophy in this strategy. New product decisions are made exclusively on the basis of consumer desires, with minimal consideration given to existing technology and process capabilities. Results of market research constitute the main source of information.
2. *Technology-targeted strategy:* The producer follows the "sell what you can do" view, taking into account the current technological possibilities. Here, the creation of demand and the sale of the produced goods are entirely under the responsibility of marketing. The technology-targeted strategy is suitable for high-tech products created as a result of very expensive R&D studies.
3. *Cross-functional strategy:* According to this strategy, the product is developed with the cooperation of marketing, production planning and control, engineering, manufacturing, and other departments. The resulting product becomes a result that best matches current technological possibilities and consumer demands.

Studies indicate that among these three strategies, the cross-functional strategy gives more successful results. However, this strategy is difficult to implement due to competition and friction between business departments. If the necessary care is not taken, it is inevitable to encounter various problems.

5.3.2 New Product Development Process

The path followed to develop a new product consists of six stages, as shown in Figure 5.3 (Wu et al. 2014; Jan Hultink et al. 1998).

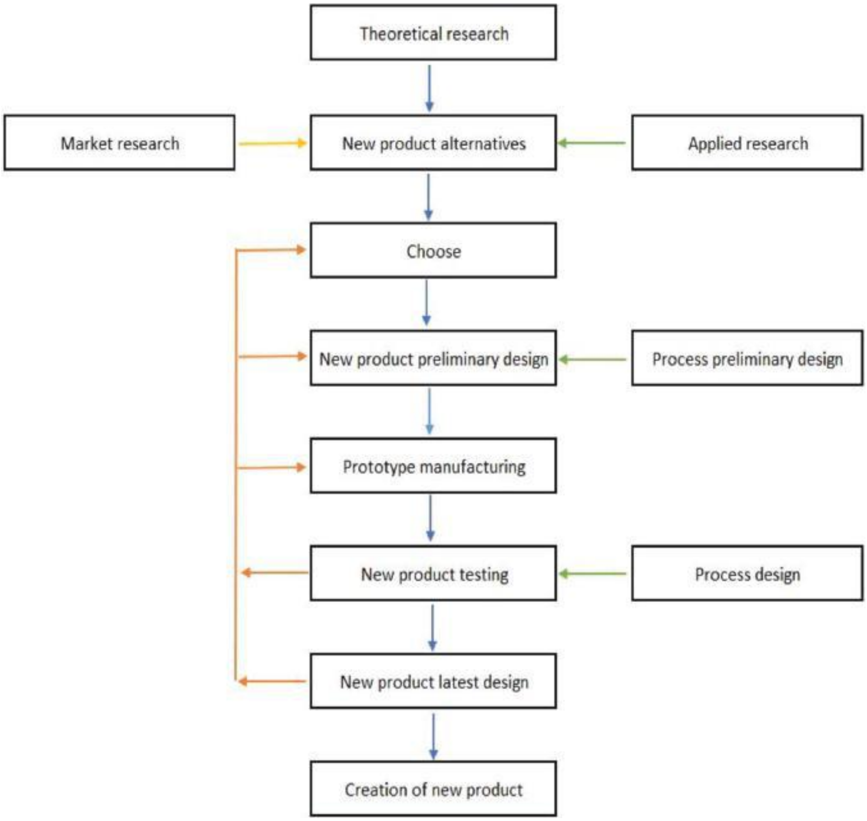


FIGURE 5.3 New product development process.

1. *New product alternatives:* Alternative new product proposals are prepared by combining the information coming from the theoretical and applied research areas with the consumer demands provided by marketing. It often happens that a newly created technology gives rise to many new product ideas. After the invention of plastic materials, transistors, electronic micro-circuits, and computers, hundreds of products have entered daily life in every country.
2. *Choose:* The emerging new product ideas are evaluated according to market potential, feasibility, and manufacturability factors. Since it is difficult to collect detailed quantitative information in the first stage, the alternatives are evaluated by the double-weighing method. Applying more detailed quantitative valuation methods after most of the alternatives have been eliminated saves time and money.
3. *New product preliminary design:* The structural and functional properties of the selected product are determined in this step. In the meantime, the aim is to find the optimum combination by carefully evaluating the cost, quality,

and performance factors. At the same stage, necessary plans are prepared for the manufacturing process of the product.

4. *Prototype manufacturing:* A full-scale model of the new product, a limited production in a small workshop, or a small number produced in a small area is considered prototype manufacturing.
5. *New product testing:* The performance of the products produced as prototypes is controlled by the manufacturer, or the use of the product by a limited number of consumers is monitored, and their reactions are evaluated.
6. *New product design:* At this final stage, the product and the manufacturing process are given final shape, and actual production begins.

After the product is produced and sold, the design process does not end there. Errors in the manufactured products are detected according to a specific plan, and necessary corrections are made by returning to the previous stages with the feedback mechanism. This process continues at a decreasing intensity throughout the life of the product.

5.4 QUALITY FUNCTION DEPLOYMENT (QFD)

Quality function deployment (QFD) is a method used by businesses to design, develop, and direct the production processes of existing products and/or services in line with customers' expectations, wishes, and needs that have not yet been perceived in order to ensure customer satisfaction. The purpose of the QFD methodology is to define the value and determine the importance of all the technical features that a product or service must have in order to fully meet the customer's needs. Many businesses conduct market research to determine customer expectations and needs. However, customers with conflicting wishes and different opinions can prevent the emergence of a clear idea. In cases where customer needs cannot be determined clearly, disagreements and erroneous interpretations between the production and engineering units of the enterprise may cause the customer to lose their voice. As a result, the focus is on what the customer does not want rather than what they want. QFD is a powerful tool that can overcome this shortcoming of market research. The concept known as *Hinshitsu Kino Tenkai* in Japanese and quality function deployment in English was developed by Professor Yoji Akao in Japan in the 1970s. Akao has proposed QFD to meet the following objectives (Akao 1997; Kisa 2019):

- Translating customer requests into technical characteristics of the business.
- Increasing horizontal communication by creating a communication environment for different functions working on the same product.
- Prioritizing the study to be done for product development.
- Identifying target innovations.
- Providing the opportunity to compare with competitors and competing products.
- Identifying target cost reduction areas.

As a result of the quality function deployment research that Akao and Mazur applied to 80 companies, “Some of the aims of the companies to apply the QFD method are listed as follows” (Akao and Mazur 2003):

- Regulating planning and design quality.
- Comparing their own businesses with a competitor’s product or service approach.
- Developing a new product or service design that will provide a competitive advantage.
- Obtaining and interpreting market data.
- Adopting the QFD approach to all in-house processes.
- Developing product or service design for customer satisfaction.
- Reducing the cost.
- Increasing product or service reliability.
- Increasing customer perception of value.

5.4.1 QFD and Product Development Process

With QFD, the negatives that are usually encountered in the early stages of product development are avoided, and product rework is eliminated, which is a problem of the traditional approach. Compared to other methods, QFD provides significant competitive advantages to businesses by highlighting more customer satisfaction, shorter time to market, and improved product performance.

With this method, the priorities of customer requests and requirements are determined, and product-related features are ranked in order of importance according to customer requests. Thus, when the designer has to choose between customer requests and requirements for technical or aesthetic reasons, the designer examines this sorting and designs the product in this order. Thus, both time loss is prevented, and the product is designed and produced to include the most desired features (Revelle, Moran, and Cox 1998).

One of QFD’s tools, the house of quality, is used to define the relationship between customer demands and product features, as shown in Figure 5.4. The steps to constitute a house of quality are as follows (Akao and Mazur 2003; Belhe and Kusiak 1996; Revelle, Moran, and Cox 1998;):

1. *Identification of target consumer characteristics and competitor products:* The first step is to identify the target market. For this purpose, a survey is conducted to determine the wishes and needs of the customers. While making these determinations, determining to whom the survey will be applied is important. For example, if the product to be produced is a sports car, the survey should be done with people who own or are interested in sports cars. A study with people who like big cars may not represent real customer wishes. Where the product to be put on the market can be sold, who the rival companies producing the same product are, what their market share is, and what characteristics of the competing products should be determined.

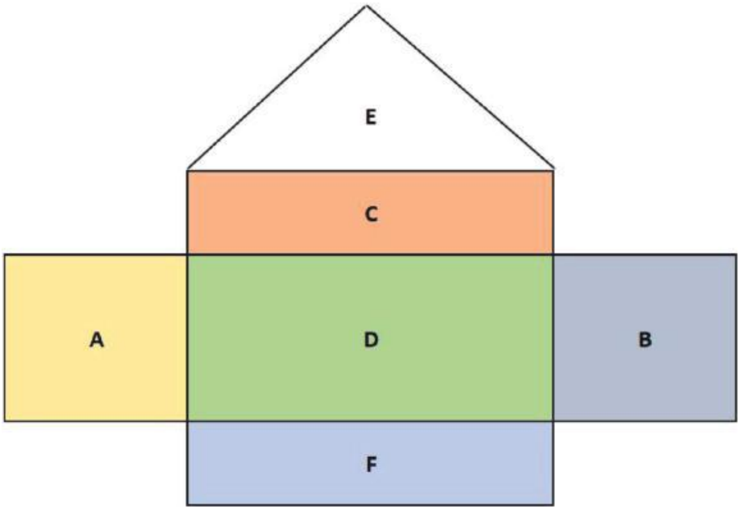


FIGURE 5.4 House of quality.

2. *Identification of consumer needs:* Customer expectations are the customer's wishes for the product or product features, and it is important to express these wishes in the consumers' own words. All the work to be done later will be guided by the elements determined at this stage. Resources, such as focus group studies, opinions of relevant people, one-to-one interviews with customers, complaints from customers, market research, customer satisfaction research, and comments at exhibitions and fairs, can be used to determine customer needs.
3. *Grouping of consumer needs:* Customer expectations are scattered, as customers do not express their views in an organized manner while determining consumer needs. These requests may be requests belonging to different parts of the product. These customer requests should be grouped in relation to each other. In this grouping, the house of quality helps to handle customer requests in a certain order while determining technical specifications during the creation.

   At this stage, the opinions of customers about the importance levels of their requests are obtained through surveys and one-on-one interviews with customers. In the matrix of the house of quality, next to the customer requests column is the severity column with the averages of customer importance levels. Various scales from 1 to 9 or from 1 to 5 can be used when determining significance levels. The number 1 on the scale represents the lowest level of importance, and the number 9 or 5 represents the highest level of importance. The importance of any customer request is calculated by adding the importance levels of each customer separately for that request and dividing by the total number of customers.
4. *Analysis of consumer satisfaction levels—customer perception analysis:* Determining the importance and satisfaction levels from the customers'

point of view alone is not enough to make a realistic plan for the development of the product or service. At the same time, it is necessary to investigate the status of the product or service and the status of competitor products. If customer requests are satisfied, how this affects the salability of the product and how much improvement is needed on the product should be determined.

The customer is asked questions about the product, and they are asked to make comparisons with the products of competing companies. Thus, it tries to determine the strengths and weaknesses of the competitors. The customer puts the company doing the research and its competitors in a rank in their own eyes. Then this ranking is converted into scoring and transferred to the house of quality.

5. *Determination of technical specifications:* The point to be considered while determining the technical needs should not be to find direct solutions to the determined customer requests. The goal is to turn each thought into one or more technical needs.

   Technical needs should be measurable and directly related to the voice of the customer. Technical needs are solved through some engineering calculations, experimental studies, or computer simulation programs. In addition, when determining these technical needs, the manufacturers who conduct the research should consider their own technical possibilities.

   Technical needs are determined through brainstorming meetings held by the project team. A point to be considered while making this determination is that the number of technical needs that will respond to any thought is not too large. The number of technical requirements determines the number of columns in the matrix, which increases the number of tests needed to develop technical data and the number of decisions that need to be made, leading to confusion.

6. *Determination of correlation matrix:* While determining the relationships between customer requests and technical specifications, this process begins by asking the question what/how it affects each cell of the matrix. If the answer to this question is no, that cell is left blank, meaning there is no relationship. If yes, the degree of relationship is indicated as weak, medium, or strong. Decisions are recorded in the matrix using symbols to indicate the strength of relationships.

   The purpose of identifying relationships is to highlight technical needs that are highly correlated with customer considerations. The filled matrix is then analyzed to identify the priorities of customer thoughts. The relationship symbols are examined in the matrix and determine which technical needs should be considered by the project team. Some symbols can be used to indicate the direction of improvement for customers.

7. *Calculation of absolute and relative importance values of technical needs:* The absolute and relative importance degrees of each technical need are calculated to meet customer expectations. As a result of the calculations, the absolute importance degrees of each column are determined. Whichever columns are of high absolute importance, more emphasis is placed on those technical needs.

8. *Determination of the relationship or correlations between technical specifications:* Many technical needs may be related to other technical needs. A study to develop one of these technical needs can help that need, resulting in a positive or beneficial effect. However, the work done to develop a need can negatively affect the related need.
9. *Comparison with competitors and determination of goals:* Engineering characteristics of the research company and competitors are compared technically according to criteria calculated by engineers and technical staff in the laboratory. Thus, in the house of quality, a comparison is made of how the customers perceive the company that conducts the research and its competitors, and the situation against the competitors is determined by comparing the engineers' own products and the competitors' products according to the technical specifications.

   As a result of the benchmarking comes the stage of determining the performance targets regarding the technical requirements. With benchmarking, both the aspects that need improvement are revealed, and the superior or weak sides are determined according to the competitors.

   The house of quality is obtained by combining the data and findings obtained from all stages.

The house of quality has six chambers:

A. Voice of the customer (VOC)
B. Comparison between competitor products and target values
C. Technical specifications
D. The relationship matrix between the voice of the consumer and the technical specifications
E. Correlation between technical specifications
F. Customer satisfaction levels

5.5 CASE STUDY

A case study was conducted by considering Fiat operating in the automobile industry and the two companies with the highest market shares operating in this industry. The steps of the case analysis are as follows:

Step 1. Identification of Consumer Needs: A focus group study was conducted to identify customer requests and needs. The focus group study was carried out with a total of ten people, five of whom were from firm A and five from firm B. The purpose here is to organize the features that businesses cannot think of for customers in line with the wishes of customers using the product. In order for the application to yield more beneficial results, care was taken to ensure that the participants in the focus group were from different education and income levels and from those who received service at different frequencies. These people were found with the help of customer relations representatives. We can express the customer requests obtained after the

TABLE 5.1
Importance Level of Customer Requests

Customer Request	Importance Level
Speedy	7
Safety	8.5
Fuel-Saving	6
Confidential	6.5
Low Price	8.5
Ergonomic	5.5

focus meeting as follows: speedy, safe, fuel-saving, confidential, low price, and ergonomic.

Step 2. Determining the Importance Levels of Customer Requests and Needs: In order to determine the importance levels of customer requests and needs, a survey study was conducted in case analysis. A consumer group consisting of ten people was asked where they would place the identified customer wants and needs on a scale of 1 to 10. According to the surveys, it has been seen that the degree of importance given by the people for each customer request is different. In order to express this difference as a single value, the arithmetic average of the importance degrees given to each customer request was taken, and the importance degrees of customer requests were determined. As a result of the survey study, the importance levels determined for customer requests were as follows.

Step 3. Determination of Technical Specifications: In order for customer requests and needs to be carried over to the service stage, each customer request must be expressed as technical characteristics. In the study, the technical characteristics were determined by the method of taking the opinions of the experts. While determining the technical characteristics, the team members working in the service department are asked for each customer request: "Which technical characteristics do we use to meet customer request X?". The technical characteristics that can fulfill customer requests for the automobile industry are as follows: load, production cost, velocity, length, and engine power.

Step 4. Determining the Relationship Between Customer Requests and Technical Characteristics: The symbols shown in the following table are used between customer requests and technical characteristics. In cases where there is not enough symbol or a weak relationship between customer requests and technical characteristics, it is concluded that an application that will meet customer requests and needs is not implemented. Likewise, the presence of many strong relationships indicates that an application has been realized that will meet customer requests and needs.

Step 5. Determining the Relationship or Correlations Between Technical Specifications: At this stage, the effects of technical characteristics on each other on determining customer requests were evaluated. In fact, many technical characteristics are related to other technical characteristics. A study for the development

TABLE 5.2
Body Ranking System

Body Ranking System		
◉	Strong	9
○	Moderate	3
△	Weak	1
	None	0

TABLE 5.3
Roof Ranking System

Roof Ranking System	
++	Strong Positive
+	Positive
	None
–	Negative
––	Strong Negative

TABLE 5.4
Comparing with Competitors of the Level of Fulfillment of Customer Requests

Customer Request	Brand A	Brand B
Speedy	4.5	3.7
Safety	3.2	2.4
Fuel-saving	2.6	3.6
Confidential	3.8	2.8
Low price	1.9	4.7
Ergonomic	4.3	3.6

of one of the identified customer requests may help or negatively affect another technical characteristic. The symbols shown in the following table are used to determine the relationship or correlations between technical specifications.

Step 6. Comparing with Competitors and Determining Goals: There are many businesses available to evaluate competitors in the industry. But to make it easier to work from the hassle of collecting information about competing businesses, the two companies with the largest market share in the automobile sector were taken into account in practice. The survey method was used when comparing brand A and brand B. Customers surveyed for the research were asked speedy, safety, fuel-saving, confidential, low price, and ergonomic–related questions. The respondents were asked to give a value from 1 to 5 for the answers to these questions. The 1 value is very bad, 2 value is bad, 3 value is normal, 4 value is good, and 5 value is very good.

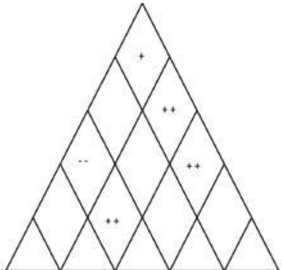
In the case study, the average of each value was taken so that the value given by each interviewer on the scale could be taken as a single value. Previous survey results were placed in the "A brand" column and "B brand" columns in the matrix. In the "Company target" column, scale scores related to how the company wants to see itself are placed. While determining the company target, the results of the survey on how the company is perceived by the customers today were explained to the business officials, and the opinions of the business officials and experts were taken in this direction. The "progress rate" column is found by dividing the "target" column by the column showing the current status of the firm. For example, in the study, the progress rate for the speedy customer request was calculated as 5 / 4.5 = 1.11.

The "point of sale" column in the planning matrix was also determined through interviews with business officials. The values in this column vary between 1 and 2. A value of 1 means that the relevant factor will not cause any increase in sales, and a value of 2 means that it will increase sales by 100%. Since sales points are a concept that shows whether an improvement in customer requests will lead to an improvement in service sales, it is determined as a result of interviews with the authorities that increasing customer requests, such as speedy, safe, fuel-saving, confidential, low price, and ergonomic, will lead to an increase in the sales of the product. The importance score is the product of the progress rate and the selling point points. In the case study, the importance score of speed for customer demand was determined as $7 \times 1.11 \times 1.4 = 10.87$. By normalizing the importance scores, the percent importance column is obtained. The percent importance column is the value that shows the percent importance of each customer request in the total customer request.

The representation of the house of quality obtained is shown in Figure 5.5.

TABLE 5.5
Relative Analysis of the Level of Fulfillment of Customer Requests

Customer Request	Importance level	Brand A	Brand B	Company Target	Progress Rate	Point of Sale	Importance Score	Percent Importance
Speedy	7	4.5	3.7	5	1.11	1.4	10.87	16.42
Safety	8.5	3.2	2.4	4	1.25	1.3	13.81	20.86
Fuel-saving	6	2.6	3.6	4	1.11	1.3	8.65	13.07
Confidential	6.5	3.8	2.8	4	1.05	1.3	8.87	13.40
Low price	8.5	1.9	4.7	5	1.06	1.6	14.41	21.77
Ergonomic	5.5	4.3	3.6	5	1.16	1.5	9.57	14.46
TOTAL							66.18	100



Customer Expectation	Importance	Relative Importance	Load (kg)	Production Cost ($)	Velocity (km/hour)	Length (meter)	Engine Power (hp)	Brand A	Brand B	Company Target	Progress Rate	Point of Sale	Importance Score	Percent Importance
			▼	▼	▲	▲	▲							
Speedy	7	16.667%	9	9	9	1	9	4.5	3.7	5	1.11	1.4	10.87	16.42
Safety	8.5	20.238%	9	9	1			3.2	2.4	4	1.25	1.3	13.81	20.86
Fuel Saving	6	14.286%	1	3	3		9	2.6	3.6	4	1.11	1.3	8.65	13.07
Confidential	6.5	15.476%	9	3	1		3	3.8	2.8	4	1.05	1.3	8.87	13.4
Low Price	8.5	20.238%		9	1		3	1.9	4.7	5	1.06	1.6	14.41	21.77
Ergonomic	5.5	13.095%	1	9		3		4.3	3.6	5	1.16	1.5	9.57	14.46
Importance			4.988	7.214	2.488	0.560	3.857						66.18	100
Relative Importance			26.106%	37.757%	13.022%	2.928%	20.187%							

FIGURE 5.5 The house of quality obtained as a result of the case study.

QFD is an efficient design for product planning and development, and its benefits are as follows:

- QFD provides design optimization by assuring quality while still in the design phase.
- QFD contributes to reducing product development times.
- QFD ensures that customer requests and expectations are expressed clearly.
- QFD provides systematic documentation of engineering knowledge that can be more easily applied to new designs.
- QFD provides increased productivity by reducing initial costs and product development costs.
- Customer satisfaction is increased by producing better quality and reliable products.
- Products and services can be offered to the market at more competitive prices.

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6 Statistical Process Control (SPC) and Quality Management

Muzaffer Alım and Saadettin Erhan Kesen

CONTENTS

6.1 INTRODUCTION

At the end of the 18th century, steam-powered machines were invented, enabling heavy operations to be done more easily. In this manner, the production systems relying on manpower progressed to a machine-power-based system. Later, with the widespread use of electricity, mass production lines were experienced, and it resulted in massive quantities of products. The development of computer systems in the early 1970s opened up a new era in production systems in which processes and machines could be controlled by automation systems. High acceleration in the development of the Internet and new generation technologies, such as Wi-Fi, Internet of Things, robotics, blockchain, and so on, have made machines and robots in the production processes reach a position where they can do their own analysis and make the most coherent decisions by themselves. Furthermore, these technologies have created

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large networks in which more devices can connect to each other and communicate within the network. During this entire Industrial Revolution period, two factors have perpetually increased: the amount of production and the energy requirement. The increase in the production amount paved the way for the emergence of many companies and the formation of a competitive environment in the market.

Changing conditions via industrial developments affect not only the production processes but also customer-company relations. Companies that strive to survive in such a competitive market environment must be capable of competing with rivals in terms of price and quality. This is because customers are now in a more selective position due to the increasing number of alternatives and can choose the most suitable one around the world due to globalization. Moreover, customer-company relationships that ended up with the sale of the product in the past have now become longer-term relationships that continue even after the use of the product. The companies are involved in branding efforts that create trust in customers to increase their loyalty to the company. For this reason, the number of large companies claiming to provide a certain assurance in quality to their customers has been on the rise. Although creating such a brand and company is a challenging process that requires great effort, the destruction of this image can occur instantaneously, even with a minor mistake. Therefore, companies have to act very meticulously and carefully in terms of the quality of their services.

We emphasize quality control and statistical process control techniques in this chapter due to their vital importance for today's industrial system. The remainder of the chapter is organized as follows: We summarize the description and historical evolution of quality control and tools. Subsequently, we discuss how advancements associated with Industry 4.0 have transformed the quality control process, as well as the opportunities and challenges that have arisen as a result of the process. Next, the relation between the quality control process and sustainability from economic, ecological, and social aspects is underlined. Finally, we demonstrate the subject by performing various statistical process control tests on a sample case.

6.1.1 Quality Control and Statistical Process Control

Quality has been defined in a variety of ways because people have different expectations of the product/service, and everyone has a different understanding of quality. As an example of differentiation in quality perception, a car that a person likes and considers to be of high quality may appear inferior to another. Though it is difficult to define quality in general, the most common definition is the level to which a product or service meets the needs and expectations of customers. Or if it is rephrased in a modern way, the quality is the suitability of a product or service for usage. Customers' shift to a more selective position as a result of increased competition within the market has pushed businesses into a vital race for quality. Quality, nowadays, has been one of the main factors that directly affect the purchasing preferences of customers, both individually and institutionally. Therefore, companies attach great importance to quality, which is a key factor in the success, development, and branding of their businesses. Moreover, the investments made to improve the quality and to consider quality as the company's strategy for the entirety of its process provide a

TABLE 6.1
Dimensions of Quality

Dimension	Meaning
Performance	This is the indicator of how well a product or service fulfills its various functions.
Reliability	The frequency with which a product fails is referred to as its reliability.
Durability	Durability refers to how long a product can be used or its service life.
Serviceability	Serviceability relates to how easy it is to build and access services related to a product's repair and maintenance.
Aesthetics	Aesthetics is about how visually pleasing a product is.
Features	This refers to the features of the product or service, especially the ones that make it unique as compared to its competitors.
Perceived quality	This is the reputation of the product among users.
Conformance to standards	Conformance relates to whether or not a product meets its intended standard.

great return (Montgomery, 2020, p. 4). Mainly, quality is composed of eight dimensions, namely performance, reliability, durability, serviceability, aesthetics, features, perceived quality, and conformance to standards (Garvin, 1987), and these dimensions are listed in Table 6.1.

Quality is related to whether or not the stakeholders' expectations of the product are met. If the product meets expectations, it is of high quality; otherwise, poor quality. Since the primary goal of a business is to meet the expectations of its stakeholders, quality management is given a high priority. According to the ISO 9000 definition, quality management is the coordination of the management and control of quality-related activities within an organization. Quality planning, quality control, quality improvement, and quality assurance are the four pillars of quality management (Hoyle, 2007, p. 21), as depicted in Figure 6.1.

Quality planning is a component of quality management that includes the setting of quality objectives as well as the planning of the activities and resources required to achieve them. Quality control is the process of determining whether or not the products produced meet specific standards by applying some tests on selected samples. The goal of quality improvement is to increase the products' ability to meet expectations. It encompasses activities aimed at improving existing quality. Quality assurance is a subset of quality management that focuses on ensuring that quality standards are fulfilled. All these parts complement each other to form quality management.

6.1.2 Historical Evolution

Quality and variation have an inverse relationship, and therefore, variation must be reduced in order to ensure good quality. As a result, products that are outside the limit determined by measuring how far the products deviate from the quality standards are not delivered to the customers. Only high-quality products are allowed to

FIGURE 6.1 Four pillars of quality management.

leave the company. Of course, it is not possible nor feasible to control the quality of each product as it would require a huge amount of time and cost. Thus, statistical techniques are widely applied in order to evaluate the conformity of services or products to the specified quality standards.

When the historical evolution of quality control is considered, the first example can be seen in 1910, when Ford Motor Company hired teams of inspectors to control the quality standards of the products. The main aim was to separate the products that did not meet the desired quality standards so that they could be scrapped, reprocessed, or sold at a low quality (Dahlgaard et al., 2008). Statistical methods first started to be used in the 1920s. The statistical control charts developed by Walter A. Shewhart for the Bell Telephone Laboratories are regarded as the first example in the field. The target of these control charts was to determine whether the variability results from the factors that were difficult to control were due to the nature of the process or if it was due to a specific cause, such as machine adjustment failure. Thus, it was possible to carry out quality improvement activities. The use of quality control techniques increased with the complexity of production systems during World War II. The US War Department issued a manual on the use of control charts in 1940. In 1946, the International Organization for Standardization (ISO) and various quality societies were founded. In 1948, G. Taguchi began developing applications in the field of experimental design. Juran and Gryna first published the quality control manual in 1957. In 1960, K. Ishikawa pioneered the concept of the quality control circle (Montgomery, 2020). Research in this area has been accelerated by the systematic use of statistical methods and experimental measurement designs for process improvements, new process development, and increasing quality and reliability by Japanese companies. Especially in the 1980s, under the severely increasing competition, the benefits of quality control were realized by the companies, and the use of control methods became customary. The Six Sigma program developed by Motorola aims to achieve product quality in which variability is reduced, and errors and defects/

TABLE 6.2
Important Milestones of Quality Methods

Year	Improvements
1900–1930	Henry Ford improved some methods to increase productivity in the assembly line and developed mistake-proof assembly, self-control processes, and inspection in-process.
1920s	Bell Laboratories formed a new quality department to improve the quality process. In England, B. P. Dudding used statistical methods for quality control.
1924	The control chart methods were introduced by W. A. Shewhart.
1946	The American Society for Quality Control and the International Organization for Standardization (ISO) were founded.
1948	G. Taguchi studied the theory and application of experimental design.
1950	A famous cause-and-effect diagram was introduced by K. Ishikawa.
1957	The *Quality Control Handbook* was first published by J. M. Juran and F. M. Gryna.
1960	The concept of a quality control circle was introduced by K. Ishikawa.
1975–1978	The idea of total quality management was forming.
1987	The Six Sigma approach of Motorola began.
1997	The Six Sigma approach was applied by many other industries.
2000s	New standards of ISO were issued, and quality became a more critical issue for a business's success.

(Montgomery, 2020, p. 10)

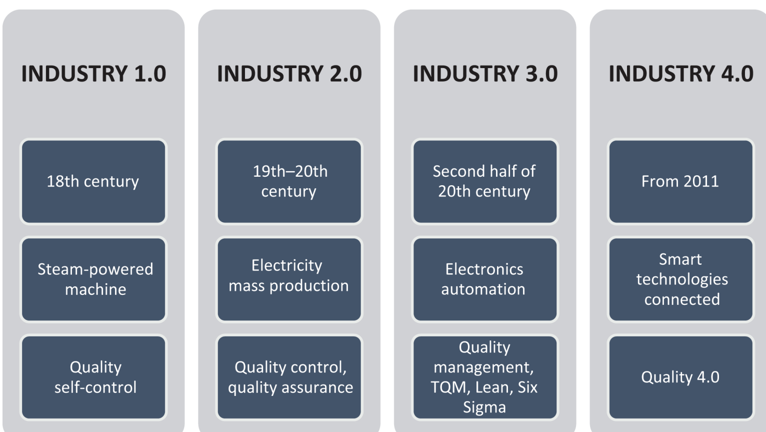

FIGURE 6.2 Historical development of Industry 4.0 and quality. (Simic, 2021)

fallouts are extremely low. Later, this approach was applied in different sectors, and successful results were obtained. The Six Sigma approach has been applied to the fields of lean manufacturing and lean entrepreneurship and is named Lean Six Sigma (Mitra, 2016). The important milestones and leading researchers with their key findings in the history of quality methods are summarized in Table 6.2.

6.1.3 Statistical Process Control

Statistical process control (SPC) is one of the primary quality control tools and has widespread use in the area of quality control. Even if everything in the process is stable, there may be uncertainty and variability that affect the quality. This occurs due to uncontrollable variables, as Shewart stated. SPC, however, is a powerful technique for detecting variability caused by controllable or uncontrollable input variables. The major methods in SPC are histograms, check sheet, Pareto chart, cause-effect diagram, defect concentration diagram, scatter diagram, and control charts, which are the most complicated ones (Montgomery, 2020, p. 180).

6.1.3.1 Control Charts

Control charts are diagrams that help to understand the random or special causes of variation occurring in a process. These are employed in the control and analysis of whether the product or service obtained is of the desired quality. Depending on the type of data and the intended use, multiple quality control charts are available. As shown in Figure 6.3, the Minitab Assistant program highlights which type of chart should be used for which situations.

Continuous data are defined as data that convey a characteristic feature of a product or process, such as length, weight, or temperature, and are commonly expressed as a decimal expression. For example, if a food company wants to see if the weights of the packages it produces are within certain limits, it should examine the weights of the packages at various periods. I-MR charts can be utilized if the data is not

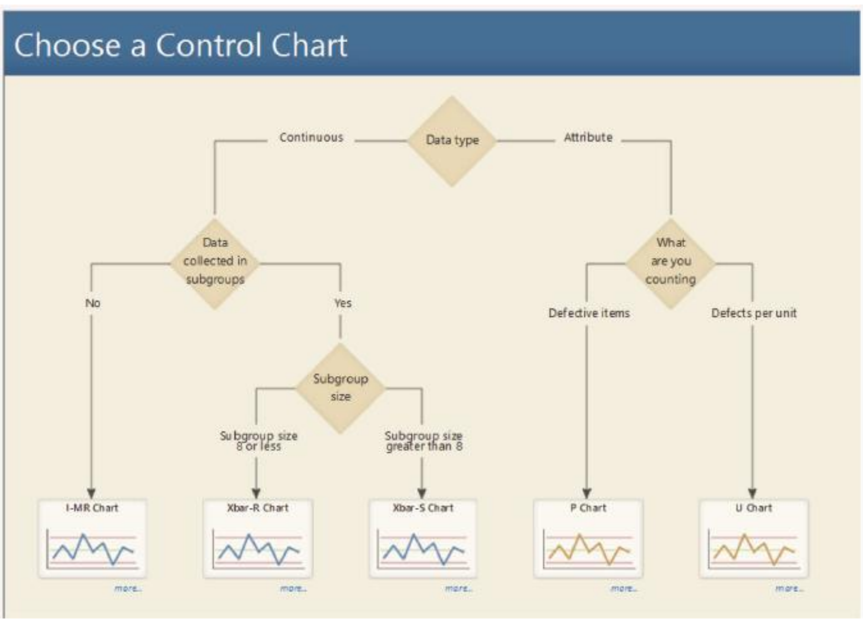

FIGURE 6.3 Selecting a suitable control chart on Minitab.

collected in subgroups. When the data is collected in subgroups, several charts may be used depending on how many subgroups there are. For situations with fewer than eight subgroups, the Xbar-R chart is used, whereas for cases with more than eight subgroups, the Xbar-S chart is preferred.

It is called attribute data if the available data shows the quantity of defective products or the number of errors in a product. For example, if a light bulb manufacturer wishes to keep track of how many broken bulbs there are in each sample over time, it must examine the data on how many defective items there are in each sample. Here, two separate charts are employed. P chart is used when a product is categorized as pass/fail or defective/nondefective, and the number or rate of defects is measured. U chart is used when there is multiple defect types for a unit of product, and the number and rate of occurrences of defects in all goods are measured.

6.1.3.1.1 Example of a Control Chart Application

The thickness of products manufactured in a metal manufacturing company is measured four times on different days, and the results are provided in Table 6.3. It is unclear whether the measurements taken are under control. Therefore, the relevant control chart analysis is performed on the data.

The data given are continuous since it is tied to the physical characteristics of the product. At each time, four measurements are performed, and that's why there are four subgroups. Following these features of data, it has been determined that the Xbar-R chart should be used for analysis (see Figure 6.3).

TABLE 6.3
Example Data

No	x_1	x_2	x_3	x_4	Xbar (Sample Average)	Sample Range
1	8.34	7.14	8.00	8.13	7.90	1.2
2	8.23	7.90	7.82	8.43	8.10	0.61
3	8.11	7.18	7.07	8.14	7.63	1.08
4	8.15	8.21	8.26	8.29	8.23	0.14
5	7.76	8.53	8.14	8.34	8.19	0.78
6	8.25	8.00	8.50	7.93	8.17	0.57
7	7.71	7.78	8.03	8.49	8.00	0.77
8	8.16	8.09	7.98	8.05	8.07	0.18
9	7.35	8.00	8.20	7.57	7.78	0.85
10	8.41	7.69	8.10	8.36	8.14	0.72
Total					**80.21**	**6.90**
Average X bar ($\bar{\bar{X}}$)					**8.021**	
R bar ($\bar{R}$)						**0.69**

The Xbar chart is for monitoring the mean of samples and for checking whether it is under control. The control limits, upper control limit (UCL), and lower control limit (LCL) for Xbar and R charts are calculated by equations 6.1–6.4.

$$UCL_{\bar{x}} = \bar{\bar{X}} + A_2 \bar{R} \tag{6.1}$$

$$LCL_{\bar{x}} = \bar{\bar{X}} - A_2 \bar{R} \tag{6.2}$$

$$UCL_{\bar{R}} = D_4 \bar{R} \tag{6.3}$$

$$LCL_{\bar{R}} = D_3 \bar{R} \tag{6.4}$$

The A_2, D_3, and D_4 factor values are used to calculate the lower and upper limits depending on the number of subgroups. $A_2 = 0.729$, $D_3 = 0$, and $D_4 = 2.282$, when the number of subgroups is 4. Upper and lower control limits are calculated, and Xbar and R charts, as in Figure 6.4, are drawn based on the calculations in equations 6.1–6.4.

The graph in Figure 6.4 shows that all data are within the calculated control limits for both Xbar and R values. This demonstrates that the mean and variability of data are steady and under control. If a point is found to be out of control, the measurement in that sample needs to be thoroughly examined, and the cause of this should be investigated. It is required to examine whether any abnormality or problem is detected by the operator who is in production. Improvements should be made after the reason is detected, and the chart would be redrawn to see if the uncontrolled condition persists. These charts here determine whether or not the process is under control and whether or not it is at the target level.

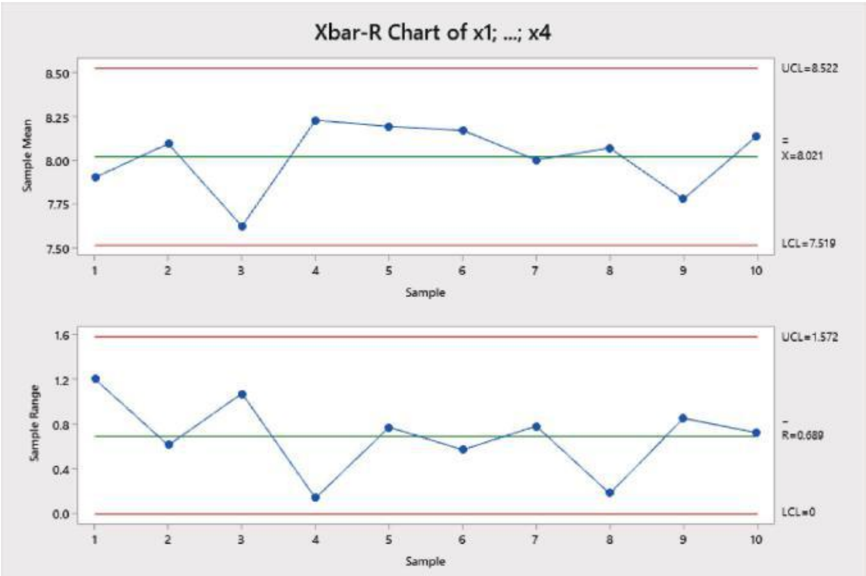

FIGURE 6.4 Xbar and R charts for sample data.

6.1.3.2 Process Capability Analysis

Process capability analysis controls whether a process can create products or services that meet customers' requests, whereas control charts test if a process is under control. In other words, it assesses how well the process performs in meeting customer requirements. Statistical calculations are used to assess the process's capability for the requested specification limits. The C_p and C_{pk} indices are used to assess the process's effectiveness. The C_p index is determined using equation 6.5 and is defined as the ratio of the customer tolerance range to the natural tolerance range.

$$C_p = \frac{USL - LSL}{6\sigma} \tag{6.5}$$

where USL (upper specification limit) and LSL (lower specification limit) are the requested limits by the customers. C_p does not take into account the central position of the process's mean. For this reason, the C_{pk} ratio is introduced to check whether the process is centering, and it can be calculated by equation 6.6.

$$C_{pk} = min\left(C_{pu}, C_{pl}\right) = \left(C_{pu} = \frac{USL - \mu}{3\sigma}, C_{pl} = \frac{\mu - LSL}{3\sigma}\right) \tag{6.6}$$

When interpreting the values of these indices, it can be said that the performance of the process is higher when C_p is greater than 1. Furthermore, a higher C_p number indicates that the process performs better in meeting customer requests. When C_{pk} is equal to C_p, it can be concluded that the process is centralized. The process is not centralized when $C_{pk} < C_p$.

6.2 QUALITY 4.0

The evolution of the industry has altered not only the manufacturing environment but also quality management (see Figure 6.2). Quality control, which was formerly handled by a foreman, was gradually shifted to quality control departments and specialists, and this development process continued with the emergence of the total quality management approach in the following periods (Simic 2021). Quality 4.0 is now being discussed as part of the Industry 4.0 transformation, which is based on smart systems and artificial intelligence.

Q4.0 refers to the new scenario that has arisen as a result of the incorporation of new-generation smart technologies in the digital age into all aspects of quality management. In a more formal definition, Q4.0 refers to the combination of traditional quality methods and new technologies for quality management in order to provide higher performance and operational excellence (Antony et al., 2021). For the manufacturing process, the main objectives of Q4.0 are as follows (Escobar et al., 2021):

- Creating a defect/error-free production process
- Improving human intellect to allow speedier root cause analysis

- Enabling faster and higher quality decision-making
- Increasing the objectivity of the subjective nature of human-based quality control

As broad as these objectives, they can be simply said as eliminating errors, making faster and more accurate decisions, and digitizing the process. New technologies, such as cloud computing, artificial intelligence, machine learning, big data, the Internet of Things, virtual reality, cyber-physical systems, advanced robotics, and smart sensors, can help to enhance quality management and techniques (Nenadál, 2020).

6.2.1 Benefits and Challenges of Q4.0

Industry 4.0 and smart systems increase the quality of the products as it enables instant access to real-time data during the process and more flexible, efficient, and fast process management (Rüßmann et al., 2015). A study conducted by the American Society of Quality shows that 82% of the companies applying smart manufacturing technologies have increased productivity and achieved a 49% reduction in the number of defects/fallouts in their products (Shrouf et al., 2014). Similarly, it has been stated that applying smart technologies have the potential to result in an 80% decrease in non-conformances and deviations and a 25% decrease in cost for services and repair. The manually handled measurements for quality control, which require a substantially longer time, can also be performed faster and more reliably with the help of new technologies (Tortorella et al., 2019). Gunasekaran et al. (2019) address the developments that Industry 4.0 bring to quality management.

Opportunities such as access to real-time data, sharing of data and information, fast communication, and easy access to the system offered by new technologies offer faster and easier monitoring and intervention during the quality control process. Cloud technology enables numerous stakeholders to share data, applications, and programs through a single point of contact. This could offer easily accessible resources, increasing the integration, allowing for better monitoring of quality and process, and providing faster and real-time communication with the supply chain stakeholders. This both enhances the quality and provides the opportunity for faster intervention in case of an issue. Blockchain technology also has great potential for quality improvement as it can provide secure and fast connection and transfer between stakeholders in finance and information flow. The Internet of Things (IoT) is a technology that allows devices connected to each other over the Internet to exchange information within the network. This enables devices to be integrated with each other and smart systems to be active in the entire supply chain.

Robotics, smart sensors, and cyber-physical systems play important roles in quality control automation. Instant data collected by these devices are processed by artificial intelligence technologies, and immediate assistance is offered. For example, products with color changes due to production error or deterioration can be separated from the other products on the production lines utilizing artificial intelligence–based image processing technology. Color changes on the product are monitored continuously by the cameras, and any quality issues can be identified immediately. As another example, smart heating sensors that keep the products in the proper temperature range are more precise, and the margin of error is decreased.

From all perspectives, new-generation technologies, directly and indirectly, have an effect on quality control approaches. In addition to the benefits of these advancements, comparable challenges in the use of Industry 4.0 technologies exist in terms of quality. One of the most significant challenges is the lack of digital skills and abilities to control such high-tech methods. Another issue is that, despite all these changes, many businesses do not have a digital strategy in place, and a quality culture has not been formed. Connecting and integrating all operations and devices may create a security issue. A security vulnerability or a network malfunction might impair the entire system. As a result, the subject of cybersecurity is becoming increasingly popular.

6.2.2 Business Implications in Q4.0

Since quality is an essential component of any business/organization, the Q4.0 concept is widely accepted and implemented in real life. Especially in quality control processes, these new-generation technologies have been employed with a variety of objectives. Illa and Padhi (2018) introduce the application of IoT to detect the defects in the high volume of data produced during the processes. Venkatesh et al. (2017) conclude that Bluetooth using Bluetooth Low Energy or the Internet of Things can provide effective quality monitoring for food safety management. Villalba-Diez et al. (2019) study the integration of deep learning soft sensors with a high-resolution quality control camera to increase the accuracy and speed of the control process. Big data and analytics are said to be effective in monitoring and controlling the quality control process (Tao and Qi, 2017; Reis and Gins, 2017). Kucukoglu et al. (2018) present an application of an artificial neural network with a wearable glove for the detection of defective operations in an assembly line. El Hachem et al. (2021) studied automating the quality control system with deep learning algorithms with an application in the automotive industry in order to eliminate the control errors caused by the tiredness of the operator who performs the check manually. Zheng et al. (2021) present an extensive review of the application areas of Industry 4.0 on operations management, and the list of applications of specific technologies on quality is summarized in Table 6.4.

TABLE 6.4
Implications of I4.0 Technologies

Reference	Application	Technology
Addeh et al. (2014)	More accurate identification of control chart patterns	Neural networks
Kucukoglu et al. (2018)	Wearable gloves supported with neural networks for detecting the defectives	
Tao and Qi (2017) Reis and Gins (2017)	Quality monitoring and controlling the quality control process	Big data and analytics
Escobar et al. (2021)	Success and challenges of big data in Quality 4.0	
Illa and Padhi (2018)	Detecting defects in high volumes of products	Internet of Things
Zheng et al. (2021)	Data analysis and automation of control processes	Artificial intelligence

6.3 QUALITY CONTROL AND SUSTAINABILITY

Sustainability means to fulfill the current needs while respecting the right of future generations to be able to meet their own needs. The meaning of respect is not to compromise their right to satisfy their needs. This will require considering the economic, social, and environmental impacts, which constitute corporate sustainability (Abbas, 2020). Due to the scarce resources that we have and the competitive business environment, the concept of sustainability has gained more importance for businesses.

The primary goal of corporations is to ensure the long-term success of their existing businesses. This can be accomplished by continuous improvement and adherence to quality standards. Since quality is defined as meeting the requirements, quality standards should be determined to meet the expectations of stakeholders. Quality management and control attempt to preserve the products and services above these standards, for which reason they are critical to the company's sustainability. Customers, employees, and other partners who are unable to find the required quality they ask for may seek alternative companies, causing the company to weaken and eventually disappear. What is at issue here is ensuring not only economic sustainability but also organizational sustainability in terms of social and corporate. For instance, if a company that produces a high income does not provide a decent working environment for its employees, the organizational management of this company may not be sustainable. Similarly, companies that do not prioritize environmental sustainability may have difficulty in obtaining raw materials in the future and may lose partners who have environmental concerns. For all these reasons, corporations must prioritize corporate sustainability as a whole in order to continue their existence.

Effective quality management aims to increase the process performance and utilization of resources, which are also key for sustainability. Therefore, there is a strong relationship between sustainability and quality management, and the context of this is considered in the literature. Abbas (2020) details this relationship based on the data collected by the six total quality management practices. The results provide insight into how to achieve corporate sustainability through quality management and knowledge management. Prajogo and Sohal (2004) state that the successful application of total quality management, in the long run, can help to sustain the competencies and performance of companies. Similarly, an application of more accurate process control can make a considerable impact on costs and CO_2 emissions (Klee, 2004). Lean Six Sigma applications are experienced in the dairy industry, which achieved an improvement in environmental sustainability (Powell et al., 2017).

Quality control is of great importance in terms of ensuring corporate sustainability. Detecting faulty products and reducing the number of these objectives of quality control guarantee more effective use of resources and waste reduction. Since fewer defective products are produced in return for the energy and resources consumed during manufacturing, efficiency improves, and therefore, both economic and ecological benefits are obtained. Another benefit is the identification of potentially defective products before they reach the customers. Such a situation offers the opportunity to save in many areas, from the distribution of the products to the customer, to the reverse logistics operations that will occur due to the return of the product. With less fuel consumption, emissions decrease and can be avoided for unnecessary logistic activities. At the same time, it will contribute to the long-term sustainability of the brand image formed by the customers.

If quality management is implemented incorrectly or with no strategy, it may not yield the desired outputs. In the case of using quality control to impose additional strain on employees and find out who is to blame for mistakes or merely notice faults, it might break the synergy in the workplace rather than provide benefits. Overall, it can be said that the main objectives of the concepts of quality management and sustainability are compatible with each other, and quality management has a direct impact on increasing sustainability.

6.4 CASE STUDY

The success of quality control relies on the data obtained throughout the process to a greater extent. In the case of having accurately, easily, and instantly gathered data, the quality control tools, such as control charts and statistical methods, provide more reliable analysis. The technologies with Industry 4.0, as explained in Chapter 6.2, can help to achieve this and transform quality control into an automated process. In this section, statistical quality control methods, including control charts and process capability analysis, are performed on the measurements obtained from a case, and the situation is analyzed for quality.

6.4.1 Introduction of Case

The use of printed circuit boards (PCB) is increasing as digitalization and new-generation smart machines and technologies become more prevalent. That is because PCBs are indispensable components of electrical and electronic devices. PCBs are insulating plates with conductive paths on the surface and solder-coated holes between the surfaces for mounting the device's electronic circuit components. Basically, a PCB is a board that holds and connects electronic components. PCB designs are typically created using computer programs, such as OrCad Proteus and PCAD, and could be different sizes based on the usage area, as illustrated in Figure 6.5.

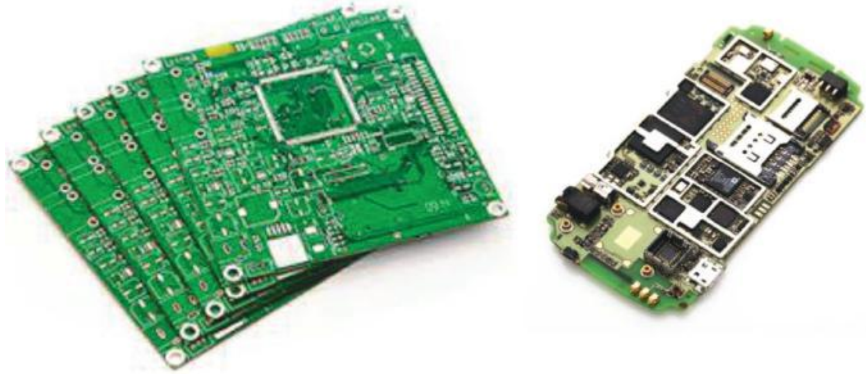

FIGURE 6.5 Printed circuit board samples.

Although PCB contains a variety of ingredients, copper is typically used to provide conductivity. Thus, it is critical to fine-tuning the amount of copper. While using less copper than necessary can cause conductivity issues, using too much causes both economic loss and resource waste. From a sustainability perspective, it is essential to use these resources without wasting them in production and to recycle these raw materials from PCBs that have reached the end of their lifespan. We performed a quality control application in this study by performing statistical quality control tests on copper concentration measured from different samples for two different PCBs. PCB-A is used in computers, while PCB-B is used in mobile phones. Three measurements are performed for each sample at 25 different time periods, and the data obtained are presented in Table 6.5.

TABLE 6.5
Copper Concentration Percentage in PCB-A and PCB-B

Sample	PCB-A			PCB-B		
	1	2	3	1	2	3
1	14.890	14.630	15.592	14.239	13.873	13.175
2	14.013	14.929	14.548	13.814	13.103	13.478
3	15.144	14.576	14.692	13.433	13.570	13.736
4	14.045	14.235	14.696	13.633	13.691	13.307
5	15.090	14.166	14.283	13.990	13.067	13.640
6	13.980	14.023	14.058	13.733	12.937	13.568
7	14.782	14.359	14.683	13.631	13.045	13.120
8	14.055	15.632	14.589	13.435	13.364	13.957
9	15.397	15.520	14.886	13.793	13.175	13.430
10	14.952	14.370	14.379	13.714	13.065	14.059
11	15.400	15.601	15.350	13.778	13.113	13.599
12	15.389	15.141	14.310	14.011	13.611	13.619
13	14.125	14.043	14.453	13.223	13.693	14.029
14	14.536	15.419	14.144	13.872	13.101	13.565
15	13.720	13.652	14.110	13.471	13.315	13.791
16	14.245	15.576	14.351	13.402	13.431	13.294
17	14.346	14.828	14.527	13.596	13.636	13.519
18	14.420	14.620	14.025	13.695	13.743	13.824
19	14.604	14.793	14.451	13.758	12.874	13.740
20	14.729	14.911	14.501	13.781	13.672	13.751
21	14.143	14.892	14.110	13.390	13.737	13.812
22	14.819	14.524	14.731	13.580	13.533	13.411
23	14.268	14.791	14.355	13.398	13.739	13.897
24	14.595	15.563	13.844	13.631	13.311	13.748
25	15.086	14.876	14.505	13.534	13.348	13.563

6.4.2 Descriptive Statistics

The main structure of the data is investigated by performing a descriptive statistical test on the measured data. To begin, each period's average of three measurements is taken, and the basic statistical values are calculated based on these averages. Table 6.6 shows the results of the calculations for each type of PCB. In addition, the fitting of the data to the normal distribution is shown in Figure 6.6 by histogram diagrams.

Based on the preliminary statistics, the mean of the measurements taken from the PCB-A type is 14.662% with a standard deviation of 0.350, whereas the mean for the PCB-B type is 13.559% with a standard deviation of 0.123. These numbers and the histograms depict the distribution of the measurements' means and give a preliminary idea of whether the results are within the expected range. Additional tests, however, are required to determine whether the process is steady or out of control. Thus, suitable quality control charts are applied to the data.

TABLE 6.6
Descriptive Statistics of Data

Variable	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
PCB-A	14.622	0.0700	0.350	13.827	14.426	14.616	14.781	15.450
PCB-B	13.559	0.0247	0.123	13.265	13.474	13.564	13.647	13.762

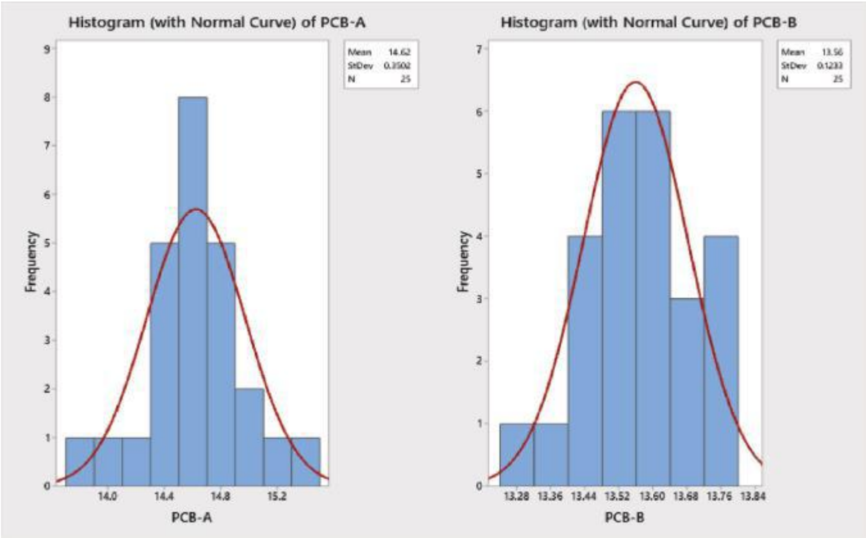

FIGURE 6.6 Histogram with a normal curve for PCB-A and PCB-B.

6.4.3 Control Charts

The measurements are continuous and include three subgroups. Xbar-R charts are one of the most suitable tests for data presented in fewer than eight subgroups. All values for both PCBs used were tested in Minitab for an Xbar-R chart, and the results are given in Figures 6.7–6.8.

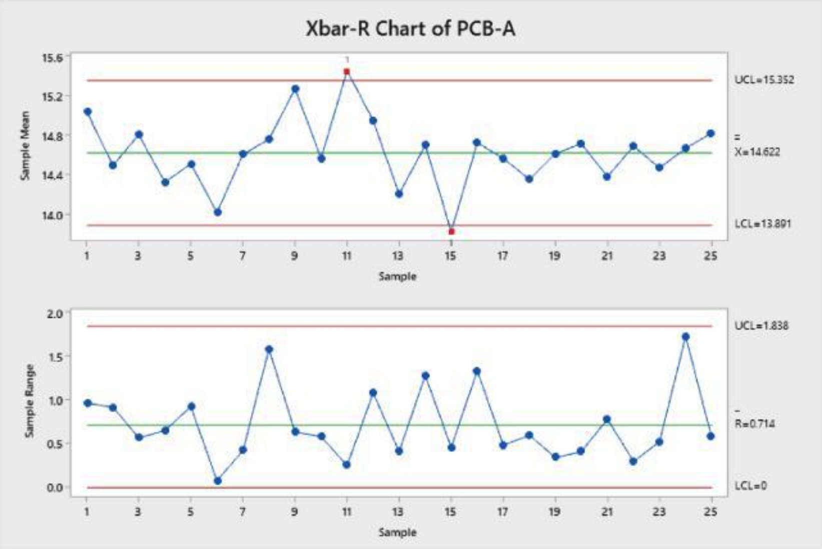

FIGURE 6.7 Xbar-R chart of PCB-A.

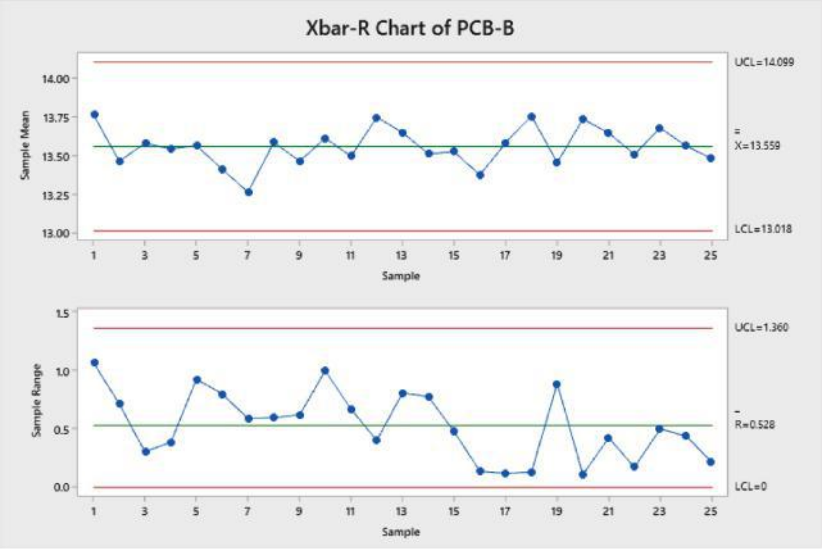

FIGURE 6.8 Xbar-R chart of PCB-B.

The Xbar chart shows the mean of the process, whereas the R chart shows whether the variation in the process is under control. Control limits are set three sigmas above and below the center line. Measurements outside these upper and lower control limits are marked with a red dot, and these points are defined as out of control. Interpreting the figures shows that two points on the Xbar chart for PCB-A in Figure 6.7 are out of the control limits. For the rest of the charts, there are no out-of-control points observed. To ensure a certain quality, the causes of abnormalities in the measurements stated outside of the control limits should be further investigated. There might be a note recorded by the operator regarding some kind of anomalies in the process. Notice that these charts do not show whether there is an error/defect in the process. Instead, these are good indicators of checking whether the process is stable and under control.

6.4.4 Process Capability Analysis

The calculation of C_p and C_{pk} qualification indices is one of the statistical process control approaches customarily used to measure the performance of the manufacturing process, as stated in Chapter 6.1.3.2. In order to measure whether the process is sufficient within the desired lower and upper limits, the results of the process capability analysis performed on the data via Minitab, and the results are given in Figure 6.9–6.10. For the printed circuit board used for computers, it is intended to

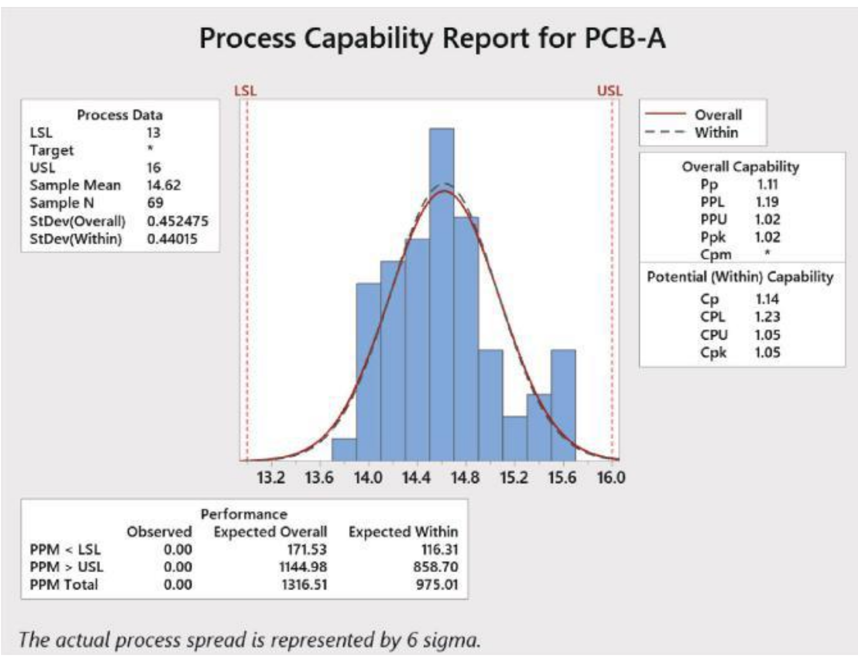

FIGURE 6.9 Process capability analysis for PCB-A.

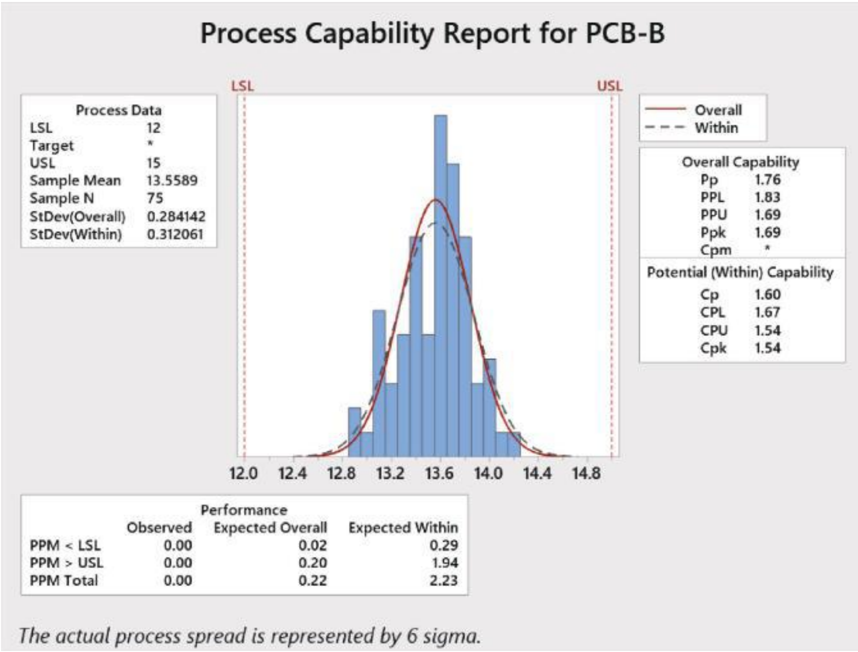

FIGURE 6.10 Process capability analysis for PCB-B.

keep the copper concentration within 13–16%. For the PCB used for mobile phones, the range is between 12% and 15%.

The C_p is 1.14 for PCB-A, and it is 1.60 for PCB-B, and that shows the performance of the process. When these two values are compared, it may be concluded that the PCB-B process is better at meeting customer expectations than PCB-A. This clearly shows which process needs further improvements. In terms of being centralized, the C_{pk} values for both are quite close to the C_p values. As the process's mean approaches the target value, the gap between C_{pk} and C_p is expected to reduce. Therefore, it might be stated that the process is close to achieving the target value. With system improvements being part of the quality goals, even higher performance can be attained by equalizing these two numbers.

6.5 CONCLUSION

It has become more and more crucial for companies to provide a certain quality standard in their products/services due to increasing business competition and customers turning to a more selective position. Despite various definitions, quality can be defined as matching expectations and is inversely related to variation. Quality control methods are used to keep the variability within a controllable limit and to ensure that the products/services meet the quality standards. Quality control processes have evolved in tandem with technological advancements and industrial periods. In particular, new technologies, such as smart sensors, artificial intelligence, the

Internet of Things, and others, have led to the emergence of the concept of Quality 4.0. Many businesses are following and implementing Quality 4.0 in their processes due to its effects on the concept of sustainability, which comes into prominence for the economy, ecology, and society. Although various technologies are used for data collection and process monitoring in Quality 4.0, statistical process control is still the most widely applied in quality control.

In this study, following brief background information regarding the quality and its historical evolution, quality control charts and process capability analysis, as some common statistical process control techniques, are introduced. These techniques are applied in a case study, and the data analysis is done by Minitab. As a result, the measurements of the data inside and outside of control limits and how to conduct a process capability analysis are thoroughly investigated.

This study can be extended in various points. For instance, data collection and measurements with higher precision can be made by more sophisticated devices enabling image processing and more data storage. It might be worthwhile to study the integration of statistical quality control techniques with smart technologies. To do so, great potential benefits for companies can be achieved from the perspective of both sustainability and quality.

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7 Layout and Location Strategies

Adem Erik and Yusuf Kuvvetli

CONTENTS

7.1 INTRODUCTION

One of the strategic decisions for production and service businesses is the facility-planning problem. Facility planning emerges as a problem that needs to be carefully considered due to the complex decisions involved. In order for a facility to have operational excellence in its supply chain, it must take into account many criteria. These are flexibility, modularity, upgradability, adaptability, selective operability, environmental, and energy friendliness (Tompkins, White, Bozer and Tanchoco 2010). Flexibility ensures that the facility can serve different requirements of the supply chain. Modularity refers to the facility's suitability for different operations. While upgradability provides possible extensions for the facility to serve at different capacities, adaptability enables the facility to operate by schedules and possible uncertainties. Selective operability refers to ensuring that the facility can perform different operations. Finally, environmental and energy friendliness refers to taking into account concepts such as the conservation of natural resources, energy conservation, and the protection of the environment, which express the determination and arrangement of the facility under sustainability.

When the facility planning is evaluated, it is possible to discuss three main problems regarding the decisions made. These problems are defined as facility location problems, facility layout problems, and facility allocation problems, as shown in Figure 7.1.

When the facility location problem is examined, the problem can be evaluated according to three different classifications. These classifications are as follows: to choose the facility's location according to (i) objective, (ii) criteria, and (iii) decisions. The facility location problems consider the objectives as single-objective and

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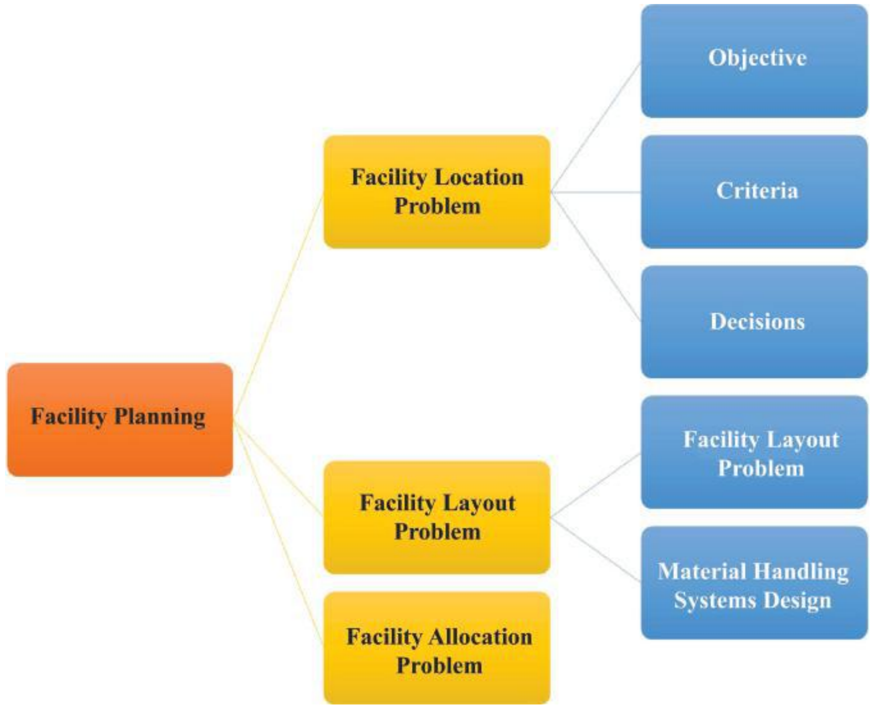

FIGURE 7.1 Facility planning problems.

multi-objective facility location problems. When the criteria are evaluated, facility location selection according to covering, median, center, and hierarchical criteria can be evaluated. When the decisions are evaluated, the integration of location selection decisions can be identified as single-facility selection, multifacility selection, routing, and allocation decisions.

When the facility layout problem is evaluated, the facility layout and the material handling design problems arise. The assignment of material handling devices on the facility layout for material handling systems is a problem to be considered. When the facility layout problem is evaluated, the problem can be classified in different ways. These can be classified in three different ways (Hosseini-Nasab, Fereidouni, Ghomi and Fakhrzad 2018):

- Static and dynamic facility layout problem
- Manufacturing systems affecting the facility layout problem (different shapes of departments and different manufacturing systems)
- Different problem formulations (objectives, modeling, solution methods, etc.)

7.1.1 Facility Location Problem

The facility location decisions can be considered with different methods. Basically, there are some methods that focus on the criteria with mathematical modeling and other algorithms.

One of the methods that can consider different criteria is the simple additive weighting method. Churchman and Ackoff (1954) proposed this method to find the optimal selection considering weighted efficiency relying on a course of action. In this method, the utility function $\left(u_i\left(x\right)\right)$ for each alternative can be calculated by equation 7.1, where w_j denotes the weight of a criterion j and r_{ij} is the normalized rating of criterion j for alternative i (Tzeng and Huang 2011).

$$u_i\left(x\right) = \sum_{j \in J} w_j * r_{ij} \tag{7.1}$$

The normalized ratings can be calculated by dividing real values by maximum values if the criterion has a benefit condition. Contrary to this situation, if the criterion is related to the cost, this time, the calculation is made by dividing the minimum values by the actual values. The best alternative has the maximum utility function value.

For example, assume that an automotive company is trying to find a new facility location in one of the cities in Turkey. The company determined the alternative cities as Adana (A1), Ankara (A2), İstanbul (A3), and Samsun (A4). The four criteria are selected from the study of Liang and Wang (1991) as transportation availability (C1), availability of skilled workers (C2), climatic conditions (C3), and investment cost (C4). The decision-maker quantifies the criteria in the range of [1,10] according to each alternative, as summarized in Table 7.1. Moreover, weights of criteria and criterion targets are also given.

The normalized ratings (r) can be calculated by dividing the maximum value of each criterion (if the criterion is a benefit), and the utility function can be calculated by equation 7.1. The normalized ratings and final ranks are given in Table 7.2.

According to the results, the most appropriate facility location is Adana, and the second one is İstanbul. A fuzzy version of this method can also be considered in the study of Chou, Chang, and Shen (2008). Other multicriteria decision-making tools can also apply to this problem, such as AHP and TOPSIS (Ertuğrul and Karakaşoğlu 2008), VIKOR method (Deveci and Kuvvetli 2012), and PROMETHEE method (Athawale, Chatterjee and Chakraborty 2012).

TABLE 7.1
Decision Matrix of the Example Problem

Alternative Locations	Criteria			
	Transportation Availability	Availability of Skilled Workers	Climatic Conditions	Investment Cost
Adana	8	6	10	4
Ankara	6	9	6	8
İstanbul	10	10	7	10
Samsun	7	6	8	6
Weights	0.2	0.2	0.2	0.4
Target	Benefit	Benefit	Benefit	Cost

TABLE 7.2
Normalized Decision Matrix and Rankings of the Example Problem

Alternative Locations	Criteria				Utilities	Rankings
	Transportation Availability	Availability of Skilled Workers	Climatic Conditions	Investment Cost		
Adana	0.80	0.60	1.00	1.00	0.88	1
Ankara	0.60	0.90	0.60	0.50	0.62	4
İstanbul	1.00	1.00	0.70	0.40	0.7	2
Samsun	0.70	0.60	0.80	0.67	0.69	3

Another method for facility location selection is the mathematical modeling approach. The facility location problem is proposed in the study of Al-Sultan and Al-Fawzan (1999), which is stated as following the notation for this aim. In this problem, there is a set of possible facility location alternatives (I) and a set of demand locations (J). The cost parameters are d_{ij} and c_i, which are the cost for demands of location j satisfied by a location alternative i, and the cost for locating the facility at a location alternative i. The first binary decision variables are denoted as x_i, which equals 1 if the facility is located at alternative location i; 0 otherwise. The second binary decision variables are denoted as y_{ij}, which equals 1 if the facility is located at alternative location i, serving the demand point j; 0 otherwise. The model is given in equations 7.2–7.5. The objective function (equation 7.2) aims to minimize total costs related to meeting the demands and setting up the cost of facilities. The first constraint (equation 7.3) ensures that each demand should be satisfied by only one facility. The second constraint (equation 7.4) forces that a facility can only serve if the facility has set up that location before. Finally, the last constraint (equation 7.5) provides a valid range for decision variables.

$$min\, z = \sum_{i \in I} \left(\sum_{j \in J} d_{ij} y_{ij} + c_i x_i \right) \tag{7.2}$$

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j \in J \tag{7.3}$$

$$y_{ij} \le x_i \qquad \forall i \in I, \forall j \in J \tag{7.4}$$

$$y_{ij} \in \{0,1\}, x_i \in \{0,1\} \tag{7.5}$$

This problem is also named the uncapacitated facility location problem, and the problem can be extended by capacity considerations (for example, Geoffrion and Bride (1978)).

7.1.2 Facility Layout Problem

The facility layout problem is one of the problems considered in the design of a facility. The problem can be considered as two different approaches. The first approach is based on the construction of a facility, and the second approach is based on the improvement of a facility layout. According to the methodologies, there are mathematical models, and other algorithms can be considered. The most popular mathematical modeling approach is called a quadratic assignment problem. Koopmans and Beckmann (1957) proposed the problem as follows:

$$min\, z = \sum_{i \in N} \sum_{j \in N} a_{ij} * x_{ij} \tag{7.6}$$

$$\sum_{j \in N} x_{ij} = 1 \qquad i \in N \tag{7.7}$$

$$\sum_{i \in N} x_{ij} = 1 \qquad j \in N \tag{7.8}$$

$$x_{ij} \in \{0,1\} \qquad i, j \in N \tag{7.9}$$

Where a_{ij} denotes the cost of flow materials between the layout alternative i and department j. The binary decision variables x_{ij} equals 1 if the department j is located at the layout alternative i.

The objective function (equation 7.6) of the model aims to minimize the total cost occurring on the assignments. The first constraint (equation 7.7) ensures that each facility location should be assigned a department. The second constraint (equation 7.8) forces that each department should be assigned a facility layout alternative. The last constraint (equation 7.9) ensures a valid range of decision variables.

Other methods for the facility layout decisions are based on the algorithms. One of the construction algorithms is CORELAP algorithm, which was proposed by Lee and Moore in 1967 and considers activity relations to build a layout (Sembiring, Budiman, Mardhatillah, Tarigan and Jawira 2018). Similar to CORELAP, ALDEP is one of the algorithms that can be used for construction with the minimum level of relations. For the improvement-based models, one of the methods is called the CRAFT method. This approach is based on the exchange of two or three departments to find better solutions. (For CRAFT and ALDEP, see Deshpande, Patil, Baviskar and Gandhi (2016) for further reading.)

7.1.3 Facility Allocation Problem

Facility allocation decisions are related to the transportation of materials between different supply chain members, such as facilities, warehouses, distributors, and customers. The basic mathematical model of the transportation problem can be stated as follows (Ford Jr and Fulkerson 1956):

$$min\, z = \sum_{i \in I} \sum_{j \in J} c_{ij} * x_{ij} \tag{7.10}$$

$$\sum_{j \in J} x_{ij} = s_i \qquad i \in I \tag{7.11}$$

$$\sum_{i \in I} x_{ij} = d_j \qquad j \in J \tag{7.12}$$

$$x_{ij} \geq 0 \qquad i \in I, j \in J \tag{7.13}$$

Where c_{ij} is the unit transportation cost between location alternative i and j; s_i and d_j denote the supply and demand capacity of the facilities. x_{ij} denotes the transportation amount between facilities i and j.

The objective function of the problem (equation 7.10) aims to minimize total transportation costs between facilities. The first constraint (equation 7.11) focus on the total distribution amount should be equal to the total available supply of the facility. The second constraint (equation 7.12) ensures that the demand of each facility should be satisfied by the other facilities. Finally, the last constraint (equation 7.13) provides the valid ranges of the decision variables.

The problem can be solved by different algorithms. One of the methods for initial solutions tries to assign less costs according to penalized values called Vogel's method (Reinfeld and Vogel 1958). The optimal solution can be found using the MODI algorithm (see Babu, Tabassum and Hassan (2016)).

This problem can be extended with different variants, such as the fuzzy mathematical programming method (Chanas, Kołodziejczyk and Machaj 1984).

7.2 SMART LAYOUT AND LOCATION STRATEGIES

With the Industry 4.0 revolution, the proposed methods and applied strategies for facility layout and settlement problems are turning into smart systems. The variability of demand and product mix has required the dynamic handling of plant layout issues in recent years. With the increase in technological infrastructure and opportunities, more comprehensive studies have emerged on the problem that has been handled dynamically. Facility layout problem simulation, radio frequency identification (RFID)–based data collection, neural network–based fuzzy clustering/data classification, facility layout design based on system layout planning (SLP), programming based on intelligent algorithms, computer-aided process planning (CAPP), and enterprise resource technological tools, such as planning (ERP), are used.

One of the main strategic decision-making periods of enterprises producing products and services is seen as facility layout planning (FLP) (Peron, Fragapane, Sgarbossa and Kay 2020). Facility layout planning includes many design problems that shape production systems in a physical space. FLP, which is seen to be very effective in issues such as cost, efficiency, and productivity in many studies, is considered an important design decision of business operation strategies (Al-Zubaidi, Fantoni and Failli 2020; Li, Tan and Li 2018; Pérez-Gosende, Mula and Díaz-Madroñero 2021). In addition, the interest in this field is increasing considerably, as it covers aesthetic and usability issues in facility layout design (Cheng and Lien 2012). Facility layout is a process involving the creation of two-dimensional CAD drawings (Sly 1998). Poor production layout design increases errors in product manufacturing and prevents sensitive production (Kumar, Singh and Lamba 2018).

Many experts in Western countries have made systematic analyses of FLP since 1950 and developed many qualitative and quantitative methods in the field (Fengque, Yifei, Fei and Dongbo 2017). With the development of technology and production systems in recent years, it has become a goal to create smart processes for businesses and to integrate these processes with new technologies.

The structure with integrated smart processes mentioned here is described as a smart factory. The most important feature that distinguishes smart factories from traditional factories is that they contain many technologies (autonomous robots, cyber-physical systems, Internet of Things, cloud computing, additive manufacturing, big data) in Industry 4.0 (Banger 2017). In smart factories, there is a framework that combines smart workshop objects, such as products, transport systems, and machines, with industrial networks, cloud technology, and supervisory control mechanisms (Tao, Zhang, Liu, Cheng, Wang and Xu 2015). Smart factories consist of two parts: the physical world, consisting of machines and people, and the virtual world, consisting of digital models, status information, and control information Chen, Wang, Feng, Li and Liu 2020). Smart factories aim to meet customer demands with maximum flexibility and in minimum time. Therefore, production systems are not goals but only methods of creating target parts or products (Mishima, Kondou and Masui 2008).

In recent years, FLP has turned into a dynamic problem where resettlement is made at certain periods, going beyond a strategic decision made during the establishment of the facility, especially with the effect of demand variability and increasingly personalized demands. The vision of the smart factory, which has developed with Industry 4.0, requires the production and use of many data in different details within the facility. Therefore, it has become inevitable to develop and implement meta-heuristic approaches and artificial intelligence–based approaches as alternative solution approach for FLP (Al-Zubaidi, Fantoni and Failli 2020). In today's competitive market, facility layout based on big data is more productive and influential (Ertuğrul and Karakaşoğlu 2008). Besides this new commercial computer-aided facility, layout planning tools should be developed to facilitate decisions regarding FLP (Al-Zubaidi, Fantoni and Failli 2020).

To improve processes and reduce idle time within the smart factory, localization must have real knowledge of the location of objects, such as tools or materials. Depending on the purpose, the accuracy of a positioning system should be in the range of 0.15m–1m. In addition, a positioning system used in a production environment must operate on a large scale and be resistant to environmental influences, electromagnetic fields, dust, and noise (Lucke, Constantinescu and Westkämper 2008). While creating the facility layout, criteria, such as distance, neighborhood, shape ratio, flexibility, maintenance, accessibility, hazardous movement, noise level, aesthetics, safety, ongoing work and inventory, space use, capital equipment use, and durability, are taken into consideration. Apart from these criteria, electrical energy consumption is used as another important criterion in the alternatives obtained for an environmentally sustainable settlement (Kumar, Singh and Lamba 2018).

With smart factory design, the principles of interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity have been defined for the transformation of traditional factories into smart factories, and these principles have been discussed with data, technology, operations, people, and cybersecurity (Poyraz 2021). In another study, technologies, tools and techniques, production systems, and analysis of supporting factors, defined as layout drivers, were considered important for optimizing the solution and integrating industrial information to achieve robust and sustainable facility layout/relocation design

(Pérez-Gosende, Mula and Díaz-Madroñero 2021). The FLP factors evaluated under four main headings are the technologies, tools, and techniques used while creating the facility layout, which type of facilities are arranged, and some supporting factors. Today, technologies, such as simulation, CIM, automation, expert systems, and Industry 4.0, are used for facility layout problems. These technologies are used in different plant types, such as FMS, lean, waste, RMS, prefabricated, and cellular. Methods such as precise, heuristic, meta-heuristic, evolutionary, planning and scheduling, and effective tools are used while planning the facility. Finally, there are factors such as security and risks, quality, ergonomics, and economics that support all these processes (Pérez-Gosende, Mula and Díaz-Madroñero 2021).

There are many methods and strategies used for smart factories in the literature. Industry 4.0 technologies are at the forefront of the issues that directly affect these methods and strategies. Wang, Wan, Li, and Zhang (2016) used four layers in smart factory designs: control, physical, data, cloud, and intelligence. Meanwhile, Baryshnikova and Taratukhin (2017) determined the three main elements as business, information, and technology architecture for facility design during and after digital transformation in the model created in their study. In another study, El Hamdi and Abouabdellah (2018) believe that the smart factory concept can be completed using layers of operations control, product lifecycle, and data collection, transmission, and visualization. According to the authors, the operation layer consists of the software, such as ERP, WMS, and MES; the production lifecycle layer consists of raw materials and raw information; the data collection, transmission, and visualization layer consists of processes, such as real-time imaging and problem analysis (El Hamdi and Abouabdellah 2018).

Xu, Xu, and Li (2018) predict that instead of creating a new smart factory structure from the beginning, it is possible to develop processes and become a part of innovation and expand automation in the factory. To create a factory that collects data and takes decisions on its own, it is sufficient to integrate the processes of product planning, design, manufacture, distribution, and sale together with Information and Communications Technology (Xu, Xu and Li 2018). Following is a list of how some technologies might affect smart factories in the future (Fengque, Yifei, Fei and Dongbo 2017):

- Spatial modeling, search, display, and interaction of the industrial Internet will be realized with RFID-based three-dimensional positioning technology.
- The artificial intelligence system will enable the smart factory to have the ability to self-decide, self-execute, and self-visualize.
- The technology of situational awareness and pattern recognition will be developed with information engineering.
- Flexible control of industrial robots, collision detection, and human-machine cooperation will be widely used.

Production facilities where flexible production can be achieved should be as small as possible to meet the requirements in production. Mishima, Kondou, and Masui (2008) wondered whether it was possible to build a "super-miniature factory" for micro-mechanical manufacturing, and it was thought that the environmental impact of production could be greatly reduced. The production system, which the established development teams call a micro-factory, has been identified as an easily manageable and more environmentally friendly system. In addition, since the small size of the machines allows for flexible layout changes, it can control the increase in costs when product designs are changed.

Another important issue that also affects the facility design problem in smart factories is the human factor. Although the new Industrial Revolution and the introduction of machine communication and smart systems give rise to the idea that the human factor will disappear after a while, it does not reflect the truth that Industry 4.0 does not need people; contrary to popular belief, people's initiative plays an uninterrupted role in the improvement of Industry 4.0 (Li, Tan and Li 2018). Therefore, while designing the facility, settlements that consider the human factor should be made. Li, Tan, and Li (2018) concluded that the dynamic facility layout problem of the production unit, which considers people factors, should provide the following four principles:

- Appropriately planning the allocation of human resources so that the layout of the facilities could be more in line with the model of human thinking and requirements of data processing
- Increasing the production efficiency of the production line, reducing the production cost, and ensuring production safety
- Optimizing employees' workload and operational posture, minimizing people's mistakes, preventing malfunctions, and creating a healthy, safe, and comfortable working environment for employees
- Developing flexibility of production facility layout

Information and Communications Technology (ICT), which has greatly influenced production processes since the late 1990s and played a role in the development of the smart factory vision, has increased the access, efficiency, and quality of almost every process related to industry and other sectors (Pérez-Gosende, Mula and Díaz-Madroñero 2021). Computer Integrated Manufacturing (CIM) and expert systems have greatly influenced plant design, especially in terms of integration. With the development of computer and digital transformation technologies, many applications, such as multipurpose location-based adaptive particle swarm optimization (PSO), simulated annealing (SA) algorithm, firefly algorithm (FA), genetic algorithm (GA), and ant colony optimization (ACO), have been applied to the facility layout problem. Smart algorithms are integrated (Xu and Song 2015; Matai 2015; Ingole and Singh 2017; Chen and Lo 2014; Giuseppe, Giada and Mario 2012).

The use of high technology, especially in the design of smart production facilities, can cause integration problems and confusion. To mark the complexity that arises in such systems, a standard and holistic model is needed to describe their activities and the relationships between them. Jung, Choi, Kulvatunyou, Cho, and Morris (2017) predicted that with the system they proposed in their study, they could show not only the dependence between activities and production control levels but also the pieces of information and software functions on which each activity is based and that the availability of these pieces of information in digital form that are to be integrated into software functions will increase the agility of factory design and renovation projects. The proposed system can improve the organization of information and activities among various stakeholders, thereby improving decision-making and workflow compared to a system without a clear factory design.

As mentioned earlier, the facility design problem is a two-dimensional (2D) problem. Moving from 2D drawings to a three-dimensional (3D) model of industrial facilities has been a significant challenge because of comprehensive equipment and labor requirements. A new object-oriented approach (VisFactory) enables users to generate 2D/3D drawings of their facilities with less time and effort than normally required to create existing 2D drawings (Sly 1998). Furthermore, with VisFactory for industrial equipment objects, such as cranes, racks, and conveyors, in the Sly (1998) study, other Autodesk developers converged to develop complementary objects, such as structural steel, walls, doors, windows, pipes, and heating, ventilating, and air conditioning (HVAC), thereby changing the way people build facilities of all kinds. The Peron et al. (Peron, Fragapane, Sgarbossa and Kay 2020) study evaluated the introduction of emerging technologies, such as 3D mapping, indoor positioning system (IPS), motion capture system (MoCap), and immersive reality (IR), for dynamic facility layout planning, and the use of these technologies supports a reconfigurable layout and supports the concept of sustainability. It has clearly shown that it affects all three pillars (costs, social aspects, and environmental protection) positively.

Varela, Manupati, Panigrahi, Costa, and Putnik (2020) used the social network analysis (SNA) method to determine the key machines of the systems, stating that to determine the facility design that will provide the effective performance of the whole system, the key machines of the systems should be found. The results of the study showed that the proposed management acted following the aim of obtaining fast and accurate solutions for plant layout setup under uncertainty, big data, and dynamically changing production environments.

All the proposed smart facility layout and layout strategies for facility layout serve smart factory purposes, either partially or holistically. However, the systems proposed in these studies should be sustainable and could update themselves over time. According to the study of Westkämper (2008), the European Union has defined the following targets for sustainable production in the Lisbon agenda:

- Producing more value for more growth and better jobs
- Increasing the competitiveness of European industries and communities in the information age
- Ensuring the sustainable improvement of economies

Scientific-based studies on climate and its consequences indicate that global warming is a major problem, and therefore, it is necessary to give higher priorities to environmental aspects and to increase efforts to reduce energy and material consumption under the influence of increasing production input costs (Fengque, Yifei, Fei and Dongbo 2017). A dynamic site decision-making process with a sustainability goal can help to prioritize environmental aspects and reduce increased production input costs (Peron, Fragapane, Sgarbossa and Kay 2020).

In this section, where the smart layout of the facilities and the related strategies are discussed, first of all; then why the facility arrangement is necessary today and which decisions it affects are mentioned. It has been underlined that the classical facility regulations are not sufficient for the design of the smart factory formed with today's technology and Industry 4.0. In the early 1950s, the design of the stationary facility and the facility, which was made when the facility was first established, has become a dynamic that requires rearrangements over the years. The new production systems that emerged with the development of technology and computer science, facilitating personalized production and communication of machines among themselves, making decisions on their own and sharing information between departments and units at every stage, and so on, have given rise to many situations. The combination of all these reasons necessitated systematic approaches to plant designs. In this section, the systems created to provide the facility design required by smart production and the strategies used while creating these systems are examined. Although there is no generally accepted method or system, almost all studies focus on cyber-physical systems, vertical integration, cloud technology, the Internet of Things, big data, simulation, digital twin, and so on. They predict that it is not possible to design a facility where smart production will be made without using the technologies that form the cornerstones of Industry 4.0.

7.3 SUSTAINABLE LAYOUT AND LOCATION STRATEGIES

Sustainability has become a necessity for companies that decrease natural resources and increase global warming in recent years. For this reason, companies have to make economic, environmental, and social evaluations. All decisions made in classical studies are focused only on the economic perspective based on cost reduction. However, for a facility's location and layout to be sustainable, it must provide decision-making in environmental and social dimensions. In this context, technology seems to be an essential driver. It is because it is possible to choose a traceable and sustainable facility layout with big data systems. In some studies, sustainability and facility layout with big data systems have been considered (Kumar, Singh and Lamba 2018; Tayal, Solanki and Singh 2020).

It may be possible to evaluate different dimensions in terms of sustainability. These can be evaluated as increasing production efficiency, environmental friendliness, and safety criteria (Durmusoglu 2018). In order to increase efficiency, the closest departments can be determined based on flow relationships. In terms of environmentalism, reducing the use of equipment that may harm the environment or using more environmentally friendly systems can be evaluated. At the same time, it is possible to evaluate the social dimension of environmentalism by ensuring occupational safety in terms of safety criteria. Other considerable dimensions of sustainability are evaluated as accessibility, maintenance, and waste management in the study of Tayal, Gunasekaran, Singh, Dubey, and Papadopoulos (2017). Energy conditions are also important. One of the facility layout problems considers the minimum energy consumption affected by the assigned machine (Ebrahimi, Jeon, Lee and Wang 2020).

According to the view of location decisions, sustainable is one of the key terms recently. Even if the airport selection problem is considered, sustainable dimensions, such as noise, total traveling times, and distances, are used as criteria (Hammad, Akbarnezhad and Rey 2017). Noise is considered an important sustainability factor also in the site selection problem of construction (Hammad, Akbarnezhad and Rey 2016). The sustainable view is also important for service operations. The taxi service center location problem is one of the important sustainable operations to locate taxis for keeping the continuity of the service (Zhu, Guo, Zeng, Zhang and Huang 2018).

A sustainable facility layout should include the continuity of the services. This can be achieved by considering dynamic versions of the facility layout problem. Dynamic facility layout problem focuses on the layout decisions over time with changing demands (Conway and Venkataramanan 1994). In the dynamic facility layout formulation, facility layout decisions over time can be extended by energy, noise, environmental, and social considerations. In one study (Lamba, Kumar, Mishra and Rajput 2020), energy consumption is modeled as equation 7.14–7.15.

$$min\, z = \sum_{t}^{T}\sum_{i}^{M}\sum_{j}^{M}\sum_{k}^{M}\sum_{l}^{M}\sum_{p}^{C}\sum_{q}^{C} E_{tik} * y_{tij} * y_{tkl} * x_{tip} * x_{tkp} \tag{7.14}$$

$$E_{tik} = \frac{\left(\dfrac{M_{tik}}{C} * S_{tik} * 9.8 * W\right)}{0.7} \qquad \forall\, t, i, k \tag{7.15}$$

Where E_{tik} denotes the energy consumption between machine i and k at time t, M_{tik} denotes the total material flow between machine i and k at time t, s_{tik} is the speed of transportation device (in this case, AGV) on the transportation between machine i and j at time t, W is the weight of the transportation device, y_{tij} is the binary decision variable that equals one if the machine is located at location j at time t, and finally, x_{tip} is the binary decision variable that equals one if the machine is located at cell p at time t.

The energy costs are included in the objective function (equation 7.14) only if the machines are located at the location points. The constraint (equation 7.15) ensures the calculation of energy consumption from transportation activities.

Briefly, sustainability offers innovative and more realistic solutions to the problems of facility layout and location selection, in addition to the decisions made by considering economic factors. In addition to the selection of location/layout plans that will minimize transportation costs, energy consumption, occupational safety of employees, improvement of working conditions, and consideration of environmental approaches are among the important topics.

7.4 CASE STUDY

The provision of production or service in a business depends on the correct functioning of the processes there. Basic factors such as people, machines, transportation vehicles, and materials affect the processes in the enterprise. It is essential that these factors are used in the right place, at the right time, and in the right way. The purpose of the facility arrangement problem is to ensure that these factors, which are basically determined, can function optimally. While minimization of costs in facility layout is the primary goal in most studies, the sustainability of the achieved layout is not considered much. Facilities should be assigned to the relevant places under the social, environmental, and economic sustainable objectives and material flows. There is a lot of waste of resources in enterprises where the facility layout is not suitable, especially energy consumption, labor, material, and so on. In addition, incorrect facility location and layout can cause social disadvantages. The facility layout problem, as with many other issues, requires the use of smart systems. With the Industry 4.0 revolution and the implementation of lean manufacturing techniques, a smart layout where there is no confusion, machines communicate, data are collected without human errors, and automatic transportation systems are located.

The problem explored in the case study is a classic example of a Static Facility Layout Problem (SFLP). In the studied problem, the amount of material moved between machines was obtained by sensors, and the flows can be predicted using machine learning for this dataset. Thus, the data obtained are free from human error, and these data can be used for planning future periods by decision-makers. With the estimates obtained here, facility layouts for future periods can be created by considering environmental and social criteria. Thus, sustainable facility layouts using smart systems that take environmental and social conditions into account can be created. A mathematical model was created for the classical SFLP solution examined in the case study. The formulation of the created model is very similar to the problem suggested by Van Camp, Carter and Vannelli (1992). The mixed-integer nonlinear programming model of the problem is given subsequently.

Indices:

k, l : $Departments : k, l : 1, 2, ..., N$

Parameters:

W : Facility width on the x axis

H : Facility height on the y axis

a_k : Required area for department k

f_{kl} : Amount of material flow between departments k and l

I_k^{min} : *Minimum length for department k* $\left(I_k^{min} = a_k / q_k\right)$

I_k^{max} : *Maximum length for department k* $\left(I_k^{max} = \min\left\{W, \left(a_k * q_k\right)^{0.5}\right\}\right)$

a_k : Aspect ratio for department k

Decision variables:

w_k : Width (the length in the x – axis direction) of department k

h_k : Height (the length in the y – axis direction) of department k

x_k, y_k : (x, y) *coordinates of the centroid of department k*

m_{kl} : $\begin{cases} 1 \text{ if department k and l overlapping in the vertical axis} \\ 0 \text{ otherwise} \end{cases}$

d_{kl}^x : *Horizontal distance between the centers of departments k and l* $\left(d_{kl}^x = \left|x_k - x_l\right| = d_{kl}^{+x} + d_{kl}^{-x}\right)$

d_{kl}^{y} : *Vertical distance between the centers of departments k and l* $\left(d_{kl}^{x} = \left|y_k - y_l\right| = d_{kl}^{+y} + d_{kl}^{-y}\right)$

Objective function:

$$minZ = \sum_{k=1}^{N} \sum_{\substack{l \neq k \\ k<l}}^{N} f_{kl} * (d_{kl}^{x} + d_{kl}^{y}) \tag{7.16}$$

Constraints:

$$\frac{w_k}{2} + \frac{w_l}{2} \leq d_{kl}^{x} + W * m_{kl} \qquad \forall k, l \ (k < l) \tag{7.17}$$

$$\frac{h_k}{2} + \frac{h_l}{2} \leq d_{kl}^{y} + H * (1 - m_{kl}) \qquad \forall k, l \ (k < l) \tag{7.18}$$

$$\frac{w_k}{2} \leq x_k + \frac{w_k}{2} \leq W \qquad \forall k \tag{7.19}$$

$$\frac{h_k}{2} \leq y_k + \frac{h_k}{2} \leq H \qquad \forall k \tag{7.20}$$

$$I_k^{min} \leq w_k \leq I_k^{max} \qquad \forall k \tag{7.21}$$

$$w_k * h_k = a_k \qquad \forall k \tag{7.22}$$

$$w_k, h_k, d_{kl}^{x}, d_{kl}^{y}, x_k, y_k \geq 0 \qquad \forall k, l \tag{7.23}$$

$$m_{kl} \in \{0,1\} \qquad \forall k, l \tag{7.24}$$

The objective function (equation 7.16) of the model is to minimize the total material transports. Constraints in equations 7.17 and 7.18 ensure that parts *k* and *l* do not overlap. Constraints in equations 7.19 and 7.20 force the center coordinates of the sections vertically and horizontally within the facility limitations. The constraint in equation 7.21 is the aspect ratio constraint that provides the width of the partitions that must be within the department constraints. The constraint in equation 7.22 provides the department space. Finally, constraints in equations 7.23 and 7.24 are valid ranges of decision variables.

With the created model, an instance with seven departments named O7 in the study of Komarudin and Wong (2010) is solved. The data relating to the instance can be accessed from the Komarudin and Wong (2010) study. When the results obtained were examined, the objective function was found to be 131.65, and the optimum facility layout is shown in Figure 7.2.

When looking at the basic model, there is a situation that considers the material flow in the facility and tries to minimize this flow. However, as stated before, social and human factors should also be considered for a sustainable facility layout. One of these factors is the risk of mental and physical damage to employees. Considering the physical and mental health of the employee is very important in terms of productivity and sustainability (Li, Tan and Li 2018). Employee's risk of physical and mental damage can be expressed as shown in equation 7.25:

$$Z_1 = \sum_{k=1}^{N} \sum_{l=1}^{N} f_{kl} * (d_{kl}^{x} + d_{kl}^{y}) * E_{kl} \tag{7.25}$$

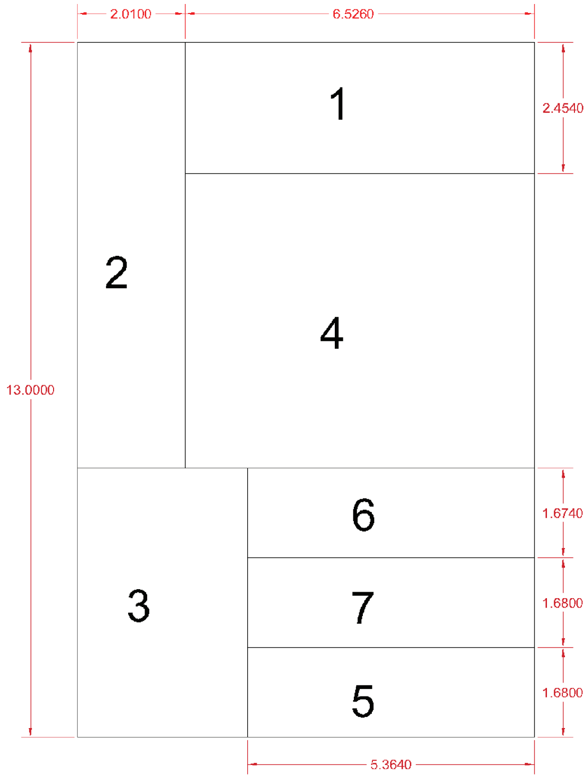

FIGURE 7.2 Optimum layout of O7 instance.

In equation 7.25, E_{Kl} represents the assessment value of the worker's posture, force strength, job difficulty, and psychological load with a coefficient in the range of 0–5. Li, Tan, and Li (2018) express the coefficient that causes physical and mental damage as follows:

0 to 1: Little risk; employees work normally
1 to 2: Less risk; affects operation efficiency
2 to 3: Normal risk; employees are asking for more sick leave
3 to 4: A bigger risk; increases employee turnover costs
4 to 5: A big risk; increases the cost of compensation

The value of Z_1 calculated in equation 7.25 is found by multiplying the worker's risk of physical and mental damage, the amount of material processed in the machines, and the distance between the machines. By adding this value to the objective function, the risk of physical and mental damage to the employee is added to the basic model. This situation reduces the distance between machines with processes that require a lot of effort and have a high risk of damage. The facility layout obtained with the new version of the model has changed. The facility layout obtained from the solution, which considers the risk of physical and mental damage to the employee, is shown in Figure 7.3.

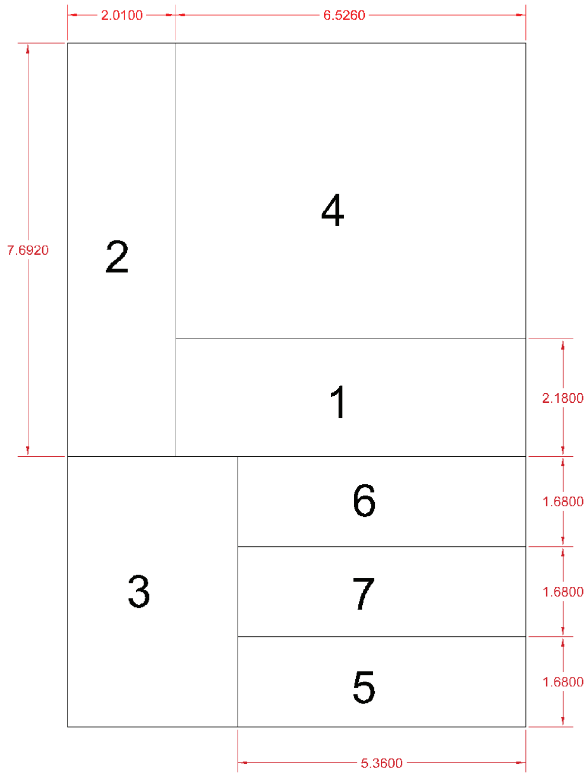

FIGURE 7.3 Layout of O7 instance under the risk of workers' physical and mental damage.

With Industry 4.0, transportation systems, like most processes in businesses, have turned to smart handling systems. Automatic guided transport devices (AGV) are used especially in many businesses and solve many problems. However, as in all other technologies, there are various challenges in these handling systems. Routing of AGVs, which do not allow frequent changes in the facility layout yet, and ensuring optimum transportation is a very challenging issue. In order to adapt the facility layout to smart systems and gain a sustainable structure, facility design should be done together with smart handling systems, such as AGV. It is also known that energy consumption has increased significantly with AGVs. Therefore, the existence of a good facility design, which considers the transportation systems, also prevents excessive energy consumption. In addition to the risks related to the mental and physical health of the employee, the issue of energy consumption of handling systems (AGVs) is also discussed in this case. Kumar, Singh and Lamba (2018) predicted the calculations specified in equation 7.26 for the effect of the energy consumption of AGVs on the facility layout.

$$Z_2 = \sum_{k=1}^{N} \sum_{l=1}^{N} C^T * (d_{kl}^x + d_{kl}^y) \tag{7.26}$$

$$C^T = (V_{kl} * 9.8 * 100 * f_{kl}) / 0.7 \tag{7.27}$$

The value of Z_2 depends on the distance between the machines and the energy consumption value $\left(C^T\right)$ shown to be calculated in equation 7.27, specified in Kumar, Singh and Lamba (2018). The value specified in equation 7.27 is directly proportional to the speeds of the AGVs and the amount of material transported. In this case, adding the Z_2 value to the objective function will be effective for less energy consumption. In this case, the developed model will force the critical machines to approach each other to consume less energy.

When the effect of energy consumption on the model is examined, it is seen that it creates a different facility layout than the first two cases. Thus, a third facility layout was obtained after the basic model and the risk of mental and physical harm to the employee. The new facility layout formed is shown in Figure 7.4. In addition, the model has created a more sustainable facility layout by considering both energy

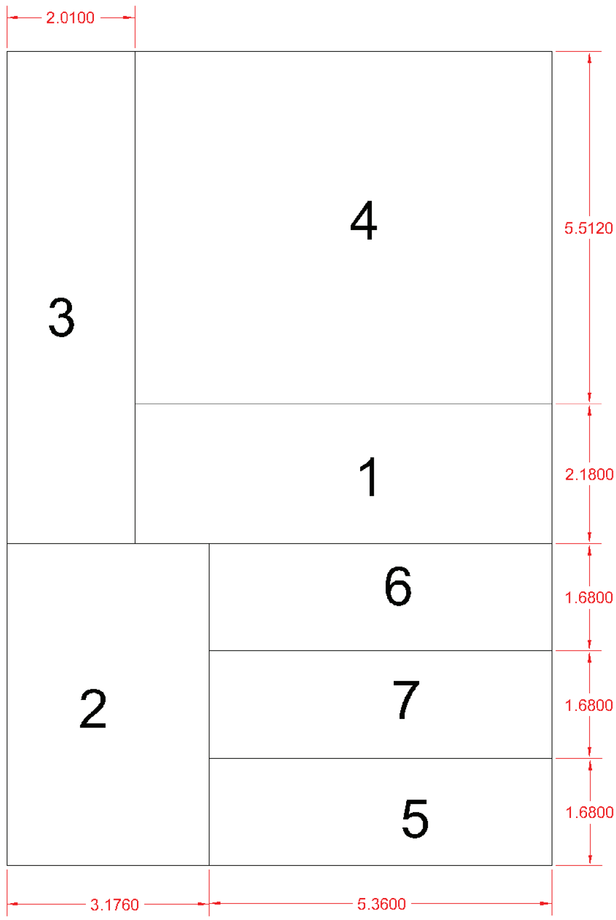

FIGURE 7.4 Layout of O7 instance under the risk of workers' physical and mental damage and energy consumption.

consumption and the risk of mental and physical damage to the employee. Finally, it can be said that the model is promising for a smart plant design in terms of data acquisition and the use of AGVs.

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8 Inventory Management

Şeyma Zeynep Mavzeroglu
and Saadettin Erhan Kesen

CONTENTS

8.1 INTRODUCTION

The philosophy of supply chain management has been put forward in order to manage material/product, money, and information between suppliers, manufacturers, distributors, retailers, and customers in the supply chain. Supply chain management has many definitions in terms of management and organization, production, and marketing functions. It is the managerial activities carried out to plan, implement, and control the flow in the process of transforming the raw material into the product and distributing the finished product to the appropriate channels in the supply chain in line with customer needs. The management of supply chains has gained importance in many sectors so that companies can keep up with economic globalization, respond quickly to customer demands, and increase their competitiveness. For this purpose, the most critical point of correct supply chain management is inventory management (Chu et al., 2015).

Inventory is the products or materials that a business intends to sell to customers for profit. Inventory management, which is the process of tracking inventory from manufacturers to warehouses and from these facilities to the point of sale, is a critical element of the supply chain. Firms keep inventory for some reasons; meeting the changes in product demand, taking precautions against the changes that may occur in the raw material delivery times, and benefiting from the economic order quantity (Buschiazzo et al., 2020). Failure to obtain the desired product when needed causes customer dissatisfaction and financial loss. In addition to the storage cost and risk of damage, keeping too many products on hand causes the products to take up unnecessary space in the warehouses.

Traditional inventory management applications are moving away from being up-to-date with the increase in multichannel distribution applications. New trends

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are adapting company requirements to new inventory management that make supply chain complexity simpler and increase the level of customer service while reducing the inventory level. One of these trend inventory management policies, implemented in order to stay competitive in today's rapidly changing business environment, is the multi-echelon inventory management policy (Yu et al., 2009). In a multi-echelon inventory system, there are multiple stages in the supply chain. "A multi-echelon system is a network composed of stages that are grouped into echelons". The first stage starts with the production of the product. After the product is produced at the manufacturer, it is sent to a distribution center and then shipped to retailers for delivery to the final customer (Sbai & Berrado, 2018).

In the actualization of this multi-echelon inventory system, it is appropriate to integrate Industry 4.0 technologies horizontally in order to ensure cooperation between manufacturers and suppliers. The material requirement of a company creates a dynamic problem. In order to solve this problem, companies need to follow their stock amounts. For such a purpose, companies make different inventory policies and decide when and how much material should be purchased. Unfortunately, many companies do their inventory management manually, which leads to unnecessary cost and time usage (Fernández-Caramés et al., 2019). In addition to this waste of time and cost, manual inventory management increases the likelihood of incorrect inventory records, resulting in different costs that arise by creating excess or insufficient inventory (Avilés-Sacoto et al., 2019).

Simulation optimization, also known as simulation-based optimization, can provide solutions to complex problems through simulation. Since inventory problems are complex problems, simulation-based solution methods are frequently used. With the simulation techniques, the behavior of the inventory system can be monitored, and the performance can be measured with the data in the system after many trials. The use of simulation techniques in inventory management allows testing of the new system in changes and new situations. It shows the results of these amendments to the experiment without disturbing the real system. Additionally, a lack of appropriate stock policies results in failure to meet demand or delayed delivery, resulting in an undesirable lost sale situation. Through simulation-based inventory management, the aim is to prevent excess or out of stocks and optimize the total cost involving purchasing, holding, back ordering, and more.

The fundamental objective of the present study is to determine the reorder point and order size that minimizes the total cost stemming from retailers' and distribution centers' sides in a simulation-based–multi-echelon inventory system. The data, such as demand arrivals, initial inventories, and delivery and lead times, are used as input, and the total cost and system performance are measured as output in the simulation model. In this way, we aim to find the most appropriate level of input variables to determine the minimum cost of the overall inventory system.

8.2 LITERATURE REVIEW

As a result of the literature review, it is understood that simulation models are a suitable methodology for analyzing different inventory management scenarios. By using simulation, different scenarios in inventory management and their results can be analyzed at a lower cost without adapting them to real life. As many studies are available in the literature considering single- and multi-echelon inventory management systems, our survey is limited to works that handle inventory management systems using simulation techniques.

Sridhar et al. (2021) aimed to find the optimal inventory parameters based on details such as customer arrival, demand distribution, and purchasing patterns for a product they chose. In addition to these details, they also used details involving lead time, inventory level, and product reorder level. They modeled the proposed system with Arena software and recorded the changes related to inventory level, lost sales, and stock level. Buschiazzo et al. (2020) developed a new simulation model regarding inventory management in the health sector. With this simulation model, they worked on both determining the purchasing plan and comparing the simulation results of different approaches. Schwartz et al. (2006) used the statistical results of simulation and inventory management using Arena software. Using the order quantity, reorder point, target stock, and inventory quantity, they created a model on how to meet customer demands at the lowest cost. Al-Fandi et al. (2019) investigate different inventory management policies in order to overcome stock-out or overstock of products in the health sector. They also analyze the current inventory system by using Arena software. Akhtari et al. (2019) examined the simulation model comparing different inventory policies (order-up-to-level and fixed order quantity). Unlike other studies, that study focused on sustainability and took into account CO_2 emission as well as cost minimization. Wiśniewski (2018) aimed to optimize inventory management in the supply chain where demand goes from customers to the store and orders go from store to suppliers, and the demand is uncertain. Doğan et al. (2017) investigated inventory management of perishable products in a multi-echelon supply chain consisting of customers, retailers, and manufacturers. They applied different inventory scenarios intending to minimize the total cost, which is the sum of purchasing cost, lost sales cost, holding cost, spoilt product costs, and increasing customer satisfaction. Khan et al. (2016) developed a model with Arena software for balancing the inventory level, reducing lost sales, and the percentage of customer dissatisfaction. Along with this model, they offered suggestions regarding reorder points and lot size. Hamdan et al. (2015) combined the discrete event and continuous simulation to improve the construction supply chain by applying inventory planning and simulation work on the assembly line, thereby reducing costs. Baesler et al. (2014) constituted a simulation model of activities in the supply chain to analyze different inventory policies in blood centers. Mutingi et al. (2013) analyzed a simulation model based on forward and reverse flows in a single-echelon supply chain made up of suppliers, manufacturers, retailers, and customers, taking into account variables related to random customer demand, optimized production levels, manufacturing, remanufacturing, delivery times, and material requirements. Patil et al. (2011) focused on the inventory relationship between retailers in a multi-echelon supply chain consisting of a single distribution center, three retailers, and one customer. A simulation model has been developed to reduce lost sales and improve sales. Yu et al. (2009) performed a simulation analysis by applying a continuous review (R, Q) policy in a multi-echelon inventory system consisting of three retailers, a distribution center, and a manufacturer, with the objective of the maximization of customer satisfaction and minimization of inventory cost.

The contribution and distinction of the study from the literature can be stated as follows. In this study, we focused on the simulation model that allows different scenarios to be used in the multistage inventory environment where the (r, Q) inventory policy is adopted. With these different scenarios, reorder points and order quantities that minimize the total cost have been experimented.

8.3 INVENTORY MANAGEMENT

Inventory is all raw materials, semi-finished products, auxiliary materials, and final products that are kept for use in production or to be sent to the final customer. Inventory management is the planning and control of inventory from raw materials to the final product going to the customer in order to determine the optimal level of inventory. It is a dynamic process as inventory levels must be constantly reviewed and must keep up with changing economic conditions.

Inventory is generally thought of as a product waiting to be sold to a customer. However, inventory exists at every stage in the supply chain, and inventory management is a vital factor in supply chain performance in keeping inventory availability and customer demand in balance. Keeping the inventory in excess causes overstock, and keeping it less than needed leads to out-of-stocks, which means the inventory cost increases, and it adversely affects the supply chain. With this negative effect, unfortunately, the costs of components within the supply chain—the manufacturer, distribution center, and retailer—and the velocity of meeting customer demand increase. Inventory management has features such as fulfilling orders, determining the safety stock, controlling and managing the purchasing decisions from the customer to the supplier and from the supplier to the manufacturer, and controlling the amount of inventory (Wang et al., 2020). Accomplished inventory management is essential for the efficient use of these features. With successful inventory management, the following can be achieved (Sridhar et al., 2021):

1. A continuous supply of materials, spare parts, and finished products can be provided to eliminate disruptions in production and to meet the customer's demand in a timely manner.
2. The optimum level of investment in stocks can be determined according to operational and sales activities.
3. Both under- and over-stocking of inventory are prevented.
4. Various inventory-related costs, such as purchasing cost, storage cost, and lost customer cost, are optimized.

Inventory management aims to achieve the minimum total inventory cost with the maximum level of customer service. Inventory cost consists of four types; namely, ordering cost, holding cost, backorder cost, and shortage cost. In an inventory system that is not successfully managed, overstock and out-of-stock frequently occur. It is sometimes preferred to keep stocks for reasons such as fluctuations in the amount/quantity of demand, constantly changing market conditions, and the desire to deliver the product to the consumer quickly. However, these inventories result in the holding cost. Inventory shortage may occur due to the inability to accurately determine future demand and errors in forecasting demand. This results in shortage cost, which occurs due to the penalty cost arising from not fulfilling the customer request within the specified time and the costs arising from customer dissatisfaction.

Under intense competition, no one wants to lose their customers, so it is an important issue to meet customer demands accurately as time and quantity. Customer service level is measured by customer fill rate. The customer occupancy rate is a percentage that shows how the system is able to meet customer demand. The customer service level is calculated in equation 8.1 (Özgür, 2006).

$$Fill\,Rate = \frac{Demand\,Met}{Total\,Demand} \tag{8.1}$$

The movement of inventory in the supply chain is important in order to meet customer demands properly and increase the level of service. Higher customer service levels and lower cost results can be achieved by the coordination of components within the supply chain or with inventory management covering the entire supply chain.

8.4 MULTI-ECHELON INVENTORY MANAGEMENT

A supply chain is a network that encompasses the manufacturer, distribution centers, and retailers in the process where the raw materials are transformed and delivered to the final customer. It is an indisputable fact that inventory management is an important issue in this network. In the traditional supply chain, the entities of the supply chain work independently of each other. Inventory management policies are carried out with different applications, unaware of each other and in isolation. Single-echelon inventory management admits that inventory is in a place and demands are met from the location, to which replenishments are also added. Essentially, the inventory is kept in more than one location in the supply chain; this is because it has been understood that inventory management should be updated as a multi-echelon inventory system. Additionally, with the advent of developing technological infrastructures, these traditional methods have begun to be left behind, and the members of the supply chain interact with each other. Through this interaction, in the multi-echelon supply chain, the supply chain entities implement the inventory management policies, and they jointly determine and target a global optimization approach. As a consequence of the consensus, the term "multi-echelon inventory system" has emerged with the common inventory strategy, where the product passes through more than one entity before reaching the final customer. In the multi-echelon inventory system, inventory management is carried out more efficiently as a result of increased interaction between supply chain entities. Emanating from these positive results, close attention to the multi-echelon inventory system has been paid (Sbai & Berrado, 2018).

There are multiple components and stages in a multi-echelon supply chain. A multi-echelon system consists of different stages that are grouped into echelons, and it is a network grouped according to the locations and the functions.

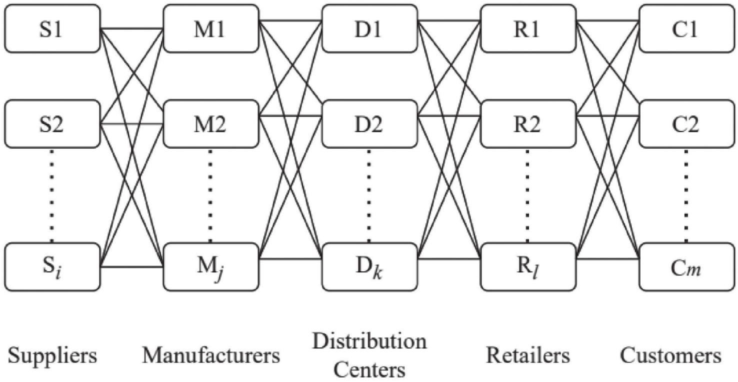

FIGURE 8.1 Multi-echelon inventory system with *i* suppliers and *m* customers. (Sbai & Berrado, 2018)

FIGURE 8.2 Serial system with *n* inventory locations. (Sbai & Berrado, 2018)

After the products are produced in the production center or manufacturer using the raw material from the supplier, the products are sent to a central warehouse. The materials in the central warehouse are then forwarded to the distribution centers. Finally, the endpoint where the customer reaches the product is the retailers that obtain materials from the distribution center. From this point of view, multi-echelon inventory management is defined as the inventory between the stages in the multi-echelon supply chain. An illustrative multi-echelon inventory system can be seen in Figure 8.1.

Multi-echelon inventory systems are classified according to their network structure as serial systems, assembly systems, and distribution systems. First, the serial systems shown in Figure 8.2 are the simplest form of the multi-echelon system. Here, the next inventory location becomes the customer of the previous inventory location. The predecessor is defined as the supplier of the successor.

Second, a somewhat more complex version of the serial system, the assembly system (Figure 8.3), refers to the fractional networks within a supply chain component. It is a system that describes the product transportation between stations in the process of turning the raw material into semi-products and then into the final product by exposure to different processes.

Third, the distribution system is the multi-echelon system that covers the chain between the main center of the material, distribution centers, and retailers. The material from the external source is sent to the warehouse or plant first. Therefore, the

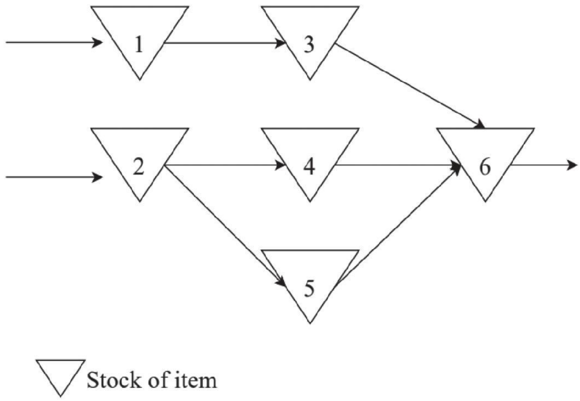

FIGURE 8.3 A multi-echelon assembly system. (Negüs, 2008)

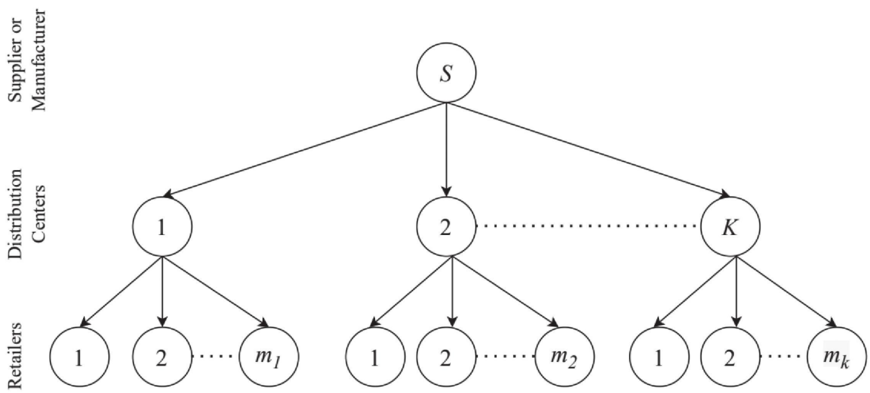

FIGURE 8.4 A multi-echelon distribution system. (Rossetti et al., 2006)

first node of the network turns out to be the central warehouse or manufacturer. The nodes that come after this node are the distribution centers, which are the intermediate stock locations and the retailers that deliver the product to the customer. An example of a multi-echelon distribution system is shown in Figure 8.4.

Multi-echelon inventory management is an integrated approach. With this approach, information can be accessed from a central point and provides an accurate determination of the effects of inventory on the entire supply chain, taking into account the factors related to inventory management. Like single-echelon inventory management, multi-echelon inventory management aims to meet specified customer service levels at the lowest cost for the entire supply chain. (Gumus & Guneri, 2009)

8.5 INVENTORY MANAGEMENT IN INDUSTRY 4.0

Industry 4.0 provides businesses with significant competitive advantages as compared to traditional production systems. The first of these advantages is Industry 4.0, which enables the efficient and effective use of resources. As a second advantage, businesses can meet the changes in production with low costs and machines that are in constant communication with each other. Third, as a result of developing technologies, real-time data becomes available in the decision-making process. Finally, with the development of instant communication between the smart machine, operator, and mobile devices with Industry 4.0, the decision-making process can be transferred to the machines. Due to this transfer, more accurate and meticulous decision-making processes are carried out (Belbağ et al., 2020).

Industry 4.0 technologies can evaluate the data obtained from different sources in a short period of time, with real-time decision-making. Considering the advantages that Industry 4.0 technologies bring to the industry sector, it is beneficial to use these technologies effectively in inventory management, which is of great importance for businesses. Table 8.1 explains how Industry 4.0 tools affect inventory management.

TABLE 8.1
Technologies and Their Impacts on the Inventory Management

Technology	Contribution to Inventory Management
Virtual and augmented reality	Augmented reality–based systems support a variety of services, such as selecting parts in a warehouse and accessing their properties, location, inventory, and delivery times.
Additive manufacturing—3D printing	These technologies create new opportunities on the production side. Thanks to these technologies, manufacturing lead times are significantly reduced and customer demands are met faster. In addition, it reduces work-in-progress inventories, processing times, and material costs, and influences scheduling, lot size, and inventory decisions.
Simulation	It is used in the analysis of the current stock level, keeping the inventory levels at the optimum level under uncertainty from the scope of cost and customer service. It helps identify opportunities for cost reduction and savings. With simulation-based solutions, reorder points and order quantities are calculated with different inventory policies that minimize the total cost.
Big data analytics	As a result of big data analytics, data, such as the availability of products, sales requests, and product returns, can be analyzed. In this way, companies can oversee the changes in the market, work on the optimization of inventory management, and meet delivery expectations.
Cloud computing	By using cloud computing, order and stock status can be checked instantly and updated if necessary. Inventory tracking becomes easier, and additions and removals can be seen and updated instantly.
The Internet of Things	IoT improves inventory management using real-time data. Inventory management is optimized by constantly monitoring the inventory with RFID, mobile apps, and wireless sensor networks.
Robotics and drones	Inventory analysis uses drones, which are much faster than humans, to scan, find, and save large numbers of items in a warehouse. AGVs (automated guided vehicles) and AMRs (autonomous mobile robots) are robotic developments that provide efficiency in warehouse management and operations.

Virtual and augmented reality are Industry 4.0 technologies that provide faster and easier access to information by combining the virtual and real world. With augmented reality, the inputs that will appeal to the human senses and activate their feelings are modified and enriched by the computer, and the new reality that emerges is presented to the user's perception. Enrichment takes place in real time and interacts with surrounding elements. With augmented reality, the user can interact with the elements that make up the real environment. It also provides the right decision-making by helping the decision-making process of the employees (Newman et al., 2022).

The additive manufacturing—3D printing method, contrary to conventional machining methods, is the method of producing the desired shape by arranging the layers on top of each other, for which reason it is also called additive manufacturing. The additive manufacturing method provides significant simplification in the production system by reducing the production complexity by making a simple design, assembling the components in a single product, reducing the need for assembly of various components, and eliminating many assembly processes. A more efficient and 3D printer–supported structure will emerge with a more effective design process instead of a complex production structure. Work-in-process stocks, processing times, and material costs will be reduced. This affects traditional scheduling, batching/batch size, and inventory decisions (Tjahjono et al., 2017). Big data is a concept that emerged as a result of the increase and differentiation of data density due to new data constantly being produced from different sources, such as social networks, sensors, and digital images. Big data analytics focuses on getting meaningful results by analyzing big data. As a result of this analysis, information about the users who provided this data is obtained (Aktan, 2018).

Cloud computing is a model that provides access to a common pool and sharing among computing resources. It ensures that the information and data in the storage of technological devices are stored on the Internet and can be accessed at any time (Armbrust et al., 2010).

The Internet of Things (IoT) is a global network created by physical and virtual objects, and these objects share data with each other. Objects are made accessible and communicated via Wi-Fi, Bluetooth, or similar network tools, enabling them to interact with other objects. With wireless sensor networks, such as RFID, sensor technologies, Internet-based information infrastructure, embedded object logic, and others, IoT provides real-time tracking of supply chain components and material flow between components. Thanks to this real-time monitoring, economic benefits are obtained (Alwadi et al., 2017).

Robots are used to support efficiency, accelerate processes, and improve safety and experiences in industries such as manufacturing, agriculture, and healthcare. Commonly used robot types are autonomous mobile robots (AMRs), automated guided vehicles (AGVs), articulated robots, humanoid robots, and cobots. Drones are defined as unmanned aerial vehicles and are used to facilitate and accelerate processes, especially in distribution activities (J. Lee, 2017).

8.5.1 Simulation in Industry 4.0

Simulation is widely used to show the current operating system in a virtual ecosystem using real-time data. By making changes to the simulation without disrupting the real-world system, the risks that may occur as a result of the change and the desired values can be calculated (Ghadge et al., 2020). The advantages of using the simulation approach: it reduces the risk to zero by performing tests without changing the real system, and it demonstrates the accuracy of the model by providing the visualization of dynamic systems. There are many simulation-based approaches used in the context of Industry 4.0 (Figure 8.5) (Paula Ferreira et al., 2020).

Agent-based modeling and simulation (ABMS) is a simulation approach to modeling systems that interact and have autonomous agents. These agents have interactions with other agents, and these interactions are defined by simple rules and affect each other's behavior. By modeling the factors one by one, their behavior in the whole system can be observed. This modeling approach is used to model social systems that interact and are influenced by each other's experiences and environments (Macal & North, 2010).

Discrete event simulation (DES) is defined as "one in which the state variables change only at those discrete points in time at which events occur" (Paula Ferreira et al., 2020), and DES is process-oriented and runs in discrete times. An event consists of an occurrence that changes the system state. A state variable carries information that is used to describe the behavior of the system at any given time. For example, the number of products waiting for quality control in a queue can be defined as a status variable, while a product entering or leaving the queue can be considered an event.

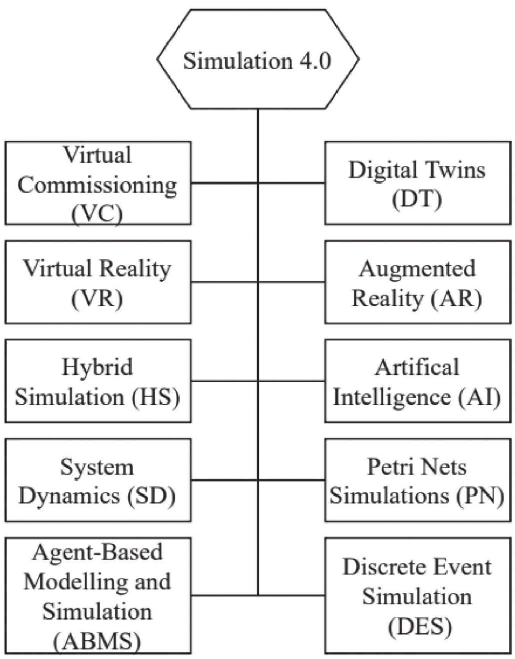

FIGURE 8.5 Simulation-based approaches applied in the context of Industry 4.0. (Paula Ferreira et al., 2020)

System dynamics (SD) is an approach that aims to solve complex systems over time. Feedback loop diagrams and differential equations are used to understand the relationships of components within these systems. The main elements of system dynamics diagrams are feedback, accumulation of flows to stocks, and delays.

Virtual reality (VR) is a technology in which real and imaginary environments are combined, and a user can be included in the virtual environment. Augmented reality is a technology that allows the user to provide information and guidance without breaking their relationship with the physical world environment. Augmented reality (AR) and virtual reality (VR) are applied in many fields, from education to production.

Intelligence is "the ability to gather and combine information necessary to solve a complex problem", and abilities, such as abstraction, learning, and adapting to new situations, are also included in the scope of intelligence. Artificial intelligence, in contrast, is intelligence in non-organic systems with these properties. It allows machines to learn from human experiences and create human-like responses (Angelov et al., 2021). AI is also defined as a technique used for the modeling and simulation of environmental systems, cellular automata, and fuzzy models.

Petri nets simulation is a mathematical and graphical modeling technique. This technique has been developed for modeling discrete event systems, simulation of flexible systems, and performance evaluation. Petri nets can be used in the design, analysis, and control of synchronous, asynchronous, and stochastic systems (Armaner, 2006).

Hybrid simulation is defined as a modeling approach that combines two or more simulation methods. It creates a model by using discrete event simulation, system dynamics, and agent-based simulation methods together (Brailsford et al., 2019)

A digital twin is "a virtual representation that serves as a real-time digital equivalent of a physical object or process" (Jiang et al., 2021). It can also be defined as a digital representation of the physical state of the real system, with simulations updated throughout the lifecycle of the product or system, from the smallest unit to the largest unit.

Due to the constantly developing market conditions, manufacturers need to update their products and production systems and bring innovations. However, when these innovations are applied directly to the real system or product, it causes a loss of time and high cost. In order to prevent this damage, virtual commissioning is used to create the prototype of the new system. Virtual commissioning enables full testing of a production system by performing a simulation involving a virtual plant and a real controller (Lee & Park, 2014).

8.6 METHODOLOGY

The aim of this study is to examine a three-echelon supply chain within the scope of multi-echelon inventory management in order to minimize the total cost arising from inventory. In order to achieve this goal, a discrete event simulation model was created and used for different scenarios. As well as figuring out which multi-echelon inventory management scenario has the least cost, the fill rate was measured in order to determine to what extent this scenario satisfies the order demands.

8.6.1 Problem Description

The problem structure here is based on three-echelon inventory management. Each echelon is the customer of the preceding echelon and the supplier of the succeeding one. The multi-echelon supply chain, which has vertical integration, starts at the manufacturer, continues at the distribution centers, and ends at the retailers. The multi-echelon supply chain consists of a single manufacturer, a single distribution center, and three retailers. The material is delivered to the last customer by the retailers. The supply chain structure studied is shown in Figure 8.6.

The (r, Q) policy or reorder point policy was applied to retailers and distribution centers (DC) in the multi-echelon inventory management used in the problem. A fixed quantity of Q is ordered when the inventory quantity falls below the reorder point r in the (r, Q) policy. As shown in Figure 8.7, the order quantities are Q_{R1}, Q_{R2}, Q_{R3}, and Q_{DC}, and the reorder points are r_{R1}, r_{R2}, r_{R3}, and r_{DC} for the retailer and distribution center, respectively.

This supply chain is based on the logic of checking the inventory and meeting the demand; if there is not enough inventory, then request. When the demand comes to the retailer, the retailer checks its inventory. If the demand size is less than the retailer's inventory level, the demand is met, and the inventory level is reduced by the amount of demand. After that, the rest of the inventory is controlled according to the (r, Q) policy. If this inventory level is below the reorder point, the order is sent to the distribution center, and the retailer order cost emerges.

Otherwise, the retailer does not create an order and uses its inventory. In case the demand to the retailer is more than the inventory level, the demand cannot be met, and lost sales cost occurs. We mentioned inventory management for the retailer. The DC inventory management works in the same manner. But unlike retailers, the DC's customers are retailers, and its supplier is the manufacturer. With this approach, a logical structure, which uses Arena 14.5 to set the simulation model for the multi-echelon inventory management, is shown in Figure 8.8.

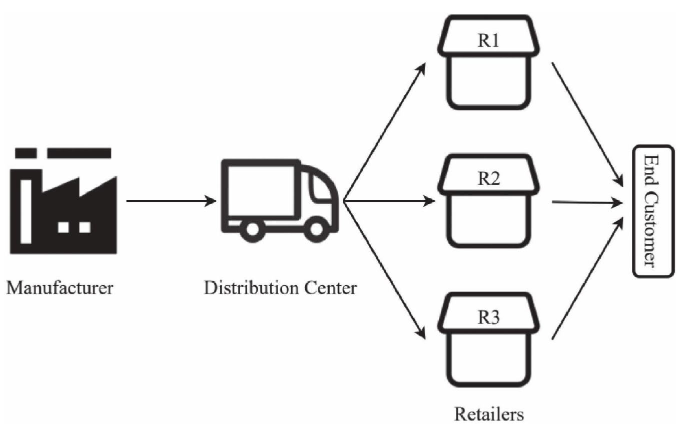

FIGURE 8.6 Multi-echelon supply chain system used in the problem.

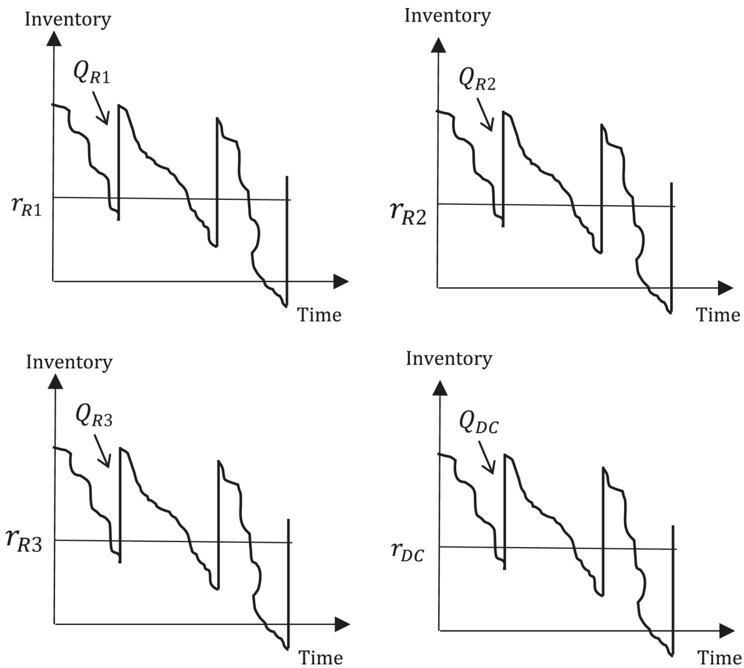

FIGURE 8.7 (r,Q) policy for retailers and DC.

The system assumptions are as follows:

1. A single-product system is considered.
2. The demands come from the end customer and follow a Poisson distribution at the retailers.
3. The initial inventory levels of the retailers are assumed to be the same, and they replenish their stock from the DC according to the (r, Q) policy. DC replenishes its stock from the manufacturer and is responsible for orders coming from retailers. In the beginning, all components are full at time 0.
4. A continuous review inventory policy (r, Q) is adopted.
5. Lead times follow a normal distribution at the retailers and DC.
6. The time to manufacture a product is zero.
7. Backorder is not allowed.

In the present study, the demands come from the end customers to the retailers, with POIS(3), POIS(4), and POIS(5), respectively. The amount of inventory in the retailer at the beginning $R1 = 26$, $R2 = 20$, $R3 = 32$, and they update their inventory level with material from DC. The inventory level of the DC is 92. The lead time for the DC (manufacturer to DC) follows normal distribution as NORM (12, 1). The delivery times mean the time of material delivery from DC to retailers. The delivery times for retailers also follow the normal distribution, NORM (3.5, 0.3) for $R1$,

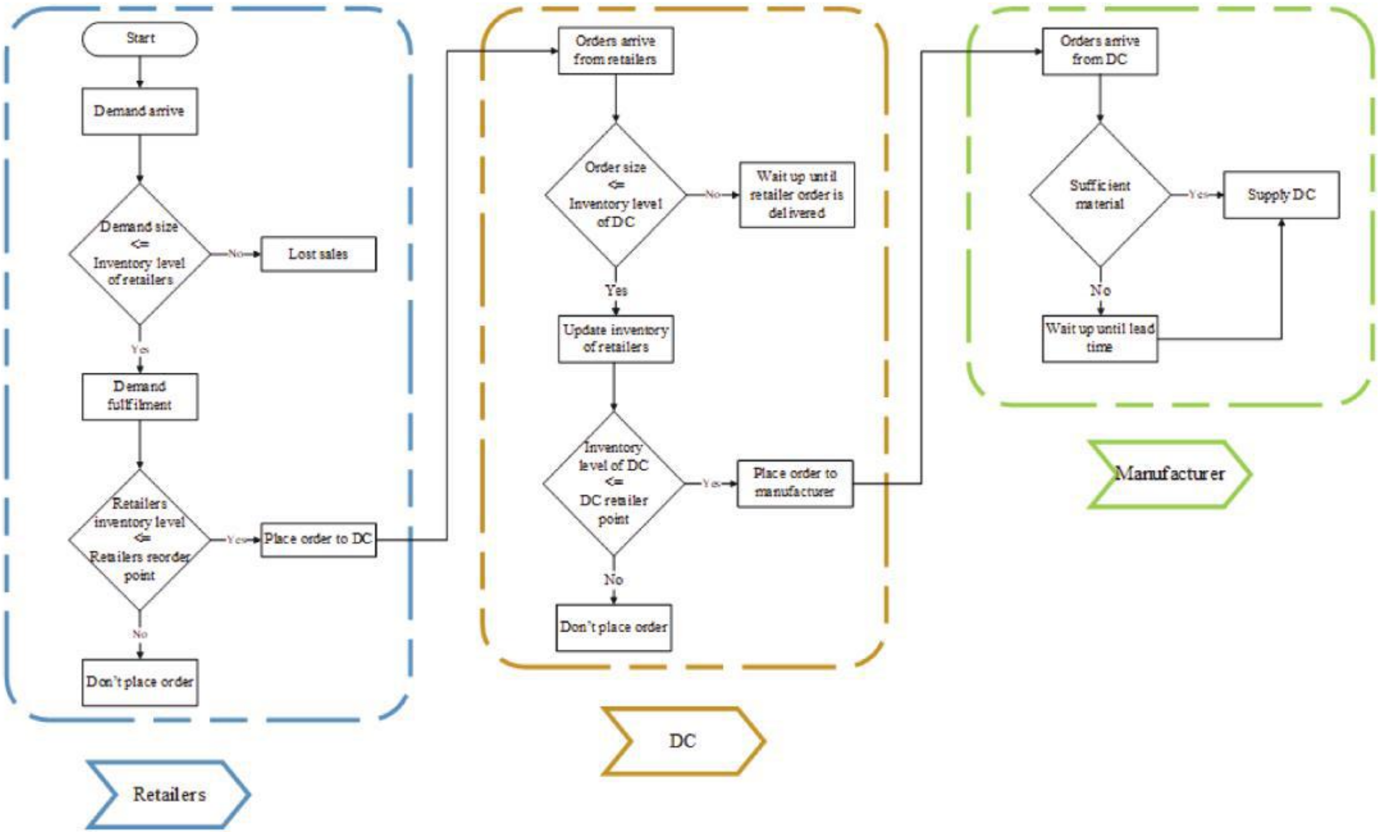

FIGURE 8.8 Logical structure of simulation model.

TABLE 8.2
Costs for the Calculation of the Total Cost

Parameters	*Cost Value*
R1 order cost	15
R2 order cost	15
R3 order cost	15
R1 holding cost	2
R2 holding cost	2
R3 holding cost	2
DC order cost	10
DC holding cost	1.5

TABLE 8.3
Values in Different Inventory Scenarios

Reorder Points of Retailers	Quantity of Retailers	DC Reorder Points	Quantity of DC
4	20	50	50
8	30	60	75
12	40	70	100

NORM (3.5, 0.3) for *R*2, and NORM (4.5, 0.3) for *R*3. The inventory holding costs for the retailers and DC and the order costs for the retailer and DC are given in Table 8.2.

As a consequence of the simulation model, it was aimed to reach r_{R1}, r_{R2}, r_{R3}, and r_{DC}, and Q_{R1}, Q_{R2}, Q_{R3}, and Q_{DC} values that minimize the total inventory cost from scenarios with different reorder points and different order sizes.

In addition to the total cost, the fill rate of the retailers, which shows how efficiently the product reaches the end customer, which is also an important performance criterion, was calculated. As seen in Table 8.3, 81 different scenarios obtained from different combinations of reorder points of retailers, the quantity of retailers, DC reorder points, and quantity of DC were experimented.

The system under study is modeled by a discrete event simulation using Arena software. Due to the complexity of the system, the system is modeled in three parts as demand–retailer relationship, retailer–DC relationship, and DC–manufacturer relationship. The demand–retailer relationship, which is an important part of the established model, is given in Figure 8.9.

The simulation was run for 10,000 minutes of replication length. The results from this simulation study are described in the next section.

8.6.2 Results and Discussions

In the present study, multi-echelon inventory management is applied in a multi-echelon supply chain consisting of three echelons. These echelons are the retailers

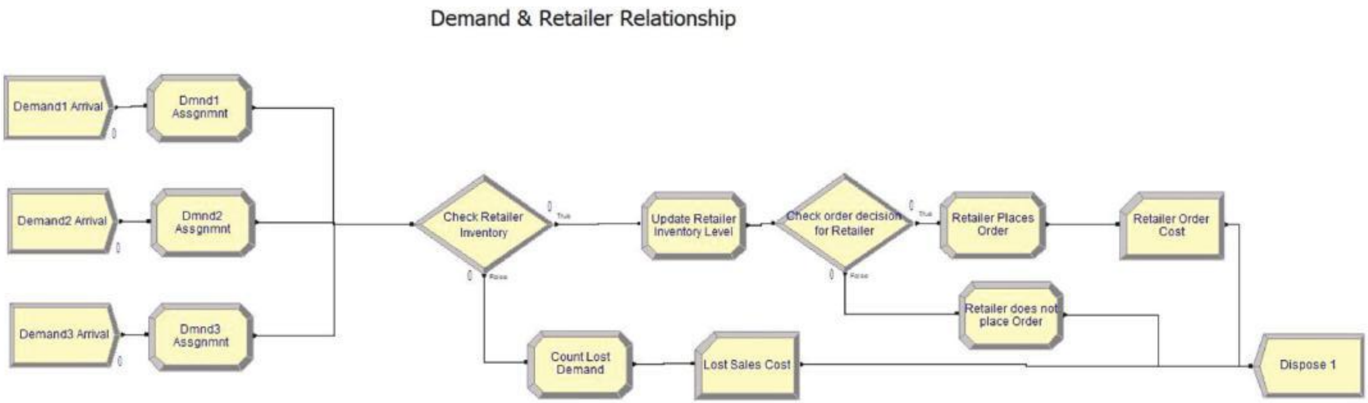

FIGURE 8.9 The simulation model.

TABLE 8.4
The Top 10 Scenarios with the Lowest Cost

Exp No	Retailers Reorder Point	Retailers Quantity	DC Reorder Point	DC Quantity	Fill Rate	Total Cost
28	8	20	50	50	97%	45,811
13	4	30	60	50	95%	47,627
29	8	20	50	75	98%	48,205
31	8	20	60	50	97%	48,251
4	4	20	60	50	93%	48,255
1	4	20	50	50	91%	48,455
40	8	30	60	50	98%	48,488
30	8	20	50	100	97%	49,415
16	4	30	70	50	94%	49,659
3	4	20	50	100	93%	49,753

where the customer's demand arrives, the distribution centers that feed the retailers, and the manufacturer who is responsible for the production. As described in the previous section, the simulation model was set up, and 81 different scenarios, obtained as a result of the combination of values in Table 8.3, were compared. As a consequence of this comparison, the reorder point and quantity with the lowest total cost were selected. After running the simulation model, it is seen that the experiment number of 28 with a 97% fill rate has the lowest cost among the other scenarios. According to this scenario, the reorder point (r) is determined for the lowest cost; 8 for retailers and 50 for the distribution center. Additionally, order quantities (Q) are 20 for retailers and 50 for the distribution center. The top 10 experiments with the lowest cost are shown in Table 8.4. The fill rate, which is used as the performance criterion of the system, was also calculated by the simulation model. The fill rate is obtained by the ratio of the met demand to all incoming demand.

Within the framework of this problem, it is seen that the scenario with the highest occupancy rate is experiment number 67, which is the 16th experiment with the lowest cost. The fill rates and total cost comparisons of the top 10 experiments with the lowest cost are shown in the graph in Figure 8.10. Detailed simulation results for the multi-echelon inventory system under study can be seen in Appendix 8.A.

8.7 CONCLUSION AND FUTURE SCOPE

This study aims to provide accurate inventory management in the multi-echelon inventory system. In this multi-echelon inventory system with the (r, Q) policy, the reorder point and order quantities that minimize the total inventory cost have been found from different scenarios. Here, the reorder quantity represents the number of items requested from the supplier, and the reorder point indicates the point at which the order must be repeated. In addition to this, the fill rate, used as an indicator of customer satisfaction, was also calculated in order to measure the service level. In

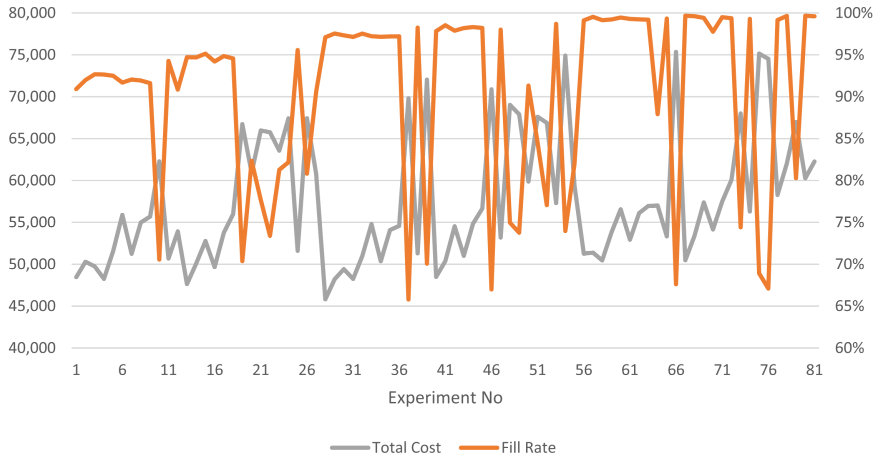

FIGURE 8.10 The fill rates and total cost of all experiments.

order to obtain these data, a simulation model has been developed in which the entities of the supply chain have a relationship; retailers with demand, distribution centers with retailers, and manufacturers with a distribution center. With the simulation model, the reorder point and the scenario with the lowest total cost were determined over 81 different scenarios. Additionally, it was aimed to calculate the fill rate in order to determine the performance of the system. The simulation model used in line with this goal has found the ratio of the met demand to all incoming demand and the fill rates. Within the framework of this problem, among 81 scenarios, the scenario with the highest fill rate, the scenario with the lowest cost, and the scenario with the highest occupancy rate was found. Minimum cost is an important issue for supply chain items. With the values of the scenario found, the inventory movements in the supply chain are performed at a lower cost compared to other scenarios. When it comes to customer satisfaction, the selection of the best scenario can be made by taking into account the fill rates. At the last stage of the study, as seen in Figure 8.10, the fill rate and total cost of the scenarios are shown on the graph for all scenarios.

As a result of the study, it is seen that the integration of simulation, which is one of the Industry 4.0 tools, with the multi-echelon inventory system provides flexibility in solving complex systems. Results were obtained by using Simulation 4.0, which emerged with the integration of Industry 4.0 and a simulation-based approach. The use of discrete event simulation, which is one of the Simulation 4.0 tools, in the supply chain is shown. With this simulation tool, different inventory management methods can be developed by applying different scenarios without disturbing the real system and incurring extra costs.

In future studies, more than one product can be used instead of a single product. More complex problems can be achieved by increasing the number of supply chain components. This problem can be modeled using different inventory management policies, and the results of the inventory policies can be compared.

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Appendix 8.A: Simulation results of the multi-echelon inventory system for various input levels

	INPUTS								OUTPUTS								
Exp No	**Rtlr 1 RP**	**Rtlr 2 RP**	**Rtlr 3 RP**	**Rtlr 1 Quantity**	**Rtlr 2 Quantity**	**Rtlr 3 Quantity**	**DC RP**	**DC Quantity**	**Dmnd Met**	**Dmnd Lost**	**Fill Rate**	**Rtlr Lost Sales**	**Rtlr Ordring**	**Rtlr Holding**	**DC Ordering**	**DC Holding**	**Total Cost**
1	4	4	4	20	20	20	50	50	3172	317	0,909	9193	9135	13390	2430	14307	48456
2	4	4	4	20	20	20	50	75	3167	276	0,920	8004	9165	13153	1630	18336	50288
3	4	4	4	20	20	20	50	100	3101	245	0,927	7105	8775	13378	1170	19326	49754
4	4	4	4	20	20	20	60	50	3063	243	0,926	7047	8580	13283	2290	17056	48256
5	4	4	4	20	20	20	60	75	3068	249	0,925	7221	8730	13226	1550	20833	51561
6	4	4	4	20	20	20	60	100	3166	287	0,917	8323	9045	13233	1210	24088	55899
7	4	4	4	20	20	20	70	50	3059	264	0,921	7656	8760	13271	2340	19232	51259
8	4	4	4	20	20	20	70	75	2987	262	0,919	7598	8730	13393	1550	23711	54982
9	4	4	4	20	20	20	70	100	3081	282	0,916	8178	8700	13239	1160	24407	55684
10	4	4	4	30	30	30	50	50	2299	959	0,706	27811	4395	13138	1750	15183	62277
11	4	4	4	30	30	30	50	75	3139	191	0,943	5539	6180	18251	1650	19071	50692
12	4	4	4	30	30	30	50	100	3030	305	0,909	8845	5835	17350	1160	20728	53917
13	4	4	4	30	30	30	60	50	3082	172	0,947	4988	5940	18304	2370	16025	47627
14	4	4	4	30	30	30	60	75	3031	170	0,947	4930	5925	18351	1580	19292	50078
15	4	4	4	30	30	30	60	100	3189	163	0,951	4727	6165	18117	1230	22524	52762
16	4	4	4	30	30	30	70	50	3133	193	0,942	5597	6045	17991	2420	17606	49659
17	4	4	4	30	30	30	70	75	3117	169	0,949	4901	6045	18596	1610	22616	53767

18	4	4	4	30	30	30	70	100	3132	180	0,946	5220	6150	18233	1230	25152	55985
19	4	4	4	40	40	40	50	50	2373	999	0,704	28971	3660	17147	1940	15011	66730
20	4	4	4	40	40	40	50	75	2802	601	0,823	17429	3975	19708	1410	18400	60922
21	4	4	4	40	40	40	50	100	2642	760	0,777	22040	3885	18615	1030	20404	65974
22	4	4	4	40	40	40	60	50	2468	894	0,734	25926	3345	17699	1770	17010	65750
23	4	4	4	40	40	40	60	75	2640	608	0,813	17632	3750	19419	1330	21429	63560
24	4	4	4	40	40	40	60	100	2758	598	0,822	17342	3930	19884	1050	25207	67413
25	4	4	4	40	40	40	70	50	3214	149	0,956	4321	4620	22996	2460	17211	51609
26	4	4	4	40	40	40	70	75	2700	641	0,808	18589	4125	19742	1460	23513	67429
27	4	4	4	40	40	40	70	100	3023	314	0,906	9106	4410	22193	1170	23927	60806
28	8	8	8	20	20	20	50	50	3137	94	0,971	2726	9345	17028	2490	14222	45811
29	8	8	8	20	20	20	50	75	3184	80	0,975	2320	9270	17063	1650	17902	48206
30	8	8	8	20	20	20	50	100	3196	88	0,973	2552	9570	16768	1280	19245	49415
31	8	8	8	20	20	20	60	50	3195	94	0,971	2726	9600	17053	2560	16313	48252
32	8	8	8	20	20	20	60	75	3199	81	0,975	2349	9375	17151	1670	20443	50988
33	8	8	8	20	20	20	60	100	3257	93	0,972	2697	9645	17050	1290	24119	54801
34	8	8	8	20	20	20	70	50	3246	95	0,972	2755	9525	16816	2540	18730	50366
35	8	8	8	20	20	20	70	75	3283	95	0,972	2755	9795	16907	1740	22889	54086
36	8	8	8	20	20	20	70	100	3193	92	0,972	2668	9435	17036	1260	24183	54581
37	8	8	8	30	30	30	50	50	2216	1152	0,658	33408	4320	14688	1720	15667	69803
38	8	8	8	30	30	30	50	75	3360	60	0,982	1740	6675	22021	1780	19072	51288
39	8	8	8	30	30	30	50	100	2365	1010	0,701	29290	5040	15443	1010	21255	72038
40	8	8	8	30	30	30	60	50	3161	70	0,978	2030	6210	21972	2480	15797	48489
41	8	8	8	30	30	30	60	75	3289	49	0,985	1421	6495	21793	1730	18938	50378
42	8	8	8	30	30	30	60	100	3234	70	0,979	2030	6375	21884	1280	22958	54527
43	8	8	8	30	30	30	70	50	3311	61	0,982	1769	6615	22271	2640	17711	51006

(*Continued*)

APPENDIX 8.A (Continued)

	INPUTS								OUTPUTS								
Exp No	Rtlr 1 RP	Rtlr 2 RP	Rtlr 3 RP	Rtlr 1 Quantity	Rtlr 2 Quantity	Rtlr 3 Quantity	DC RP	DC Quantity	Dmnd Met	Dmnd Lost	Fill Rate	Rtlr Lost Sales	Rtlr Ordring	Rtlr Holding	DC Ordering	DC Holding	Total Cost
44	8	8	8	30	30	30	70	75	3319	57	0,983	1653	6630	21987	1770	22799	54839
45	8	8	8	30	30	30	70	100	3337	61	0,982	1769	6645	21885	1330	25017	56646
46	8	8	8	40	40	40	50	50	2271	1119	0,670	32451	3660	17856	1940	14972	70879
47	8	8	8	40	40	40	50	75	3377	69	0,980	2001	4995	26547	1780	17867	53190
48	8	8	8	40	40	40	50	100	2490	832	0,750	24128	3735	20272	990	19896	69022
49	8	8	8	40	40	40	60	50	2446	870	0,738	25230	3660	20027	1940	17040	67898
50	8	8	8	40	40	40	60	75	3135	298	0,913	8642	4665	24546	1650	20368	59872
51	8	8	8	40	40	40	60	100	2843	522	0,845	15138	4020	23179	1070	24196	67603
52	8	8	8	40	40	40	70	50	2616	779	0,771	22591	3930	20498	2090	17770	66878
53	8	8	8	40	40	40	70	75	3240	43	0,987	1247	4770	26565	1700	23014	57296
54	8	8	8	40	40	40	70	100	2467	868	0,740	25172	3600	19985	960	25194	74911
55	12	12	12	20	20	20	50	50	2768	608	0,820	17632	7890	17080	2100	14694	59396
56	12	12	12	20	20	20	50	75	3453	31	0,991	899	10380	20869	1840	17281	51269
57	12	12	12	20	20	20	50	100	3359	16	0,995	464	9930	20761	1320	18910	51385
58	12	12	12	20	20	20	60	50	3330	29	0,991	841	9885	20931	2630	16173	50460
59	12	12	12	20	20	20	60	75	3293	26	0,992	754	9900	20798	1760	20584	53796
60	12	12	12	20	20	20	60	100	3253	18	0,994	522	9750	21034	1300	23945	56551
61	12	12	12	20	20	20	70	50	3334	24	0,993	696	9945	20906	2650	18740	52937
62	12	12	12	20	20	20	70	75	3238	25	0,992	725	9570	21019	1700	23088	56102
63	12	12	12	20	20	20	70	100	3321	27	0,992	783	9930	20804	1330	24120	56967
64	12	12	12	30	30	30	50	50	2911	400	0,879	11600	5985	22589	2380	14467	57022
65	12	12	12	30	30	30	50	75	3268	22	0,993	638	6555	25508	1750	18866	53317

66	12	12	12	30	30	30	50	100	2267	1086	0,676	31494	4530	17319	900	21105	75349
67	12	12	12	30	30	30	60	50	3293	11	0,997	319	6600	25583	2640	15323	50465
68	12	12	12	30	30	30	60	75	3340	13	0,996	377	6675	25757	1780	18799	53389
69	12	12	12	30	30	30	60	100	3341	20	0,994	580	6600	26109	1320	22768	57377
70	12	12	12	30	30	30	70	50	3308	76	0,978	2204	6690	25364	2670	17214	54142
71	12	12	12	30	30	30	70	75	3335	17	0,995	493	6615	25728	1770	22865	57471
72	12	12	12	30	30	30	70	100	3297	21	0,994	609	6630	26024	1330	25477	60070
73	12	12	12	40	40	40	50	50	2485	855	0,744	24795	4050	22094	2150	14908	67997
74	12	12	12	40	40	40	50	75	3346	24	0,993	696	5010	30658	1780	18160	56305
75	12	12	12	40	40	40	50	100	2255	1017	0,689	29493	3345	20953	890	20475	75156
76	12	12	12	40	40	40	60	50	2236	1096	0,671	31784	2970	20642	1570	17551	74517
77	12	12	12	40	40	40	60	75	3391	29	0,992	841	4995	30332	1780	20329	58277
78	12	12	12	40	40	40	60	100	3338	12	0,996	348	5025	30887	1340	24413	62013
79	12	12	12	40	40	40	70	50	2620	644	0,803	18676	3660	24160	1940	18545	66981
80	12	12	12	40	40	40	70	75	3251	11	0,997	319	4905	30653	1750	22637	60264
81	12	12	12	40	40	40	70	100	3231	13	0,996	377	4860	30815	1300	24910	62262

9 Planning and Scheduling

Ece Yağmur and Saadettin Erhan Kesen

CONTENTS

9.1 INTRODUCTION

Planning is a key management function that helps decision-makers to set desired goals and decide on the actions required to achieve these goals. Scheduling is the lowest-level decision phase of planning in which the actions are already taken, and only the question of allocating the orders for their assignment must be answered (Rajpathak 2001). In the literature, although scheduling and sequencing concepts are often used interchangeably, scheduling encompasses both the sequencing and assignment processes. So scheduling can be defined as the problem that deals with the assignment of a limited number of resources to tasks over time to achieve the goals considered in the planning process. As seen from the definition, planning and scheduling activities are interconnected with each other and should be handled in an integrated way. However, conventionally, they are handled separately, and planning activities are structured in a hierarchical way, including strategic, tactical, and operational level plans having their own goals and restrictions according to the detailed levels of decision. In this case, when a decision made at a higher level significantly limits lower-level options, it becomes a central plan. This centralized planning may be practical only up to a certain level for specific conditions. Because the decision-maker in the planning phase does not have any predictions about resource

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availability and operational characteristics, some essential information should be communicated from scheduling to planning for better joint decisions.

Since the early 1950s, researchers have been concerned with many scheduling problems (personnel scheduling, project scheduling, timetabling, vehicle scheduling, flight scheduling, maintenance scheduling, etc.). Among these, the most frequently encountered scheduling problem is undoubtedly production scheduling. The production scheduling models are categorized according to resource configuration and the nature of the tasks (Baker and Trietsch 2013). While resource configuration indicates the machine environment, the nature of tasks depends on whether the environment is static or dynamic and whether the parameters are deterministic or stochastic. The first studies in the literature focus on pure problems, including deterministic and static models, and analyze the combinatorial solution process. The solution procedure of Johnson (1954) enabled scheduling to become an independent area within OR. An optimal schedule is guaranteed by the Johnson rule for the permutation flow-shop problem with two machines so as to minimize the makespan value. Jackson (1955) proposes a priority rule (EDD, earliest due date) for maximum lateness in a single-machine environment. Smith (1956) also addresses the single-machine scheduling and proposes a priority rule (SPT, shortest processing time) for minimizing the sum of completion time. As an exact solution method, a branch and bound procedure is implemented in the flow-shop scheduling for the first time (Lomnicki 1965) to minimize the sum of completion times.

Along with the complexity theory, scheduling problems are investigated based on their complexity, and new methods are searched to generate efficient solutions in a reasonable time for NP-hard problems. So approximation algorithms and heuristic approaches have come to the fore in recent studies. More detailed information on the development of the scheduling literature can be found in the study of Potts and Strusevich (2009). If developments both in the problem structures and solution techniques are considered, it is clearly seen that as the problem becomes more complex, state-of-the-art methods have become insufficient, and new challenges have emerged. Thus, it is inevitable that the changing conditions with the last Industrial Revolution will make a serious challenge in the scheduling literature, and it will even enforce all previously developed methods, which can no longer be applied effectively.

9.2 SCHEDULING IN INDUSTRY 4.0

9.2.1 Smart Scheduling

Industry 4.0 enables autonomous systems to be constructed by integrating information technologies with operational processes through digital conversion. The factories organized to realize this Industrial Revolution are known as smart factories. In smart factories, self-optimizing systems are created with advanced computer science concepts, including the Internet of Things (IoT), big data, and cloud computing. Each component of the autonomous system must be qualified as smart (i.e., smart machines, smart processes, smart engineering, etc.) to ensure decentralized systems. In other words, in smart factories, products and resources are arranged to know their current situations (the current stage of products, alternative resources, flows, material movements, workload, the energy consumption of resources, the failure probabilities of resources, etc.) anytime. So the process will require not only the optimization of operations in the physical production environment but also the active use of information transformation simultaneously for autonomous management. To perform these analyses at the same time, a logical connection structure should be established between products and resources. Since the concept of smart factories requires broader research, this section is limited to the scheduling activities in smart manufacturing. Although Industry 4.0 has profoundly affected the manufacturing process, the effects of this revolution on the scheduling process have not been explicitly discussed in the literature. In the production phase, many operational-level decisions are considered to ensure the whole production activities are conducted on time. So scheduling is a crucial task that plays an important role in arranging operations and processes. Traditionally, scheduling has generally focused on a single scenario under many assumptions and is configured according to the physical production environment characteristics. However, in a production system operating according to the Industry 4.0 principle, in addition to physical production itself, a virtual computing environment must also be dealt with. The whole system, in which physical and virtual components are interconnected through controllers, sensor systems, and networks, is called a cyber-physical system (CPS).

Scheduling is only in physical production environments and in CPS, of course, should be handled differently from each other. Real life consists of a dynamic environment in which customer expectations and demands are constantly changing, and unforeseen events may occur. Therefore, producing alternative solutions that adapt quickly to change in a dynamic environment is a more difficult and complex task than generating the solution under certain assumptions. In addition to this difficulty, it is very important to meet customer expectations and demands in a timely and correct manner since the competition in the global world is quite intense. According to customer-oriented production, each product will be unique and will require different processes, and in such a production environment, economies of scale cannot be mentioned. So a mass customization concept has emerged to benefit from the cost-reducing advantages of mass production while conducting customer-oriented production at the same time. This policy can only be achieved through flexible production processes with dynamically programmed resources and interchangeable tools and equipment.

Simulation technology has been one of the appealing and helpful methods used within the framework of Industry 4.0. Simulation enables decision-makers to mimic and evaluate the performance of complicated processes without disrupting them before implementation. Thus, different scenarios can be tested against particular performance criteria with no implementation cost. The data obtained by the simulation model are also used to establish relationships between dependent and independent variables. Therefore, reliable outcomes of the performance criteria can be obtained based on varying combinations of input levels through the simulation model. As can be seen in Figure 9.1, simulation has different application areas in Industry 4.0.

Discrete event simulation (DES) is used for modeling real-world systems as a sequence of events in time. In this way, the dynamic behavior of the system can be modeled easily, and different methods can be analyzed without breaking the existing

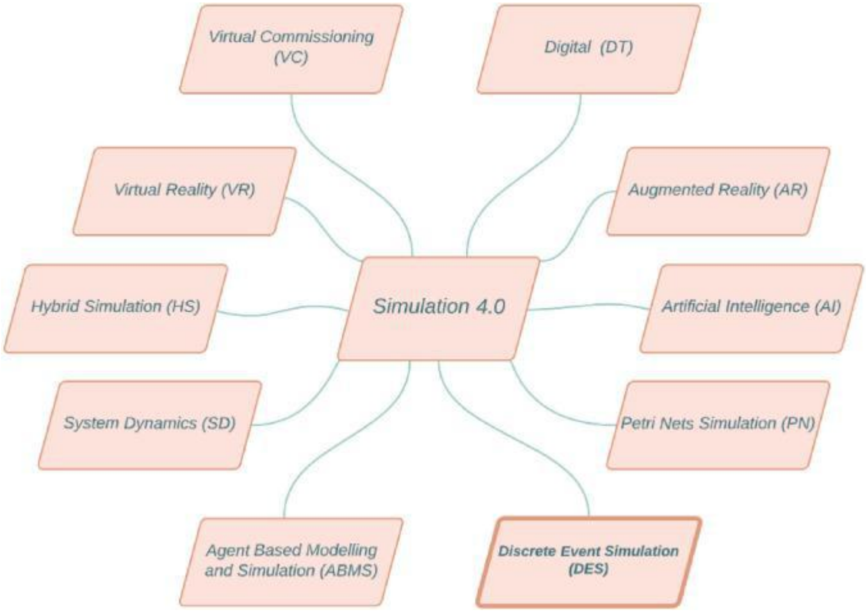

FIGURE 9.1 Simulation-based approaches applied in the context of Industry 4.0. (de Paula Ferreira et al. 2020)

system. DES models include the variability, interactions, and dependencies of the real system. This provides a clear perspective to the decision-maker and enables the systems to be managed effectively.

Siemens is one of the world's leading companies that implement Industry 4.0 to a large extent and offers technological solutions both in its factories and to other companies. The most striking of these technologies is Tecnomatix® Plant Simulation, which has been developed to improve system performance. Another interesting feature of this program is that it optimizes energy consumption and enables showing current, maximum, and total energy consumption dynamically, as seen in Figure 9.2. Based on these technological applications to build a smart production platform, in this study, we consider a manufacturing system where real-time data can be accessed with sensors and show CPS features are investigated. We will also make use of DES, and the details of which are given in Chapter 8.5.

9.2.2 Related Literature

Although the concept of Industry 4.0 is still an alien term for many companies today, it has vital importance for businesses to yield flexible and dynamic solutions due to developing technology and the pressure of competition; thus, it is also quite a new research topic from an academic point of view. The literature investigating the scheduling activities in smart manufacturing can be summarized as follows: Kück

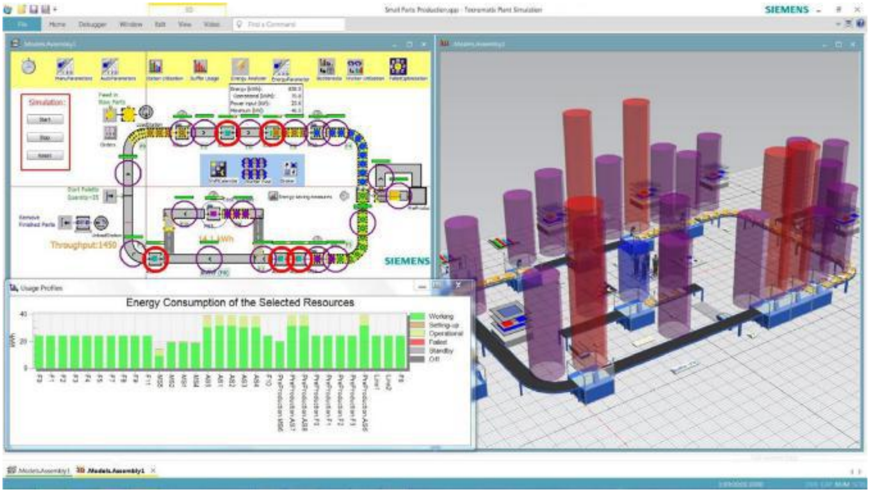

FIGURE 9.2 An overview of plant simulation developed by Siemens. (www.plm.automation.siemens.com/)

et al. (2016) cope with a dynamic manufacturing system and propose a two-phased optimization approach. While in the first phase, a schedule is generated by the simulation-based optimization approach, in the second phase, the simulation model is continuously updated according to the feedback from the CPS. Waschneck et al. (2016) develop a model for simultaneously designing the manufacturing process regarding available alternative stations. The problem can be considered as a multi-stage job shop scheduling problem on alternative machines with different time-dependent processing times and time-dependent machine availability. In the study of Yang and Takakuwa (2017), a simulation-based model for single-machine scheduling is proposed, and a manufacturing execution system (MES) is used as a cyber system to provide real-time data for the dynamic problem. Zaayman and Innamorato (2017) evaluate the application of Simio (an object-oriented simulation system) for digital manufacturing systems. Fu et al. (2018) examine a flow-shop scheduling problem with time-dependent processing time to minimize the makespan and total tardiness. Because of the learning effect and deterioration, processing time has a stochastic structure, so the actual processing time of each job depends on its starting time and position in the schedule. Leusin et al. (2018) investigate a multi-agent model for a dynamic job shop scheduling problem in a real case in the automotive industry. The integration of scheduling functions with the ERP system is carried out by the Preactor software providing forecasting data. Daniel Alejandro Rossit et al. (2019) address smart scheduling and propose a new decision-making mechanism, including tolerance scheduling. According to this approach, an initial schedule is generated, and then, the tolerance scheduling problem is solved to determine tolerances that allow changes that do not significantly affect the system. If the change is within tolerances, the current production process continues; otherwise, the rescheduling procedure starts, and a new schedule is generated with new tolerances. Turker et al. (2019) propose a decision support system to increase the performance of dispatching rules in dynamic scheduling. According to the proposed simulation model, if the number of jobs waiting in the queue of any workstation falls to a critical value, schedules on preceding workstations can be updated to feed this workstation. Zhang et al. (2019) examine the flexible job shop scheduling problem in a smart factory and propose a solution methodology that can be performed step-by-step based on smart agents. Ghaleb et al. (2020) develop real-time scheduling models considering unexpected job arrivals and machine breakdowns, and investigate the impact of real-time information on the rescheduling process. Ivanov et al. (2020) examine innovative strategies by emphasizing the challenge of creating products and processes simultaneously in Industry 4.0 era. Kocsi et al. (2020) propose a decision support system comprising a hybrid of the mixed-integer programming (MIP) model, the simulation model, and the genetic algorithm for the objective of minimizing the makespan. According to the results, rescheduling time decreases by more than 50% with more than 90% accuracy. Parente et al. (2020) review the literature on production scheduling in the Industry 4.0 environment and underline the advantages and challenges of implementing smartness. Ramadan et al. (2020) introduce a dispatching model for a flexible job shop problem with real-time data. Shukla et al. (2020) address an energy-efficient scheduling problem with real-time data in which the uncertain timing constraints are modeled with type-2 fuzzy logic. Grassi et al. (2021) propose a decentralized scheduling approach for the cloud manufacturing environment, addressing the disadvantages of centralized production planning and inventory control. They propose a simulation model to evaluate two different dispatching rules. Jiang et al. (2021) assess the evolution of the scheduling approach from the Industry 3.0 to the Industry 4.0 revolution. They examine the development stages of cloud manufacturing scheduling in detail and provide the reader with a broad perspective on the change and development of scheduling activities. Kumar et al. (2021) use fuzzy logic for selecting jobs based on a multicriteria approach to overcome the breakdown of the machine and unexpected arrival of products. According to the Fourth Industrial Revolution, each product can be considered unique because of intensive customization and has a different use of a resource, which generally results in variable processing times. Thus, at least one of the resources in the production cell may not be used and missing. Rossit et al. (2021) consider a permutation flow-shop scheduling problem in a manufacturing cell with missing operations.

9.3 SUSTAINABLE ACTIVITIES IN SCHEDULING

Today, when natural resources are consumed rapidly and unconsciously, we must take strict responsibilities to leave a sustainable life for future generations. Individual contributions are, of course, important, but considering the rapid depletion of scarce resources, industrial factories that have the greatest impact on the environment and economy should be considered first. The impact of the Fourth Industrial Revolution on economic, environmental, and social sustainability is quite a new research topic. Due to the very limited number of companies that fully implement the Industry 4.0 principle, smart factories have been examined in a relatively general structure, and quantitative data could not be presented in the literature. Müller et al. (2018) investigate the opportunities and challenges of Industry 4.0 implementation in terms of sustainability in five different industrial sectors.

Sustainable manufacturing aims to minimize the negative impacts of the production process on the environment through conserving energy and natural resources. For this purpose, all levels in the manufacturing process, from designing to planning and control, must be carried out by the principles of sustainability. Since the concept of sustainability is a new issue for both traditional and smart manufacturing processes, a production system that addresses all three dimensions of sustainability has not yet been handled enough according to the Industry 4.0 principle. But it is clear that smart manufacturing performs better recycling and reuse processes by the effective use of information technologies. While sustainability activities are carried out, all three dimensions should be considered for evaluating performance criteria; otherwise, undesirable results may occur. For example, the use of autonomous robots can reduce the workload of workers, but from a social perspective, it can also reduce the need for labor. Another point that is worth mentioning is that Industry 4.0 will reduce the high operational costs in the production process, but in this case, high installation costs will also be born for the use of advanced technology (Kamble et al. 2018). In this respect, studies that evaluate the advantages and disadvantages together and compare the output of the traditional approach and smart approach will be more valuable, especially for factories that are unwilling to implement the basic principles of Industry 4.0.

9.4 CASE STUDY

Based on these technological applications to build a smart production platform, we consider a manufacturing system where real-time data can be accessed with sensors and show CPS features are investigated. The CPS examined consists of an AGV (automated guided vehicle) system, which is commonly used with an edge computing device in smart factories. AGVs are defined as battery-driven industrial trucks with contactless steering (Müller 1983). These computer-controlled, wheel-based vehicles are utilized in many areas.

As seen in Figure 9.3, we handle an AGV system for work-in-process movement in a job shop environment. In the system, we also take better data management advantages of edge computing. Edge computing is a distributed network that makes closer cloud computing applications and data generation sources (i.e., IoT devices). It enables IoT sensors to monitor machines with low latencies and perform real analytics in real time. To take full advantage of this capability, a simulation model is used to create a virtual copy of the physical system. As seen in Figure 9.3, wireless sensor networks are used by the control console for data monitoring, output prediction, and optimization of production processes.

9.4.1 General Description of an AGV System

The AGV system transfers parts through a system. There are five different parts produced in the system, and each of them arrives at the receiving area according

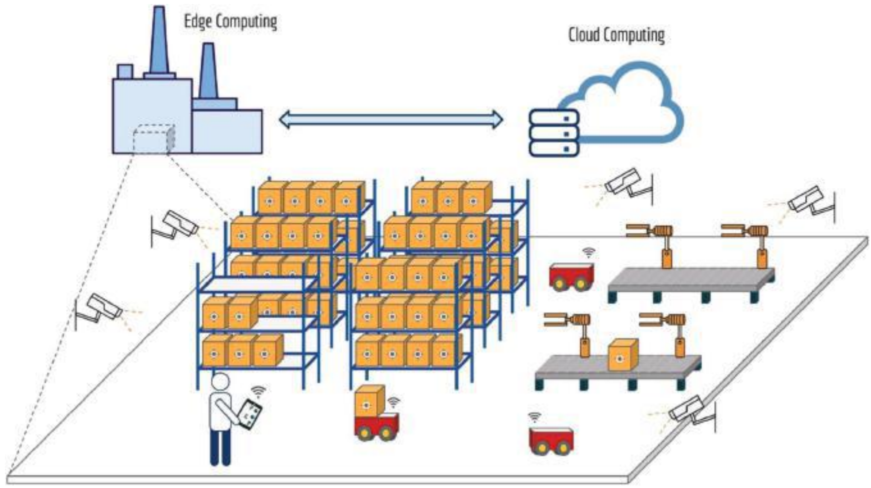

FIGURE 9.3 Edge computing–based manufacturing in Industry 4.0. (do Carmo et al. 2019)

TABLE 9.1
Job Shop Environment

Part	Route
1	Milling, drilling, planing, painting, inspecting
2	Milling, turning, drilling, planing, sawing, painting, inspecting
3	Turning, drilling, planing, painting, inspecting
4	Turning, drilling, planing, sawing, painting, inspecting
5	Milling, pressing, milling, turning, drilling, planing, painting, inspecting

to an exponential distribution with a mean of ten minutes, with equal probability (i.e., 0.2). Each part is processed according to an arbitrary sequence (i.e., job shop), which is given in Table 9.1, and each operation has at least one alternative machine to be processed except for pressing, sawing, and inspecting station (i.e., flexible job shop), as seen in Figure 9.4. There is unlimited storage capacity in front of each station.

Alternative machines in any station have different characteristics in terms of power and speed, as seen in Table 9.2. It would not be wrong to say that as the performance (i.e., speed) of machines increases, the amount of energy consumption will also increase. The processing time is set to 80, 90, 100, 110, and 120 minutes for Part 1, 2, 3, 4, and 5, respectively, for 1 unit speed. So the actual duration time of each machine is calculated by the processing time divided by the predefined speed of the assigned machine.

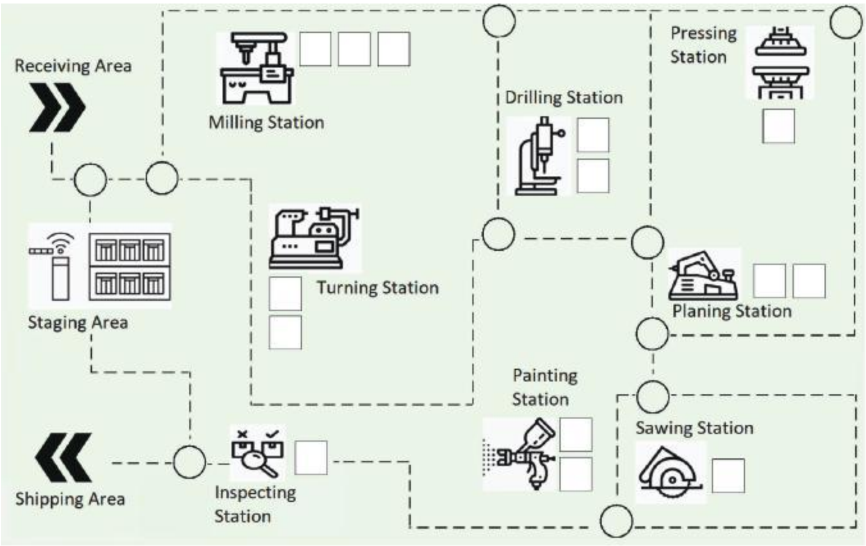

FIGURE 9.4 Facility layout of the AGV model.

TABLE 9.2
Resources Environment

Station	Number of Machines	Energy	Speed
Milling	3	10, 15, 20	2, 4, 6
Turning	2	16, 24	5, 10
Drilling	2	12, 15	4, 6
Planing	2	15	5
Pressing	1	18, 24	4, 8
Sawing	1	20	8
Painting	2	15, 20	4, 6
Inspecting	1	25	10

After the operation at the last machine (i.e., inspecting) is completed, each part leaves the system by any available AGV. All the arcs in the AGV system are bidirectional, and each of the distances between the stations is given in Figure 9.5.

In addition, each part has a predefined due date dd_i, which is determined by the following equation, where a_i and $MTPT$ represent the arrival time and mean total processing time of part i, respectively.

$$dd_i = a_i + \left(MTPT \times allowance\_factor\right) \tag{9.1}$$

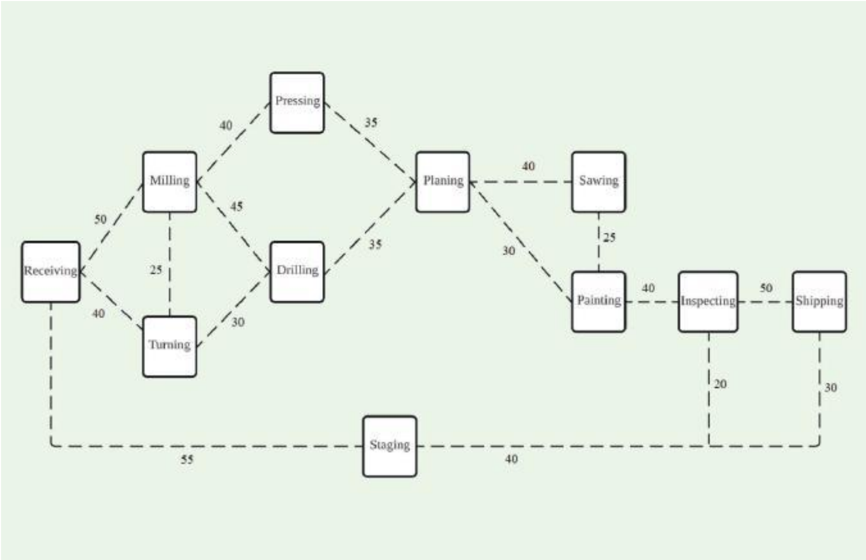

FIGURE 9.5 Network of an AGV model.

9.4.2 Experimental Design

We define performance criteria in three categories; two of which are related to sustainability aspects, and one of which is related to customer-oriented measurement as follows:

- Environmental sustainability criteria: total energy consumption
- Economic sustainability criteria: utilization of AGVs, and the total number of completed parts and average flow times of parts
- Service-level criteria: total tardiness

So we define five performance criteria, which are considered dependent variables, to evaluate different scenarios.

As seen in Table 9.3, we define $81(3\times3\times3\times3)$ factor combination, each of which is simulated three times. For statistical analyses, the average values of each performance measure are considered. In a full factorial design, we would like to see the main and interaction effects of the following factors:

- For the allowance factor used in equation 9.1, we define three levels as tight, medium, and wide. The allowance factor is uniformly distributed with parameters $U(0.75,1.5)$, $U(1.5,2.25)$, and $U(2.25,3)$ for tight, medium, and wide levels, respectively.
- For the scheduling rule (or dispatching rule), which prioritizes all the jobs that are waiting for processing on each resource, we use three different rules, which are selected according to the dependent variables. According to EDD

TABLE 9.3
Factor Levels

Factor	Level 1	Level 2	Level 3
Allowance factor of the due date	Tight	Medium	Wide
Scheduling rule	EDD	STR	CR
Machine selection rule	Min power	Max speed	CYC
Number of AGVs	3	4	5

(earliest due date) rule, the order having the earliest due date is selected first. According to the STR (slack time remaining) rule, the order having the least slack time remaining, calculated by equation 9.2, is selected first, where t represents the current simulation time.

$$STR_i = dd_i - MTPT_i - t \tag{9.2}$$

And finally, according to the CR rule, the order having the least CR, calculated by equation 9.3, is selected first.

$$CR_i = \left(dd_i - t\right) / MTPT_i \tag{9.3}$$

- For the machine selection rule, we define three levels as maximum speed, minimum energy, and cyclical rule, which ensures using all machines equally as possible to reduce machine failure.

- Finally, we want to see how the number of AGVs affects the performance measures and define three numbers of AGV levels as 3, 4, and 5.

We give a warm-up period of 1.000 min for the system to reach steady-state behavior. After 1.000 min, we allow 4.320 min to terminate the simulation with 3 runs, which is sufficiently long to compensate for the adverse effect of initial bias that would occur. Output values obtained with three runs are analyzed statistically. Statistical tests regarding main and interaction factor effects are conducted by using MANOVA (multivariate analysis of variance). The significance level (α) is set to be 0.10 for all tests.

9.5 EXPERIMENTAL RESULTS

In this section, we interpret the simulation results and integrate the inferences obtained from the cyber system into the physical system. Because of the large experimental factor combinations, in the following subsections, only the factors with a statistically significant effect on each performance measure are given.

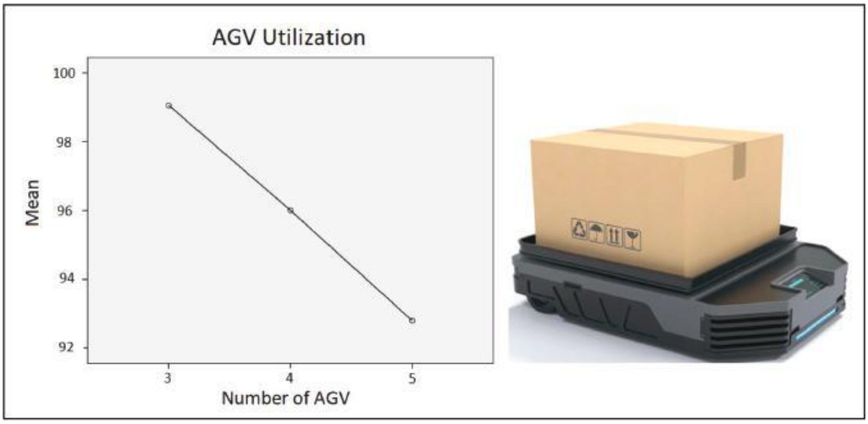

FIGURE 9.6 Statistical plot for AGV utilization.

9.5.1 AGV Utilization

According to current Internet sources (www.agvnetwork.com), AGV costs may differ depending on the AGV types, starting from $14.000 for an AGC (automated guided cart), near $30.000 for a towing tractor, $60.000 for an automated pallet jack, around $80.000 for a forklift AGV, and $150.000 for an automated VNA (vector network analyzer). Increasing the number of AGVs did not have a statistically significant effect on the number of completed parts in the system. As seen in Figure 9.6, with the increase in the number of AGVs, naturally, the utilization rate of AGVs decreased. After the AGV completes its mission, it returns to the staging area each time until it is called to the next mission location. Therefore, the utilization rate of AGVs did not decrease very seriously even though the number of AGVs increased. Considering the installation cost of AGVs, three AGVs will be enough for this production environment.

9.5.2 Total Tardiness

One of the objectives of the decision-maker is to minimize total tardiness that might result in late deliveries. Today, many businesses aim to increase service quality as their primary goal while at the same time reducing their cost due to increasing competition. According to this approach, schedules are generated considering the due dates determined by the customers. Naturally, schedules can be prepared more flexibly if the pre-determined due date is wider. For example, other important orders (e.g., which have closer due dates or perishable products) can be scheduled before these orders. When we analyze Figure 9.7, as expected, the total tardiness value decreased as the due date level went from tight to wide.

Another factor that has a significant effect on total tardiness is the scheduling rule. According to Figure 9.7, the total tardiness value is found to be minimum for the STR rule. STR rule is used if the mean total processing time of part i is relatively larger

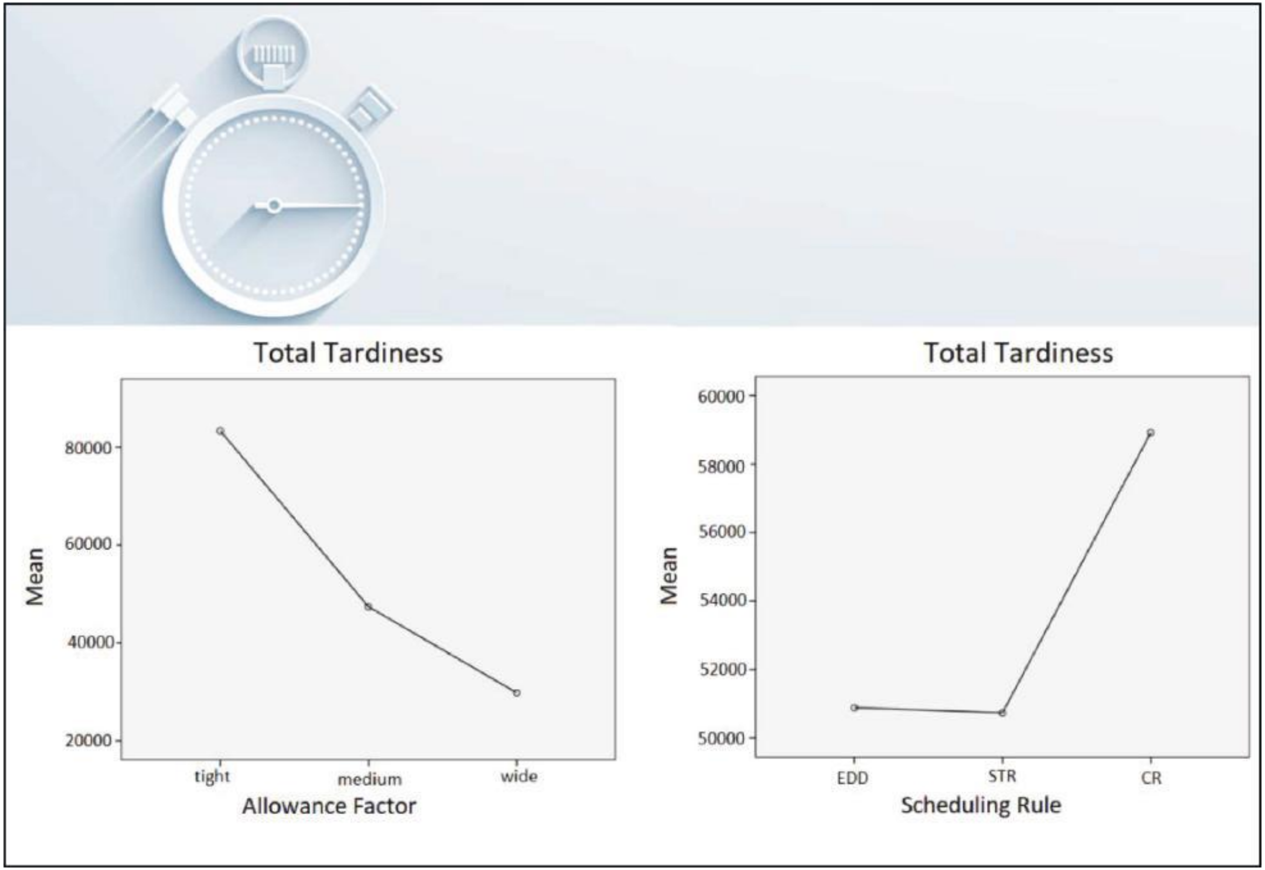

FIGURE 9.7 Statistical plots for total tardiness.

than the due date of order i (Kesen and Sert 2020). Similarly, the EDD rule produces a better total tardiness value than the CR rule.

9.5.3 Total Energy Consumption

As mentioned before, there are alternative machines that can perform the same process in the production environment. However, the production speed and power consumption of the machines are different from each other. If we want to minimize the total tardiness value, it may be logical to select an alternative machine with high speed. However, the machine selection rule has not a statistically significant effect on total tardiness. According to Figure 9.8, it has been observed that the machine selection rule has a significant effect on the total energy consumption, and the highest consumption is observed when high-speed machines are preferred. However, how true is it that low-power machines are always preferred to reduce energy consumption or, vice versa, high-speed machines are always preferred to increase customer satisfaction? In this case, machine failure problems may be encountered depending on the use of the same machines. Therefore, the cyclical selection rule would also be a preferable option for decision-maker.

9.5.4 Average Flow Time of Parts

In this section, the average flow time for a randomly selected part is evaluated. According to statistical results, both the scheduling rule and the number of AGVs have a significantly important effect on the average flow time of Part 4. Depending on the increasing number of AGVs, a decrease in the flow time is observed. Besides, the STR rule is the best rule in terms of the average flow time of Part 4.

9.5.5 Total Number of Parts

The most interesting of the inferences is that no factor has a direct effect on the total number of parts produced in three days. When we analyze the AGV and machine utilization rates, they are found to be quite high for the whole experimental set; that is, there is no idle time in the system to increase the throughput. The reason why the number of AGVs has a statistically significant effect on the flow time (as seen in the previous subsection) but not on the number of completed parts can be explained by the return of AGVs to the staging area when they are discharged. From the throughput point of view, this may seem inefficient and different options (e.g., AGVs stay at the last station they were assigned to instead of going to the staging area) may be presented to the decision-maker.

9.6 CONCLUSIONS AND FUTURE DIRECTIONS

Planning and scheduling are key functions of the manufacturing process. While performing these functions effectively has been already difficult in the traditional sense, it has become more complex with the last Industrial Revolution. In order to overcome this difficulty, it would be useful to emphasize some solution approaches that

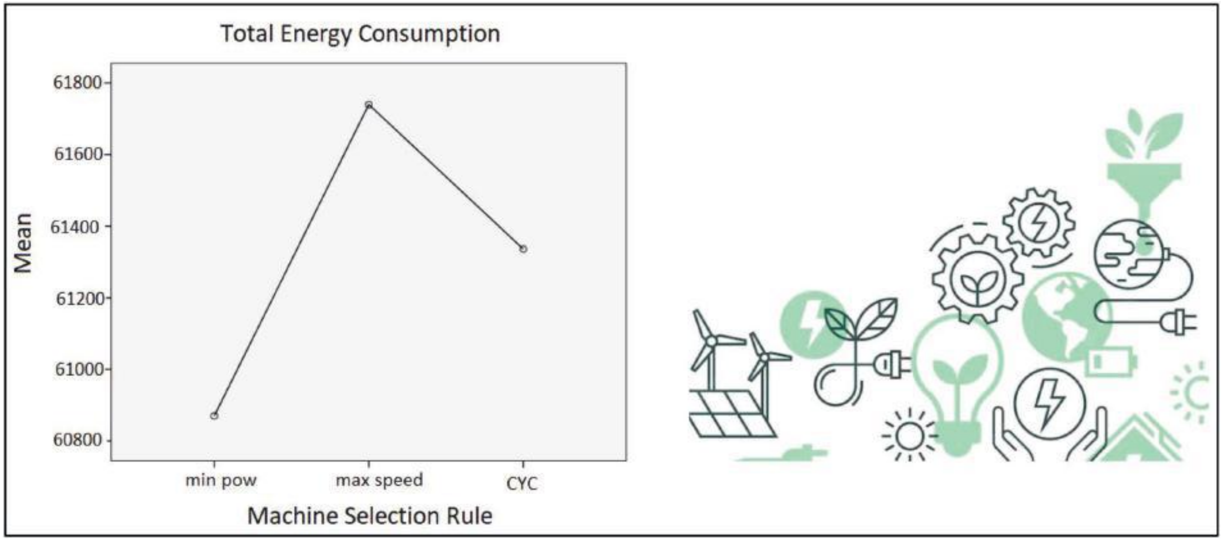

FIGURE 9.8 Statistical plot for total energy consumption.

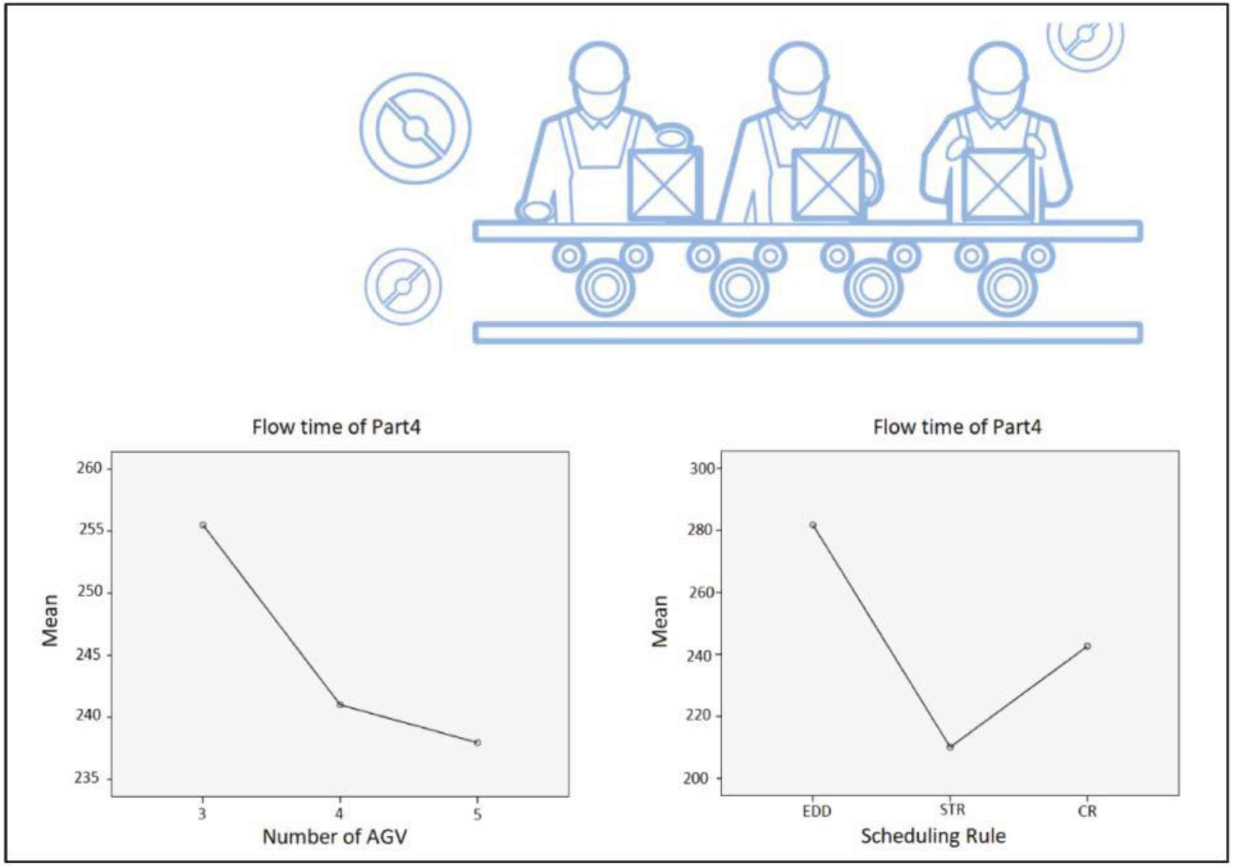

FIGURE 9.9 Statistical plots for average flow time.

emerged with the Industry 4.0 revolution. One of the most popular approaches, especially considering the dynamic nature of the system, is discrete system simulation.

In the study, instead of static scheduling models limited by a large number of assumptions, a decision-making mechanism in accordance with Industry 4.0 principles has been proposed by using the power of simulation to compare different scenario analyses in CBS. In this way, a less costly and more flexible production scheduling approach has been adopted.

The flexible job shop production environment in which AGVs are involved in the transportation of parts is handled as a case study. For the production environment, the effects of different factor levels on outputs have been investigated with the use of simulation and statistical analyses. So the decision-maker will be able to see these effects without needing to make any changes to the physical system, and the costs of trying the new system are eliminated. Energy consumption of machines has also been considered within the framework of the sustainability principle.

Since the number of studies in which scheduling activities are carried out within the framework of smart factories is limited in literature, it is hoped that the study will provide a new perspective for readers.

In further research, the OptQuest software can be integrated into a scenario analysis to determine optimal factor levels for dependent variables. Besides, different scenarios can be suggested for the problem of AGVs returning to the staging area.

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10 MRP and ERP

Birsen İrem Selamoğlu

CONTENTS

10.1 INTRODUCTION

Increasing competition in the digital age forces companies to find ways to rapidly adapt to digital and technological changes. Industry 4.0 technologies connect smart objects and equipment in production systems. These smart systems make it possible to collect data in real time, use it instantly and make decisions accordingly.

The increase in production volume with these developing technologies and global warming have revealed the responsibility issue in terms of natural resources. For this reason, the concept of sustainability has emerged in addition to technology, and the aimed is to make business processes sustainable. Business enterprises have to consider sustainability in their business functions. This reveals the necessity of evaluating all processes in terms of economic, environmental and social aspects. One of the processes related to business enterprises is material requirements planning and enterprise resource planning.

In this chapter, smart and sustainable material requirements planning systems and enterprise resource planning systems are discussed, and a smart and sustainable MRP framework is proposed.

10.2 THE EVOLUTION OF MANUFACTURING PLANNING AND CONTROL SYSTEMS

In the 1960s, the main target of manufacturing companies was minimising cost and producing a high volume of products. Computer-based inventory control systems (ICs) were developed to fulfil many companies' basic manufacturing and planning

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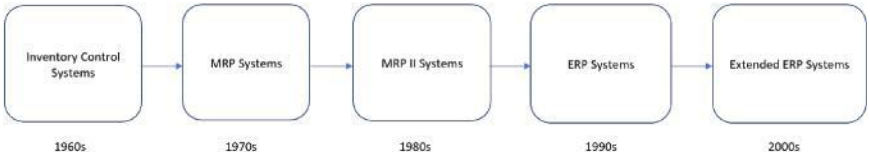

FIGURE 10.1 Evolution of ERP.

needs. ICs were used until the mid-1960s. Thanks to these systems, economic order quantity and economic reorder point were automatically computed (Jacobs and 'Ted' Weston 2007; Olhager 2013). However, these reorder point systems were costly, and large technical staff was needed in order to support big mainframe computer environments (Katuu 2020).

Since basic reorder point systems fell short of meeting the needs of manufacturing companies, material requirements planning (MRP) systems were developed in the mid-1960s (Rondeau and Litteral 2001). Marketing gained prominence in the 1970s. Companies focused on finding the best marketing strategies. They also needed more integrated systems for production planning. Hence, MRP systems were rapidly adopted as they offered more sophisticated approaches for ordering inventory and manufacturing planning (Jacobs and 'Ted' Weston 2007). They were developed in a way so that they could integrate certain functions, such as forecasting, master production planning, production planning and inventory control (Demir, Paksoy and Kochan 2020).

In the 1980s, quality gained importance, and companies focused on achieving high-quality manufacturing. While increasing the quality of manufacturing, companies also tried to diminish overhead costs. In response to the needs of the companies, manufacturing resource planning (MRP II) systems were developed. Compared to MRP, MRP II systems integrate additional modules, such as financial planning and capacity planning, along with production and inventory planning (Demir, Paksoy and Kochan 2020).

Enterprise resource planning (ERP) systems were introduced in the 1990s. They integrated various business functions, such as manufacturing planning, financial planning, project management, transportation and marketing (Katuu 2020).

In the 2000s, the term "ERP II" emerged. It includes an integrated structure that consists of customer relationship management (CRM), supply chain management (SCM), business intelligence (BI) and the Internet (McGaughey and Gunasekaran 2007). The evolution of ERP is depicted in Figure 10.1.

10.2.1 Material Requirements Planning (MRP)

Material requirements planning (MRP) is a computer-based system that is concerned with inventory planning and control. It determines the number of components and materials to be ordered or produced and ensures that they are on hand when needed. The MRP system is shown in Figure 10.2.

Demand for finished goods is called independent demand, and demand for the components of the end products is said to be dependent demand. MRP systems deal

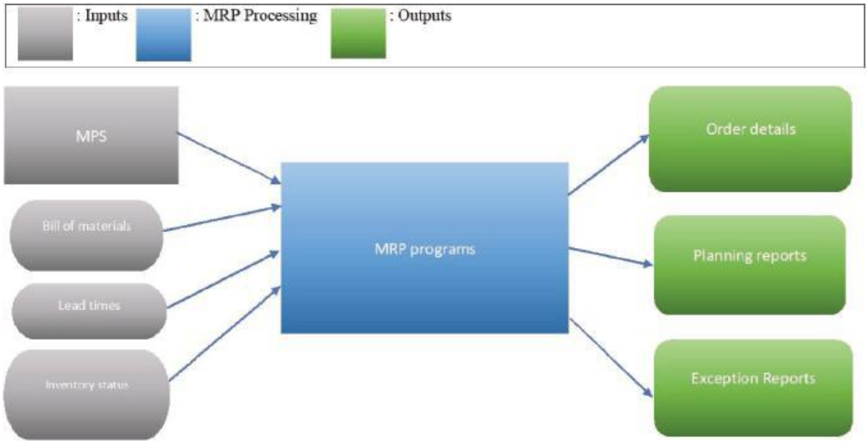

FIGURE 10.2 MRP system. (Adapted from Stevenson 2020)

with dependent demand. Master production schedule (MPS), bill of materials, inventory status, planning order releases and lead times are the inputs of an MRP system (Heizer, Render and Munson 2017).

An MPS outlines the number of finished goods to be produced and when they need to be ready. The MPS is prepared in accordance with an aggregate plan. The aggregate plan shows the total demand for a certain product family, whereas the MPS is prepared based on each product's demand that belongs to the corresponding product family.

A bill of material (BOM) is a list that contains information regarding the components required to produce a finished item. A bill of material depicts a product structure and starts with Level 0, indicating an end product. BOM can be visualised by using a product structure tree. If a component is to be used at more than one level, it is placed on the lowest level where it is used. This system is known as low-level coding (Stevenson 2020).

10.2.1.1 Example 10.1

Suppose a company produces an item, *I*. Three *B*s and two *C*s are required in order to produce one single item, *I*. Each *B* consists of one *D* and two *E*s, and each *C* has three *E*s and two *F*s. Each *F* has four *G*s. The product structure tree of item *I* is shown in Figure 10.3.

Suppose this company has a new order of ten *I*s. Given the preceding information, we can determine the required quantities of *B*, *C*, *D*, *E*, *F* and *G* to produce ten *I*s. Calculations to find the required quantities are given in equations 10.1–10.6:

$$\mathrm{B}: 3 \times 10 = 30 \tag{10.1}$$
$$\mathrm{C}: 2 \times 10 = 20 \tag{10.2}$$
$$\mathrm{D}: 1 \times 30 = 30 \tag{10.3}$$

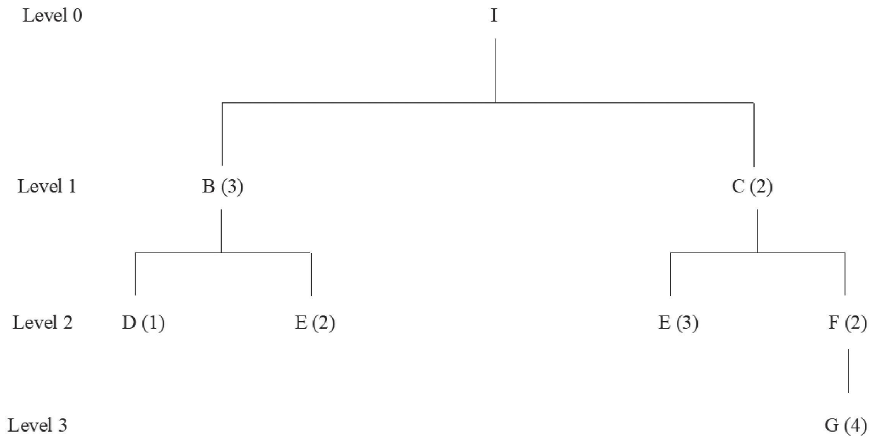

FIGURE 10.3 The product structure tree of item *I*.

$$E:(2\times 30)+(3\times 20)=120\,(\text{Note that E is required for both B and C.}) \quad (10.4)$$

$$F:2\times 20=40 \quad (10.5)$$

$$G:4\times 40=160 \quad (10.6)$$

The inventory records give information about all items on hand and pre-ordered items. It is crucial to know what is in stock, as while computing the net requirement of a component, the amount that is already in stock will be extracted from the gross item requirement. In this way, it becomes easier to determine the total number of components that needs to be ordered or produced. Once the order quantity is determined, the order is placed, considering the lead time.

10.2.1.2 Example 10.2

Using the information given in Example 10.1, determine the required quantities of *B*, *C*, *D*, *E*, *F* and *G* to produce ten *I*s, when the company has some of the components in stock. The quantities on hand are given in Table 10.1.

TABLE 10.1
Components and the Number of Units in Inventory

Component	In Inventory
B	10
C	10
D	20
E	40
F	5
G	30

TABLE 10.2
The Required Number of Units of Each Component

Component	Required No. of Units
B	20
C	10
D	0
E	30
F	15
G	30

The required number of each component is computed as in equations 10.7–10.18:

$$\mathrm{B}: 3 \times 10 = 30 \tag{10.7}$$
$$30 - 10 = 20 \tag{10.8}$$

Thirty *B*s are needed to produce ten *I*s. However, the company has ten *B*s in stock.

Therefore, by extracting the amount in hand (30 − 10 = 20), it is found that 20 *B*s are needed.

$$\mathrm{C}: 2 \times 10 = 20 \tag{10.9}$$
$$20 - 10 = 10 \tag{10.10}$$

Twenty *C*s are needed to produce ten *I*s. However, the company has ten *C*s in stock.

Therefore, by extracting the amount in hand (20 − 10 = 10), it is found that ten *C*s are required.

$$\mathrm{D}: 1 \times 20 = 20 \tag{10.11}$$
$$20 - 20 = 0 \tag{10.12}$$
$$\mathrm{E}: \left(2 \times 20\right) + \left(3 \times 10\right) = 70 \tag{10.13}$$
$$70 - 40 = 30 \tag{10.14}$$
$$\mathrm{F}: 2 \times 10 = 20 \tag{10.15}$$
$$20 - 5 = 15 \tag{10.16}$$
$$\mathrm{G}: 4 \times 15 = 60 \tag{10.17}$$
$$60 - 30 = 30 \tag{10.18}$$

The required number of units of each component is given in Table 10.2.

Lead time is the amount of time between placing orders for components or products to be purchased and receiving these orders. Duration of preparation, processing and transportation are included in the procurement period. Since procurement time is one of the fundamental inputs of MRP, the correct computation of this period will affect the accuracy of the MRP system.

10.2.1.3 Example 10.3

A master production schedule for item *I* is demonstrated in Table 10.3.

The lead times of each component and the number of components on hand are shown in Table 10.4 and Table 10.5, respectively. There is no lead time for item *I*.

Using the information given earlier, prepare an MRP schedule for item *I*.

The MRP sheet for the components of *I* is given in Table 10.6. The gross requirements line of an MRP sheet provides information about the required amount of a component. This amount is determined by considering the planned-order releases of the corresponding component's one level above items, which also must be its parent items (Stevenson 2020). Sixty units of *B*s and 30 units of *B*s are needed in week 4 and week 8, respectively. Since item *I* has no lead time, *B*s and *C*s do not need to be ready

TABLE 10.3
Master Production Schedule for Item *I*

Weeks	1	2	3	4	5	6	7	8
Item *I*				20				10

TABLE 10.4
The Number of Components in Stock

Component	In Inventory
B	70
C	50
D	0
E	25
F	20
G	0

TABLE 10.5
Lead Times of Components

Component	Lead Time (in Weeks)
B	1
C	1
D	2
E	3
F	3
G	2

TABLE 10.6
MRP Sheet for Components of Item *I*

Item: B
Description:

Safety stock: -	**Period (weeks)**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lot size:	**Gross requirements**					60				30
L4L	**Scheduled receipts**									
Lead time: 1	**On hand**	**70**	70	70	70	10	10	10	10	10
	Net requirements									20
	Planned order receipts									20
	Planned order releases								20	

Item: C
Description:

Safety stock: -	**Period (weeks)**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lot size:	**Gross requirements**					40				20
L4L	**Scheduled receipts**									
Lead time: 1	**On hand**	**50**	50	50	50	10	10	10	10	10
	Net requirements									10
	Planned order receipts									10
	Planned order releases								10	

Item: D
Description:

Safety stock: -	**Period (weeks)**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lot size:	**Gross requirements**								20	
L4L	**Scheduled receipts**									
Lead time: 2	**On hand**	**0**								
	Net requirements								20	
	Planned order receipts								20	
	Planned order releases						20			

Item: E
Description:

Safety stock: -	**Period (weeks)**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lot size:	**Gross requirements**								70	
L4L	**Scheduled receipts**									
Lead time: 3	**On hand**	**25**	25	25	25	25	25	25	25	0
	Net requirements								45	
	Planned order receipts								45	
	Planned order releases					45				

Item: F
Description:

Safety stock: -	**Period (weeks)**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lot size:	**Gross requirements**								20	
L4L	**Scheduled receipts**									
Lead time: 3	**On hand**	**20**	20	20	20	20	20	20	0	0
	Net requirements									
	Planned order receipts									
	Planned order releases									

in earlier periods. Scheduled receipts show the record of orders placed before the MRP sheet of an item is prepared. If there are items in stock, they are displayed in the corresponding line of the MRP sheet. This amount needs to be updated if a scheduled receipt is expected to be received in a specific period. It is easily calculated by adding the new incoming amount to the current one. Likewise, the amount on hand is calculated and updated accordingly, considering the gross requirements, net requirements and planned order receipts (Stevenson 2020). Net requirements give information regarding the exact amount required in each period. For instance, 30 *B*s are needed in week 8, and there are 10 *B*s in inventory. With this information, the net requirement is found to be 20 (30 − 10 = 20). Planned order releases provide information on when an order will be placed based on lead time. The arrival time of an order is displayed in the planned order receipts line. The net requirement for *B* is 20 at the beginning of week 8. However, since the lead time for *B* is given as one week, the order is to be placed in week 7. Hence, it will be ready in stock by week 8. In this example, there is no safety stock held in the inventory. In order to avoid stock shortages, it is essential to keep safety stock when uncertainties occur in demand and supply.

It is crucial for a company to decide when and how much to order or to produce. Companies use various lot-sizing plans. As they aim to minimise the total cost, the decision is made accordingly. In Example 10.3, the lot-for-lot (L4L) technique is used. This technique ensures that the net required amount is provided when an order is placed. Another technique is called fixed-order quantity ordering. This approach assures that a predetermined number of quantities is supplied each time, regardless of the net requirement. The fixed-order period model guarantees that the net requirements for a pre-set number of periods are covered each time. In addition to the plans earlier, economic order quantity models are also used to find lot sizes (Heizer, Render and Munson 2017).

According to the product structure tree of item *I*, to produce one *B*, one *D* is required. As the net requirements are 20 units of *B* at the beginning of week 7, 20 *D*s must be ready by week 7. Since there is a two-week lead time for item *D*, the order must be placed in week 5.

Item *E* comes under both *B* and *C* in the product structure tree. Thus, its gross requirements are calculated taking into account the planned order releases of both *B* and *C*.

Since gross requirements for *F* are equal to the amount in the inventory, there will be no planned order releases. Furthermore, according to the product structure tree, *F* is the only parent component of *G*. Hence, there is no need for item *G*.

10.2.2 Manufacturing Resource Planning (MRP II)

Manufacturing resource planning, also known as MRP II, is an extension of MRP. When companies realised that the classical MRP system was insufficient, they sought new ways to improve it further. There was no mechanism to verify whether a company had enough capacity to meet demand. In other words, companies did not take into account the capacity requirements needed to complete the plan successfully. In order to cope with this issue, a feedback loop system called closed-loop MRP has emerged (Stevenson 2020).

MRP II is an extended version of the classical MRP that also uses the principle of the closed-loop MRP. MRP II uses the list of components required to produce one unit of product and the details of the resources needed to make that product, such as workload, tool, machinery (Cieśla and Gunia 2019). Unlike MRP, thanks to the feedback loop, MRP II provides control of the availability of resources required for production.

The primary goal of MRP II is to link a company's functions, such as production, marketing, finance, personnel and purchasing, to the scheduling process to enhance the performance of the manufacturing company (Shehab, Sharp, Supramaniam and Spedding 2004). In this way, it becomes possible for various departments to follow up on all resources during the production process, promptly detect any problems and take action accordingly.

10.2.3 Enterprise Resource Planning (ERP)

ERP is a system that integrates all business functions, such as manufacturing, marketing, finance, purchasing, customer relations, human resources, in an enterprise. ERP uses a database where all the data is gathered. Thanks to this integrated system, the data can be accessed by various departments of the enterprise in real time. SAP is one of the well-known vendors of ERP software.

MRP II deals with the internal resources of an enterprise. However, as an extension of MRP II, ERP encompasses what MRP II does and aims to schedule and control supplier resources considering dynamic customer orders (Shehab, Sharp, Supramaniam and Spedding 2004).

An ERP system consists of modules, and it gathers all enterprise functions in one database. Thus, it prevents the user from encountering the interface of more than one software. It also has some other advantages. For instance, standardised software makes it possible to produce accessible and highly detailed reports and provide comprehensive audits since all data is stored in a single database (Akyurt, Kuvvetli and Deveci 2020).

There are also several drawbacks to this system. As it is costly, it may not be affordable for smaller business enterprises. Its implementation takes too much time. Furthermore, since there will always be updates, the implementation process will never halt. If a problem occurs in one of the modules, the whole system may be affected severely. Similarly, if there is missing data, the system may stop functioning smoothly. Another issue is training employees and making them adapt using this system. The personnel may have difficulties understanding and using the system properly (Shehab, Sharp, Supramaniam and Spedding 2004; Katuu 2020).

10.3 SUSTAINABLE MRP AND ERP SYSTEMS

Sustainability in business refers to the intersection of economic, environmental and organisational responsibilities in business management. Taking care of natural resources is possible by managing and transforming business processes in environmental, economic and social dimensions. In this section, the ability of business enterprises to adapt to the transformation to achieve sustainability in systems such as MRP and ERP will be discussed.

Sustainability in business enterprises has gained importance as environmental issues increased dramatically, such as climate change and industrial pollution (Chofreh, Goni and Klemeš 2018). Nowadays, both customers and investors are looking for companies that have embedded sustainable practices in their business processes. For this reason, it has become vital for companies to adapt to change and incorporate sustainable practices into their processes (Chofreh, Goni, Shaharoun, Ismail and Klemeš 2014). Sustainability information systems are substantial for companies to alter their traditional systems into sustainable business practices (Chofreh, Goni, Shaharoun, Ismail and Klemeš 2014).

Sustainable MRP considers the sustainability concepts of the MRP operations. Classical MRP systems are economic-oriented models and are generally preferred methods for providing cost-efficient solutions for businesses. As companies need to fulfil their environmental responsibilities, adapting sustainable approaches for MRP systems has been crucial. However, this adaptation process is one of the long-standing issues (Melnyk, Sroufe, Montabon and Hinds 2001). The Green MRP system is one of the tools developed to lessen industrial waste and minimise the cost of waste. Although promising results have been achieved with the Green MRP system, it is suggested that further improvement is needed (Melnyk, Sroufe, Montabon and Hinds 2001).

In addition, reverse MRP applications have been developed to promote sustainable MRP systems. One of these systems is carried out using disassembly processes, which is one of the reverse logistics activities. In this approach, MRP sheets are prepared considering the disassembly activities. Here, the parts obtained from the disassembly of the returned products are reflected in the MRP form (Gupta and Taleb 1994). This approach helps to diminish waste and reduce the cost of production as the demand for the components is met by the disassembly process. An improved version of the reverse MRP for scheduling removal is the one in which the lot-sizing problem is also taken into account (Barba-Gutiérrez, Adenso-Diaz and Gupta 2008). As this approach satisfies the demand for the components, it will lower the market prices of the parts needed. Hence, there will be a positive economic impact on companies. It is crucial to ensure that this approach also works successfully in uncertain demand situations (Barba-Gutiérrez and Adenso- Díaz 2009).

An ERP system includes all business functions and collects all data in a single database. Likewise, a sustainable ERP (S-ERP) system consists of all ERP system components (for business functions) that take sustainability efforts into account (Chofreh, Goni, Shaharoun, Ismail and Klemeš 2014). In order to tackle the problem of transforming business functions into sustainable practices, the sustainability information system has emerged (Chofreh, Goni, Shaharoun, Ismail and Klemeš 2014).

Failure is inevitable in terms of time and cost if the sustainable ERP is not appropriately implemented. For this reason, practitioners should know specific rules related to the application process thoroughly and ensure an error-free application (Chofreh, Goni and Klemeš 2018).

A sustainable ERP system has two dimensions: the first is the sustainability dimension, and the other is the decision-making dimension. In this context, a framework has been proposed for ERP implementation considering the sustainability and decision pyramid (Chofreh, Goni and Klemeš 2018). It can be seen in Figure 10.4.

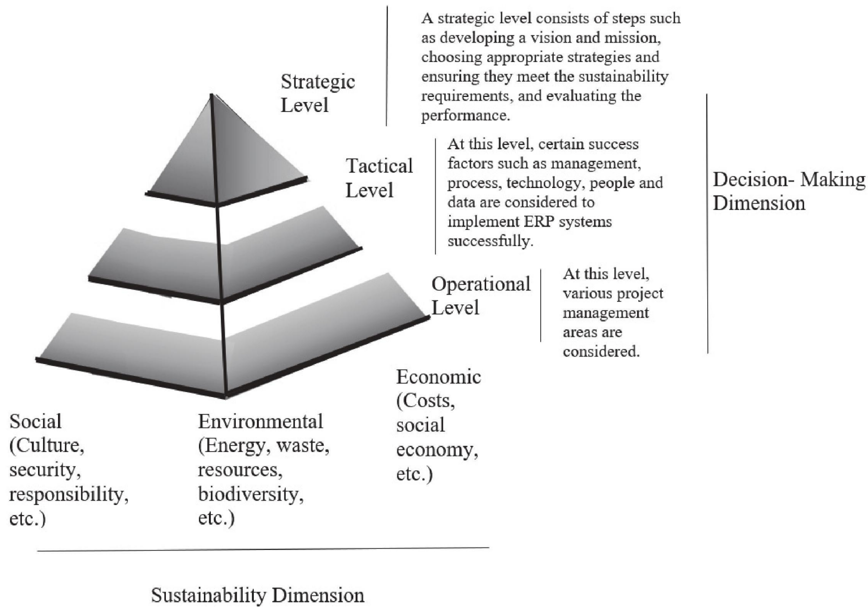

FIGURE 10.4 S-ERP pyramid. (Adapted from Chofreh, Goni and Klemeš 2018)

Companies must consider social, environmental and economic aspects of sustainability in order to fulfil the sustainability dimension. Likewise, sustainability requirements need to be considered at the management level, and decisions must be taken accordingly.

Since an ERP system requires software, green IT practices gain importance. The concept of green software emerges as a part of green IT systems. Green information technology is a concept that focuses on making software development, design, hardware and all sub-components of all information technology systems environmentally friendly. Furthermore, green IT aims to provide energy-efficient computing and responsible disposal, and it uses recycled products. In addition, a green methodology is used in the implementation processes of green IT systems, and assessments are done accordingly. Finally, it aims to reduce environmental-related risks (Murugesan 2008). In other words, it ensures that information technology processes are carried out with lower costs and in a more environmentally friendly and socially responsible way.

In terms of ERP systems, a green ERP software concept consists of different criteria, such as energy efficiency, feasibility, portability and usability. In order to reduce the risk of failure, it is crucial to provide adequate user training and ensure that the system is understood thoroughly by the employees who use the green ERP software (Ursacescu, Popescu and Smeureanu 2019). Finally, sustainable ERP systems can provide a holistic tool for sustainability in business processes.

10.4 MRP AND ERP IN THE INDUSTRY 4.0 CONTEXT

Companies are constantly facing new challenges. In this competitive world, they must find ways to adapt their business practices accordingly and improve their responsiveness. The Fourth Industrial Revolution, also known as Industry 4.0, was initiated by the development of Information and Communications Technology, which enabled more competitive production systems by connecting smart objects and equipment (Rojko 2017). Industry 4.0 aims at exploiting new technologies in order to increase efficiency and profit while decreasing production costs. Hence, it forces companies to continuously search for new ways to improve their systems (Rojko 2017).

This new system makes it possible to collect data in real time and process it automatically. Moreover, thanks to artificial intelligence and smart systems, the data can be collected, stored, processed and analysed in large quantities (El Hamdi, Abouabdellah and Oudani 2018).

The time of the invention of the Internet approximately coincides with the emergence of ERP systems. As every data is gathered, it becomes possible to transfer it to staff who need to access it. Therefore, they receive the required information promptly. For instance, while customer service is acquainted with orders status, logistics is informed about deliveries simultaneously (Cieśla and Gunia 2019).

Companies have adopted most Industry 4.0 technologies. For instance, cloud computing and big data technologies achieve remarkable improvement in automatically collecting data from the source for ERP systems. Other technologies, such as IoT devices, artificial intelligence and autonomous robots, provide improvements, as well (Akyurt, Kuvvetli and Deveci 2020).

MRP systems in the era of Industry 4.0 are mainly based on the Internet of Things. Real-time data collection technology links the material flow control and the ordering system. As real-time data are collected, if required, the MRP sheet is updated per up-to-date state. Besides, thanks to additive manufacturing technology, logistics flow has been diminished; thus, the MRP system has become less complex (Bueno, Godinho Filho and Frank 2020).

Since an ERP system connects all business functions of a company in a single database, converting an ERP system into a smart system plays a crucial role in transforming a company into a smart factory (El Hamdi, Abouabdellah and Oudani 2018). Industry 4.0 technologies greatly enhance classical ERP systems. For instance, thanks to automatic sensors, it is possible to collect real-time data, which is also more credible. In addition, cloud technologies make it possible to store big data, as the amount of data handled is enormous. Besides, the decision-making ability of ERP systems enhances thanks to artificial intelligence techniques (Akyurt, Kuvvetli and Deveci 2020).

10.5 CASE STUDY

This part of the study is planned to make a smart and sustainable extension for the classical MRP application. Along with the proposed system, a system such as the one shown in Figure 10.5 will be proposed in machine learning and demand forecasting. Both applications will be made together with the classical MRP system, a sustainable MRP logic based on disassembly from reverse logistics activities integrating with

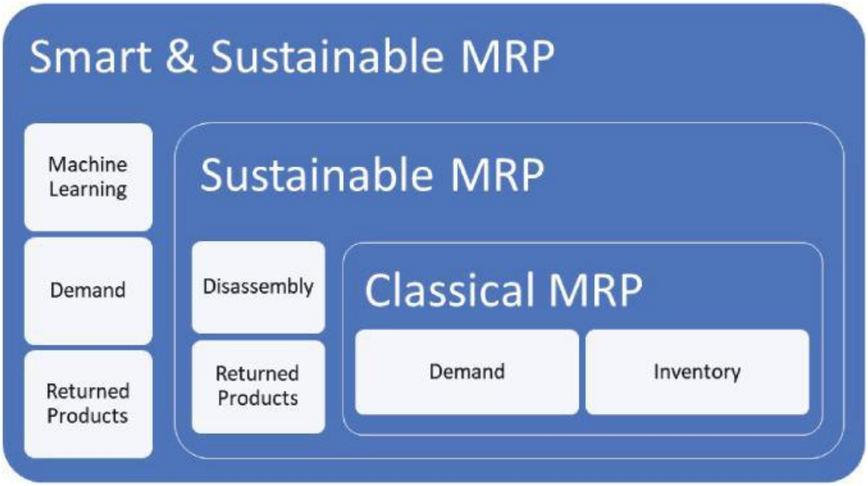

FIGURE 10.5 The proposed smart and sustainable MRP framework.

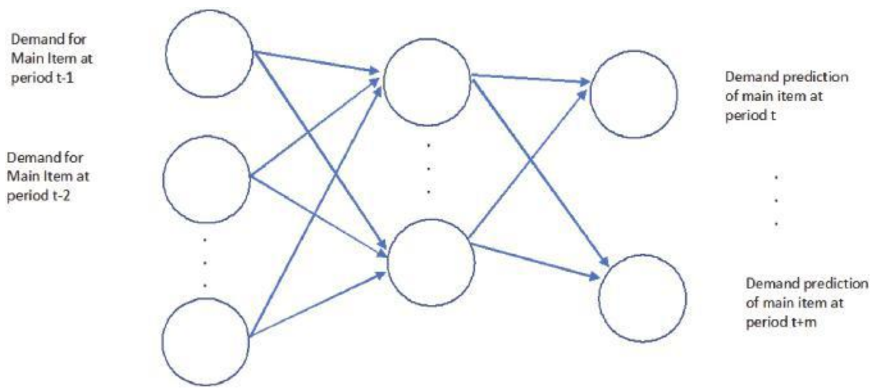

FIGURE 10.6 The proposed artificial neural network architecture for SS-MRP.

smart predictions. The proposed artificial neural network architecture can be seen in Figure 10.6. This approach is named smart and sustainable MRP (SS-MRP).

The proposed artificial neural network (ANN) model uses demands for the main product in the previous *n* period as inputs to make the forecast. Artificial neural networks work in a way that mimics human brain activities in order to make predictions (Kuvvetli, Deveci, Paksoy and Garg 2021).

The predicted demand values and the prepared MPS are used as inputs for the proposed SS-MRP system. The reason for proposing this structure is the requirement to dynamically adjust the amount of returned products per the change in the demand for the main product. It is possible to predict the demand in a smart way by changing the number of neurons in the hidden layer. Mean absolute percentage error (MAPE) was chosen as the performance criterion.

In order to feed the ANN, the past 100 weeks' demands for product A were used. The retrospective forecast period (*n*) was taken as six weeks, and accordingly, the artificial neural network model was created to find the forecast period for the next five (*m*) weeks. The MATLAB Neural Network Toolbox is used for modelling the ANN. The Levenberg-Marquadt algorithm was chosen as the training algorithm (Hagan and Menhaj 1994). The epoch number was determined as 500, and the dataset was divided into three parts: training, test and validation sets, with ratios of 70%, 15% and 15%, respectively. The results obtained at the end of the tests are summarised in Table 10.7. Figure 10.7 depicts the MAPE values obtained by using different numbers of hidden neurons in each hidden layer.

TABLE 10.7
The Predictive Performance

MAPE		**Hidden Layer**				
		1	**2**	**3**	**4**	**5**
No. of Hidden Neurons	1	0,2099	0,7932	0,7821	0,7822	0,7822
	2	0,2321	0,7211	0,7831	0,2715	0,8178
	3	0,2276	0,2483	0,6215	0,7821	0,7821
	4	0,3509	0,2166	0,9452	0,8732	0,8073
	5	0,3016	0,7622	0,5020	0,2799	0,7841
	6	**0,1873**	0,8034	0,8786	0,7824	0,7989
	7	0,3093	0,5174	0,8465	0,9354	0,8013
	8	0,4680	0,5292	0,5510	0,7821	0,7754
	9	0,4593	0,4036	0,7874	0,9316	0,7927
	10	0,2904	0,2452	0,3158	0,6645	0,7719
	11	0,3895	0,7992	0,5500	0,6970	0,9383
	12	0,4984	0,4167	0,7926	0,7075	0,9609
	13	0,3711	0,4278	0,6752	0,7575	0,6316
	14	0,5179	0,6906	0,8267	0,8433	0,7366
	15	0,2956	0,3976	0,6414	0,7736	0,6757
	16	0,3330	0,3817	0,4172	0,7155	0,7308
	17	0,4462	0,5586	0,6206	0,5380	0,9175
	18	0,2988	0,6048	0,7704	0,7588	0,7039
	19	0,3867	0,3762	0,6884	0,9771	0,5282
	20	0,2404	0,6253	0,9219	0,8227	0,7962
	21	0,3854	0,6000	0,4851	0,5948	0,6606
	22	0,4724	0,7174	0,8166	0,4774	0,5902
	23	0,5397	0,6086	0,6113	0,4496	1,1653
	24	0,3365	0,6022	0,8564	0,8158	0,6430
	25	0,3551	0,4950	0,4805	0,5434	0,8094
	26	0,2156	0,3797	0,8198	0,8312	0,6466
	27	0,2921	0,4716	0,7789	0,7492	0,7198
	28	0,2859	0,4788	0,6459	0,7165	0,5586
	29	0,2556	0,6144	0,8645	0,8050	0,6860
	30	0,3489	0,6022	0,5069	0,6465	0,8283

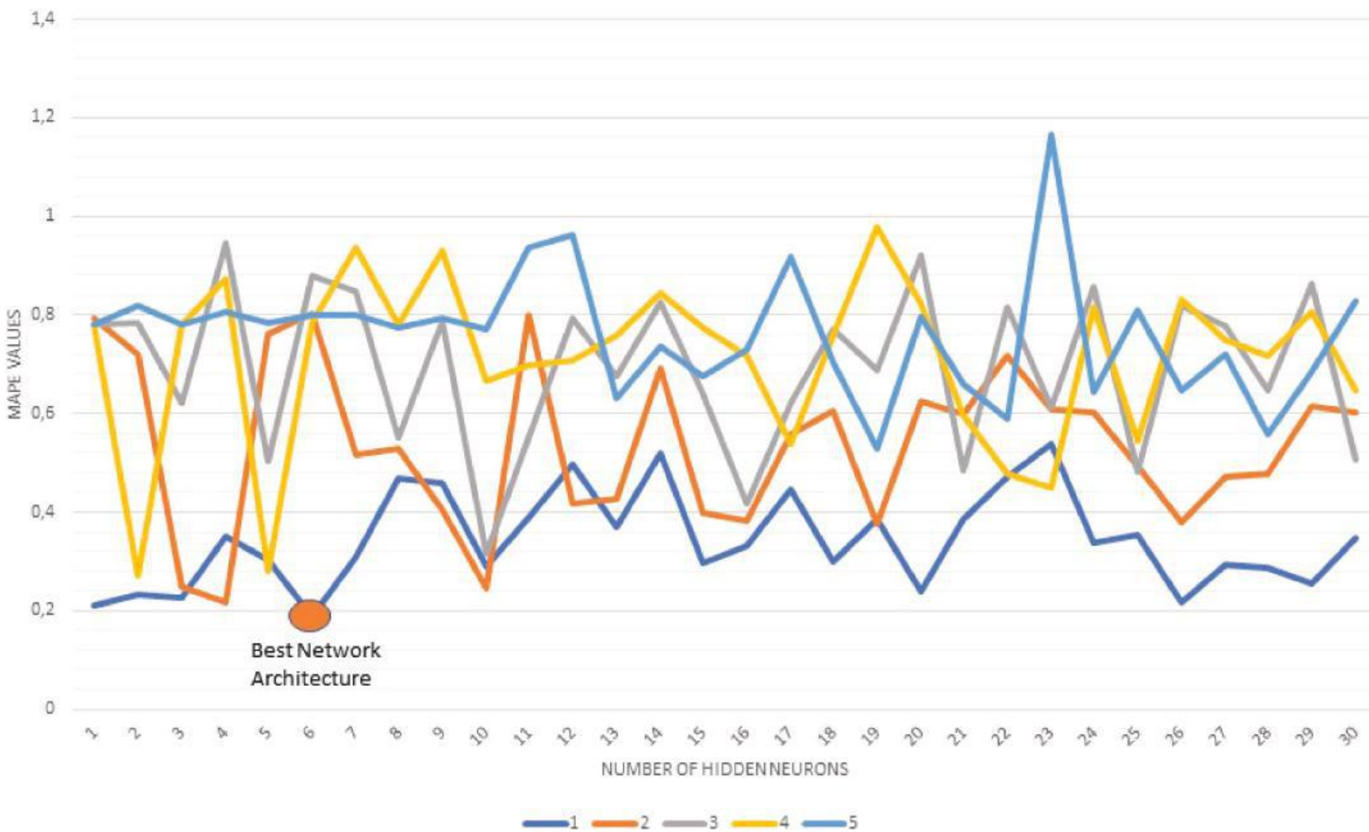

FIGURE 10.7 Number of hidden neurons vs. MAPE values.

The results obtained from Table 10.7 and Figure 10.7 show that the prediction performance deteriorates as the number of hidden layers used increases. For this reason, the number of hidden layers is determined as one. When the number of neurons is evaluated according to the number of hidden layers, it can be said that there is a random distribution. Therefore, the best number of neurons was determined in a single hidden layer neural network with six neurons, which provides the lowest MAPE value.

The best prediction performance is achieved when the network has six neurons in the hidden layer. Using the predicted demand values found from the best ANN for item A, an MPS was prepared accordingly, and then the next step of the study was conducted.

According to the product structure tree of item *A* in Figure 10.8, one *A* consists of two *B*s and one *C*. Figure 10.9 depicts that an *A* can be disassembled into two *B*s and one *C*. Hence, if the demand for components *B* and *C* are known, then the requirements for root item *A* are calculated, and its disassembly schedule can be prepared accordingly. This concept was introduced by Gupta and Taleb (1994). Following the first step of the proposed method, the predicted demand values for item *A* are used to prepare the reverse MRP sheet. It is easy to calculate the requirements for components *B* and *C* with these predicted demand values.

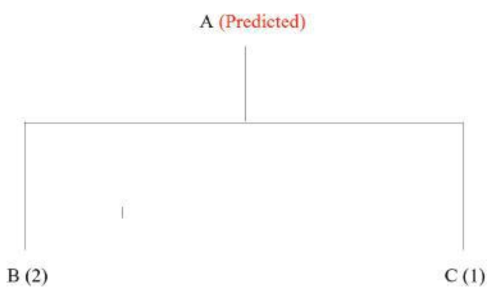

FIGURE 10.8 Assembly structure.

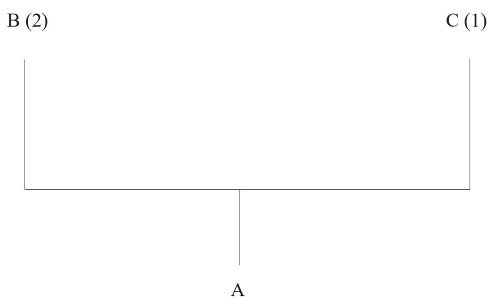

FIGURE 10.9 Disassembly structure.

TABLE 10.8
Reverse MRP Sheet for Item *A*

Item *C*		**W1**	**W2**	**W3**	**W4**	**W5**
Gross requirements		0	45	50	0	20
Scheduled receipts from external sources		0	0	12	5	0
On hand before disassembly		8	0	0	5	0
Net requirement		0	37	38	0	15
Item *B*		**W1**	**W2**	**W3**	**W4**	**W5**
Gross requirements		0	85	0	60	35
Scheduled receipts from external sources		0	10	0	15	0
On hand before disassembly		5	0	82	37	2
Net requirement		0	70	0	0	0
Item *A*		**W1**	**W2**	**W3**	**W4**	**W5**
Gross requirement disassembled		0	42	43	0	17
Item *C* (Inv. Update)		**W1**	**W2**	**W3**	**W4**	**W5**
Scheduled receipts from disassembly		0	37	38	0	15
On hand after disassembly	8	8	0	0	5	0
Item *B* (Inv. Update)		**W1**	**W2**	**W3**	**W4**	**W5**
Scheduled receipts from disassembly		0	75	77	0	30
On hand after disassembly	5	5	5	82	37	32
Item *A* (Dis. & procurement sch.)		**W1**	**W2**	**W3**	**W4**	**W5**
Disassembly sch.		0	42	43	0	17
Scheduled receipts from external sources		0	0	0	5	0
On hand	0	0	0	0	5	0
Net requirement		0	42	43	0	12
Time-phased planned order release		42	43	0	12	0

Table 10.8 shows the reverse MRP sheet for item *A*. The disassembly and procurement schedule for item *A* has been prepared using the information given for components *B* and *C*. For this example, we assume that the disassembly success rate is 90%. In other words, only 90% of *B*s and *C*s are available to be used once one item *A* is disassembled. Therefore, the calculations are made taking this information into account. Furthermore, the lead time for root item *A* has been given as one week.

According to the proposed approach, an integrated sustainable and smart framework is achieved in which uncertainties in new and returned products can be taken into account. Demand prediction of item *A* is obtained from the ANN model, and the requirements are calculated using the predicted values. Besides, material requirement planning of forward and reverse flows is considered in an integrated manner as the sustainable aspect. Thereby, more integrated, robust and sustainable supply chains can be organised.

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11 Just-in-Time and Lean Management

Sercan Demir and Turan Paksoy

CONTENTS

11.1 INTRODUCTION

Lean manufacturing is a production philosophy that aims to maximize productivity while simultaneously eliminating waste in a manufacturing system. "Waste" is defined by lean philosophy as "anything that does not add value to a product or service." Lean manufacturing focuses on creating customer-centric manufacturing or service systems in which employee involvement is constantly encouraged. Lean manufacturing enjoys a very extensive collection of tools and techniques. Companies use these tools and techniques to improve production efficiency and minimize cost by eliminating different types of waste, such as overproduction, waiting time, movement, and defects. This chapter briefly explains the basics of lean operations, just-in-time (JIT), and Toyota Production Systems. Later, the lean manufacturing tools and characteristics of lean organizations are discussed.

11.2 LEAN OPERATIONS

Lean manufacturing consists of a comprehensive set of techniques aiming to reduce and finally eliminate Ohno's seven wastes and help companies become leaner, flexible, and responsive. When a lean manufacturing system is matured, it reduces material usage, requires less investment, uses less inventory, consumes less space, and

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uses less manpower. A lean process does not include the uncertainties and chaos of conventional manufacturing plants. It allows employees to work with greater confidence, ease, and peace than in the typical chaotic manufacturing system (Wilson 2010, p. 9).

García-Alcaraz and Maldonado-Macías (2016) define lean manufacturing as a philosophy of excellence in manufacturing that leans on three pedestals: eliminating all types of waste, demonstrating respect for the workers in the workplace, and being consistent in improving productivity and product quality.

Companies adopt lean manufacturing to reduce and eliminate all kinds of waste and build competitive advantage by increasing business productivity. Lean manufacturing philosophy was initiated in the Toyota Production System (TPS) in the 1970s and gained huge recognition with the publication of the book *The Machine that Changed the World* in 1990. Lean manufacturing relies on improved manufacturing flows, customer-centric production, visual management, and ergonomic design of the workplace. Lean manufacturing offers strategic solutions for the challenges in market competition, inventory problems, customer service level, and issues with manufacturing work-in-process (WIP) (Pinto et al. 2018).

Gupta and Jain (2013) classify the steps of lean manufacturing implementation into four groups:

- Identification of hidden and unhidden waste in a system.
- Categorization of wastes based on their types and identifying root causes.
- Coming up with a solution for each root cause.
- Testing and implementation of the solutions.

Many businesses in various industrial sectors worldwide implement the lean manufacturing philosophy due to its advantages and benefits. Some of these are minimizing inventory, implementing managerial practices in manufacturing processes, increasing business efficiency, minimizing waste, improving productivity and customer service levels, increasing product quality, being more responsive, and reducing cost (Pinto et al. 2018). The Environmental Protection Agency (US EPA 2003) defines "lean manufacturing" as follows:

> the systematic elimination of waste from all aspects of an organization's operations, where waste is viewed as any use or loss of resources that does not lead directly to creating the product or service a customer wants when they want it.

"Waste" is defined as "any activity that adds no real value to the product or service being created or delivered." The Japanese word for "waste" is *muda* (Pereira 2009).

Ohno (1988) identifies seven wastes in a production system. According to the US EPA (2003), lean manufacturing methods aim to eliminate eight waste types. Pereira (2009) classifies wastes in a production system under nine categories. Different types of waste in a manufacturing environment are illustrated in Table 11.1.

Ohno (1988) defines "waste" as "the needless, repetitious movement that must be eliminated immediately." He classifies the work into two categories: value added and non-value added.

TABLE 11.1
Definition of the Seven (or Eight) Wastes in a Production System

Type of Waste	Ohno (1988)	EPA (2003)	Pereira (2009)
Overproduction	Producing without demand	Manufacturing items for which there are no orders	Producing more than its customer (internal or external) needs
Waiting time	Any delays in the actions of a worker that add value and create output	Delays caused by stock-outs, lot processing delays, equipment downtime, and capacity bottlenecks	Delays caused by queues in a manufacturing system
Transportation	Any unnecessary movement of material or products	Transporting materials over long distances	Moving things around that adds no real value to the product or service
Over-processing	Taking unnecessary steps to process the parts/products	Actions that are unnecessary to produce the product	Doing more than a customer's request or demand.
Inventory	Keeping unnecessary inventory on hand	Surplus or unused raw material, WIP, or finished goods	Having uncontrolled or surplus inventory
Movement	Any motion that does not add value to the product	Unnecessary or straining human motions	Any movement of people that does not add value to the product or service.
Defects	Manufacturing defective products	Manufacturing of products results in scrap, rework, inspection, and/or defective materials	Any work that does not meet customer expectations
Skills	—	Failure to utilize employees for process improvement	Inability to fully use employees' talents.

1. Value-added work: The processes that add value by changing the shape of a product or assembly operations. Value-added work transforms the parts or raw material into work-in-process or finished goods.
2. Non-value-added work: This kind of work may be considered a waste. However, they must be done under the present working conditions. Activities that do not affect the transformation of materials are grouped in this type of work.

Figure 11.1 explains the three types of activities in a manufacturing process.

11.3 JUST-IN-TIME AND TOYOTA PRODUCTION SYSTEM

In his 1988 book, *The Toyota Production System Beyond Large Scale Production*, Taiichi Ohno compares the conventional American mass production system and the production system and production needs of Japanese society following World War

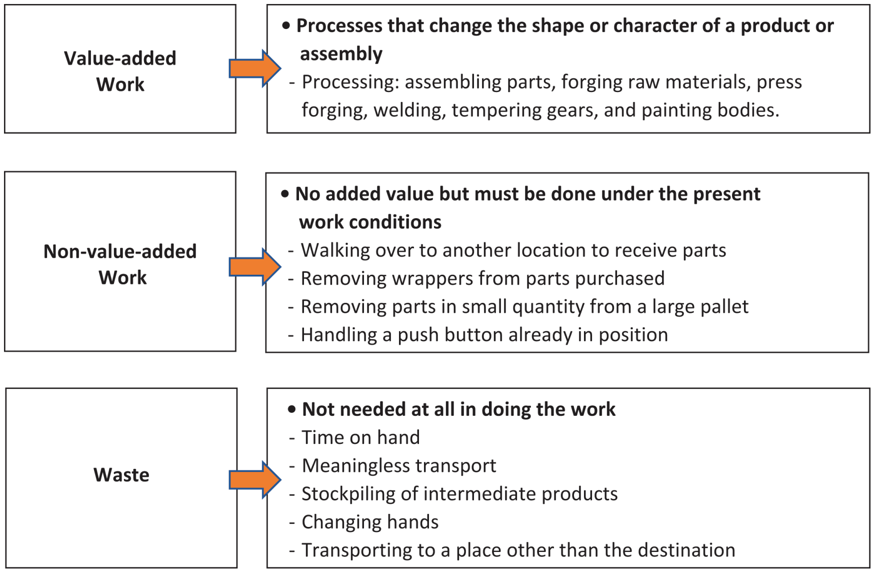

FIGURE 11.1 Types of activities in a manufacturing process. (Adapted from Ohno 1988)

II. During the 1960s, Japan's economy experienced rapid economic growth as the country imitated the American mass production system in various production fields. However, following the Oil Crisis in 1973, the economy of Japan slowed downed and reached a state of zero growth rate. This was when Japan understood that blindly imitating the American mass production system was not appropriate to the needs of Japanese society and might have been dangerous for the economy (Ohno 1988).

Taiichi Ohno states that producing many models in small batches inexpensively instead of mass-producing fewer types of cars was the only solution for the Japanese economy to survive. He adds that at that time, Japanese entrepreneurs thought that this novel production philosophy could even overtake the conventional mass production system. Hence, Toyota Production System's principal objective appeared to produce many models in small quantities at an inexpensive cost.

Wilson (2010) defines the characteristics of the TPS system as the continuous focus on eliminating waste, based on a strong foundation of process and product quality, fully integrated, constantly developing, and maintained by strong organizational culture:

- Continuous improvement
- Process standardization
- Stockless production

The Toyota Production System (TPS), namely lean production, was initiated by Toyota Motor Corporation in the 1970s. The TPS focuses on combining management methods and tools to eliminate the seven types of waste defined by Taiichi Ohno, ultimately generating profit through cost reduction and process efficiency. This philosophy considers anything that does not generate value as waste (*muda*) (Wagner et al. 2017).

"Lean manufacturing" and "just-in-time" (JIT) are two terms that are frequently used together. According to DeRose (2017), lean manufacturing principles are applied primarily to improve quality and reduce waste, while JIT's manufacturing philosophy aims to strike the ideal balance of inventory and workflow to avoid excess and shortages.

Taiichi Ohno developed the lean manufacturing system. This philosophy was extended and improved by many researchers such as Hiroyuki Hirano (5S system), Seiichi Nakajima (total productive maintenance), Kenichi Sekine (continuous flow), and Shigeo Shingo (jidoka and single-minute exchange of dies) (Dennis 2017). Chapter 11.4 will discuss lean manufacturing tools and their applications.

11.4 LEAN MANUFACTURING TOOLS

The lean manufacturing concept was introduced in Japan for the first time and was first implemented by Toyota. While the traditional manufacturing concept primarily focuses on inventory in a manufacturing system, lean manufacturing considers inventory a waste (Gupta and Jain 2013). Waste is anything that is not essential to add value to a product or service. In terms of cost, waste implies any non-value-added cost, such as inventory, setup, scrap, and rework. From the consumer viewpoint, if the consumption of internal and external resources does not add value to the customers, they are considered waste (Rawabdeh 2005). According to Kilpatrick (2003), implementing lean practices brings three categories of benefits to businesses: operational, administrative, and strategic. Some of these benefits are given in Figure 11.2.

Various types of lean tools are available for the successful implementation of lean management. Some of these tools are briefly explained in Table 11.2.

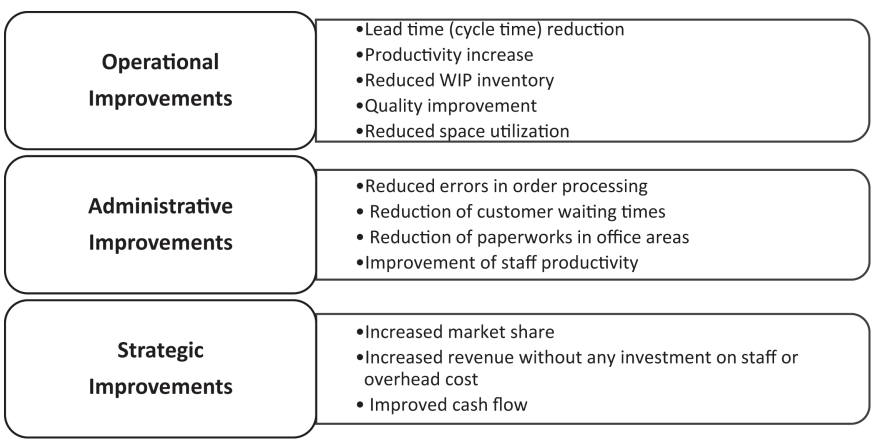

FIGURE 11.2 Benefits of lean manufacturing. (Adapted from Kilpatrick 2003)

TABLE 11.2
Description of Lean Manufacturing Tools

Lean Management Tool	Explanation
Value stream mapping (VSM)	VSM is a lean tool that aids in understanding the flow of material and information through every step of a manufacturing process. The purpose of VSM is to detect and eliminate waste by implementing a future state value stream that can turn into reality in a short time (Chaple and Narkhede 2017).
Pareto diagram (chart)	Pareto chart is a frequency block diagram displaying the relative frequency of different attributes in descending order (Grosfeld-Nir et al. 2007).
Spaghetti diagram (plot)	Spaghetti plot is a method to view the movement of an object, such as a worker or material, in a system with the help of a line (Senderská et al. 2017).
Genchi Genbutsu	Genchi Genbutsu is one of the critical elements of the TPS, and it means going and seeing the real facts in the actual workplace for a complete and careful understanding of a situation (Gao and Low 2014).
Jidoka	The Japanese word *jidoka* means "intelligent automation" or "autonomous automation." The main objective of jidoka is to establish small and autonomous control cycles to monitor and detect defective products and prevent them from being disseminated (Deuse et al. 2020).
Just-in-time (JIT)	JIT is an operating concept that aims to eliminate waste and make the process more efficient. It was developed in the 1950s and achieved significant success at Toyota (Canel et al. 2000).
Total productive maintenance (TPM)	TPM is a manufacturing approach that aims to maximize the effective use of equipment by means of the participation and motivation of all workers (Cua et al. 2001).
Kanban	The Japanese word *kanban* means "card" or "sign", and in lean practices, kanban refers to control cards used in a pull system. Kanban is a visual control system that aims to eliminate waste such as overproduction, increase flexibility and agility in response to volatile customer demand, and reduce cost by eliminating waste (Arbulu et al. 2003).
Daily management system (DM) (T-kart)	DM is a continuous process that allows people to visualize whether the work is done in the right way and whether the performance is good enough or not to achieve the expected business performance (Ferro and Gouveia 2015).
One-piece flow	One-piece flow refers to moving one part at a time between sequential operations in a production process. One-piece flow production system emphasizes factors such as sequencing, setup time, and make-to-order policy during production scheduling (Sundar et al. 2014).
Cellular manufacturing	Cellular manufacturing refers to the physical division of a facility's machinery into production cells, each aiming to produce a family of parts (Drolet et al. 1996).
Heijunka	*Heijunka* is a sequencing discipline that aims to balance the production of different products over a certain period to achieve a constant flow of various parts in a manufacturing system (Furmans 2005).
Computer integrated manufacturing (CIM)	CIM aims to develop superior IT solutions and establish a foundation for the implementation of integrated and computerized systems into manufacturing processes (Delaram and Valilai 2018).

Lean Management Tool	Explanation
SMED	In Japan, SMED was developed by Shigeo Shingo in the 1950s in response to increasing flexibility in customer demand and a requirement to produce smaller lot sizes. This method is rapid and efficient for converting a manufacturing process from running the current product to running the next product (Ulutas 2011).
Poka-yoke	Poka-yoke is a quality management technique that helps prevent human errors in a production line. The Japanese word *poka-yoke* means "avoiding inadvertent errors." Shigeo Shingo developed this technique to eliminate defective products (Malega 2018).
Visual management (VM)	VM is a lean tool that helps workers track their jobs and assess whether they are being done correctly. Hence, a worker can know whether the activity is being carried out safely or might cause an injury. Some VM systems are information boards, space boundaries, and andons, which are electronic panel systems that notify employees when a problem occurs (Sá et al. 2021).
5S	The 5S method is a lean management tool to create a highly efficient, organized, and ergonomic working environment. 5S is the shortened form of five words that represents the concept: *seiri* (selection), *seiton* (systematization), *seiso* (cleaning), *seiketsu* (standardization), and *shitsuke* (self-discipline) (Falkowski and Kitowski 2013).
ABC analysis	ABC analysis is an inventory categorization method that classifies inventory items into three groups: A, B, and C. Category A items are the most valuable and fast-moving items, category B items are of lower value than category A items, and category C items are the least valuable and slow-moving items (Nallusamy 2016).
Andon	Andon is a visual management device that shows the status of operations in a system and signalizes any abnormality (Kemmer et al. 2006).
Pull system	Pull system is the application of just-in-time system to material management where the amount and time of material flow are determined based on the actual utilization rate of material. Toyota uses kanban to operate the pull system (Kim 1985).
Customer relationship management (CRM)	CRM is a strategic management technique that merges the potential of IT and relationship marketing strategies to develop strong relationships with key customer segments and build an efficient value chain (Payne 2012).
Suggestion system	Suggestion system is a management technique that aims to encourage employees to be active in a process by empowering them to present their ideas and suggestions through surveys, meetings, and suggestion forms (Schröders and Cruz-Machado 2015).
Takt time	Takt time is a metric used to synchronize manufacturing and sales velocity. It represents the frequency in which a product needs to be manufactured to meet a customer's demand (Chaple and Narkhede 2017).
5 whys analysis	Five whys analysis is a lean management technique to identify the root cause of a specific problem by asking why the problem happens until finding the root cause (Chen et al. 2010).

(*Continued*)

TABLE 11.2 (Continued)

Lean Management Tool	Explanation
Problem-solving methods	Problem-solving methods are necessary tools for management and process improvement efforts. The first step of problem-solving is to rapidly identify the root cause of the problem and implement an appropriate solution that guarantees that the problem will not occur in the future (Wojtaszak and Biały 2015).
Ishikawa diagram (fishbone diagram)	The Ishikawa diagram shows the relationship between an effect or problem and its potential causes. It allows the categorization of the causes and produces good results in a short time since the visual representation is easy to construct. This diagram is also called a fishbone or cause-effect diagram (Iuga and Rosca 2017).
Scatter diagram (scatter plot)	Scatter plot is a tool that shows how two variables are related to one another. These plots help detect the amount of correlation, or the degree of linear relationship, between two variables (Syduzzaman et al. 2014).
Workflow diagram	A workflow diagram is a basic visual layout of a business process that shows the movement of material, identifies waste areas, and helps plan future improvements (Wang 2010).
Histogram	A histogram is a graphical representation of recorded values in a dataset based on their frequency of occurrence (Lai and Cheng 2016).
Quality control charts/	Quality control charts are graphs plotting the changes of a process in chronological order (Abujudeh et al. 2017).
Process capability analysis (PCA)	PCA is a quality technique used to estimate the proportion of parts that do not meet engineering requirements in a stable production process (Gildeh and Moradi 2012).
Check sheet	Check sheet tables are used to record the frequency of defects or problems, and it is a useful method of systematically recording, collecting, and illustrating data patterns from observations (Lai and Cheng 2016).

11.5 LEAN ORGANIZATIONS

Lean organizations are systems that aim to achieve business excellence, and they are extensively applied worldwide. Lean organizations are built on the philosophy of continuously examining and looking for better ways to improve a method for an activity, even if it has been improved. In a lean organization, a value-added activity must be done at the lowest possible cost while maximizing the customer expectation for that particular product or service. Any activity that adds cost but does not add value is considered waste (Chiarini 2013). According to Womack and Jones (1997), rethinking what can be done in continuous flow is one of the important means of growth for a lean organization.

One of the main goals of a lean organization is to reduce inventory since holding inventory brings about the various cost associated with it. The inventory costs include the capital tied up in inventory and the loss of interest of that capital, material handling damage cost, increased labor cost for material handling, and increased space and storage costs (Wang 2010).

Waste can be classified in many ways. Chiarini (2013) categorizes waste into four groups (see Table 11.3).

Many companies used to ensure the readiness of the right components at the right time by carrying a huge amount of inventory in their warehouses and using them when needed. After Toyota introduced the JIT system, these companies became more aware of the inventory cost and set up supply chains in which inventories are received when they are needed. When first developed, JIT offered a radical approach that changed the manufacturing process in many aspects. JIT reduces waste by supplying parts only when the process requires them. JIT eliminates the need for carrying buffer stocks at each stage in a manufacturing process. The workers can control their inventory needs without a need for a central authority, and various products can be produced on the same assembly line simultaneously (Hindle 2008).

Some of the strongest edges of a lean organization are its ability to communicate to customers to understand their expectations and collaborate through its functional areas to verify customer satisfaction. Lean operations minimize waste by adopting and applying the tools of continuous learning, creativity, and teamwork (Heizer et al. 2017).

TABLE 11.3
Classifying the Types of Waste

1. Three MUs (traditional Japanese approach)	- *Muda* means more capacity than workload (real waste) - *Mura* means capacity that swings around the fixed target (the waste is not steady) - Muri means more workload than capacity (workers and machines too busy)
2. Four Ms (traditional Japanese TQM approach)	- The four Ms are related to the fishbone or cause-and-effect diagram introduced by Ishikawa in the 1950s. The different types of waste are defined based on their origin: man, material, machine, and work method.
3. Seven wastes (Japanese approach adapted by the USA)	- Toyota engineer Taiichi Ohno developed the most well-known and common waste classification. 1. Overproduction or asynchrony means producing too much, too early, or too late to meet the customer's demand 2. Inventory wastes are raw materials, work in process (WIP), and finished products that are stored 3. Motion waste is the unnecessary movement of the workers 4. Defectiveness is non-conforming products and services 5. Transportation wastes are unnecessary movements of products between processes 6. Overprocessing means processing more than customers' demand 7. Waiting refers to unnecessary waiting before beginning the next activity
4. Cost of poor quality (American TQM approach)	- If products or services do not satisfy the customers' or an organization's requirements, the cost of poor quality emerges. The cost of poor quality is classified into two groups: 1. Prevention and appraisal costs 2. Internal and external defectiveness

(Adapted from Chiarini 2013)

11.6 CASE STUDY: IDENTIFICATION OF LEAN MATURITY LEVELS: A MULTIDIMENSIONAL MATURITY MODEL PROPOSAL

In this section, a mathematical model developed to measure the level of lean maturity in enterprises is presented as a case study. Lean tools are listed in the first column of Table 11.4 as follows: 1. Value stream mapping (VSM), 2. Pareto diagram (chart), 3. Spaghetti diagram (plot), 4. Genchi Genbutsu, 5. Jidoka, 6. Just-in-time (JIT), 7. Total productive maintenance (TPM), 8. Kanban, 9. Daily management system (DM) (T-kart), 10. One-piece flow, 11. Cellular manufacturing, 12. Heijunka, 13. Computer integrated manufacturing (CIM), 14. SMED, 15. Poka-yoke, 16. Visual management (VM), 17. 5S, 18. ABC analysis, 19. Andon, 20. Pull system, 21. Customer relationship management (CRM), 22. Suggestion system, 23. Takt time, 24. 5 whys analysis, 25. Problem-solving methods, 26. Ishikawa diagram (fishbone diagram), 27. Scatter diagram (scatter plot), 28. Workflow diagram, histogram, 29. Quality control charts/ Process capability analysis (PCA), 30. Check sheet.

11.6.1 Dimension 1: Implementation Status

11.6.1.1 Managerial Contribution/Efficiency Criteria KPIs

KPI 1: Shortening total production time (MLT)
KPI 2: Increasing OEE
KPI 3: Reducing workplace usage area
KPI 4: Reducing total material/energy/labor hour usage

11.6.2 Dimension 2: Contribution of Lean Tool to KPI in the Company

$$\text{Firm's Maturity Start Score of Lean Tool} = \sum (\text{Implementation Status}) \times (\text{KPI Effect}) / 4 \tag{11.1}$$

Normalized lean tool maturity beginning level

11.6.3 Dimension 3: Organizational Internalization Level (Integrity)

Individual maturity level of lean tool

$$\text{Contribution to Average KPI} = \left(\sum \text{OS}i\right)/30$$

$$\text{General Lean Maturity Level} = \left(\sum \text{IM}i\right)/30$$

11.7 CONCLUSION

This chapter briefly discusses lean operations and lean organizations by explaining the use and benefits of lean manufacturing tools. Toyota introduced the lean manufacturing concept to eliminate waste and improve production efficiency. Later,

TABLE 11.4
A Multidimensional Lean Maturity Model

Lean Management Tool	Dimension 1 Implementation Status	Managerial Contribution/ Efficiency Criteria KPIs	Dimension 2 Contribution of Lean Tool to KPI in the company	Firm's Maturity Start Score of Lean Tool: Σ(Implementation Status) x (KPI Effect) /4	Normalized Lean Tool Maturity Beginning Level	Dimension 3 Organizational Internalization Level (Integrity)	Individual Maturity Level of Lean Tool
	0= never used **5= actively used**	KPI 1: Shortening Total Production Time (MLT) KPI 2: Increasing OEE KPI 3: Reducing workplace usage area KPI 4: Reducing total material/ energy/labor hour usage		**(OP*i*)**	**(OSi)**	**1= Not adopted at all** **5= Deeply internalized**	
	Dimension Weight (W_1)		**Dimension Weight (W_2)**			**Dimension Weight (W_3)**	
1.Value Stream Mapping (VSM)	0 1 2 3 4 5	KPI 1	0 1 2 3 4 5	**OP1** = (12 + 6 + 15 + 3)/4= 9	**OSi** = 9/25 = 0,36	0 1 2 3 4 5	**IM1** = (3x0.36)/ 5= 0,216
		KPI 2	0 1 2 3 4 5				
		KPI 3	0 1 2 3 4 5				
		KPI 4	0 1 2 3 4 5				
			⋮				
30.Check Sheet							

$$\text{Contribution to Average KPI=} \left(\sum \text{OS}i\right)/30$$

$$\text{General Lean Maturity Level=} \left(\sum \text{IM}i\right)/30$$

many companies adopted lean management, and it became one of the most popular management philosophies in various industries, such as automotive, high-tech, healthcare, logistics, and hospitality. Since the main goal of lean management is to eliminate waste in a manufacturing or service system, appropriate lean techniques must be implemented meticulously. Efficient implementation of lean management leads to improved lead time, reduced cycle times and stocks, improved quality, less floor space, minimized machine breakdowns, reduced defects and scraps, a safer workplace, and increased employee motivation. On the customer side, lean manufacturing ensures that the customers do not pay for anything that does not add value (e.g., waste) to their expectations, their quality requirements are met, and the reliability and timing of the delivery are improved.

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12 Total Productive Maintenance

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CONTENTS

12.1 STRATEGIC IMPORTANCE OF MAINTENANCE AND RELIABILITY AND IMPACT ON COMPANIES

The continuation of production in accordance with the programs depends on the smooth operation of machinery and facilities, which are the essential elements of production. Maintenance of the machines at a specific time and elimination of the failures that occur unexpectedly should be done without disrupting production flow as much as possible.

The importance of maintenance activities increases when the production system grows or the number of production increases. A malfunction of a few machines in a production line consisting of hundreds of benches can disrupt the whole production system dynamics with chain effects. For instance, a malfunction that occurs at one point in an oil refinery causes the entire system to stop. The occurrence of failures in manufacturing systems, such as iron-steel, cement, and sugar, affects all production

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processes. Especially with technological developments, companies have started to focus on automation. An additional factor should be considered when faced with any malfunction in automation-oriented companies (McCarthy and Rich 2004). Experts with sound knowledge should carry out troubleshooting of automatic machines. For this reason, companies need skilled operators for maintenance. Especially in companies with complex mechanisms and electronic control devices, it is mandatory to employ qualified operators.

In contrast, airplanes are one of the ways to travel fast and reliably when traveling from place to place. By using the developing technology, designs that prioritize flight safety are realized to ensure reliability in aircraft. Amusement parks are frequented by those who want to have fun, especially children. For amusement parks to continue as prevalent entertainment venues, their facilities must be sparkling, and the entertainment vehicles must be highly reliable.

Maintenance and reliability studies aim to ensure the continuity of the system's capability. Variations are minimized through well-executed maintenance activities. Maintenance activities should be designed to reach the performance and quality standards expected from the system. Maintenance activities include all activities done to keep a system's equipment in working order. Reliability is the probability that a machine part or a product will perform its function correctly for a particular time under specified conditions. Maintenance and reliability activities are necessary to keep system disruption to a minimum. Maintenance and reliability activities allow improvements in operating costs and, therefore, increase system efficiency (Kobu 2010).

12.2 RELIABILITY

Breakdowns are an indispensable part of real life. Therefore, understanding how these breakdowns occur is a vital reliability issue. Reliability is defined as the probability that the desired function of a product will operate undisturbed, under certain conditions, over a specified period (Heizer, Render, and Munson 2020). Reliability should be measured with the answer to questions such as "How long will the product work before it breaks down?", "How much will the products fail before the warranty period expires?", and "How long should a warranty period be given for a new product?"

Some units in any product stack may have runtimes of 100 hours, 200 hours, or 2,000 hours. In other words, life is a random variable. Probabilities, distributions, mean, and measures of variability should be used when examining this type of random variable behavior. Reliability is a possibility because of being a random variable function. Statistics are used in the estimation and calculation of reliability (Figure 12.1).

As shown in Figure 12.1, as the number of components in a system increases, the system's reliability tends to decrease rapidly. A confidence curve is used to measure the reliability of a system consisting of components with different reliability. The reliability of a system, *R*s, can be found by multiplying the reliability of the components, as seen in equation 12.1:

$$R_s = R_1 \text{ X } R_2 \text{ X } R_3 \text{ X } R_4 \text{ X} \ldots\ldots\ldots\ldots \text{X } R_n \tag{12.1}$$

where R_i is the reliability of component i, $i = 1, 2, \ldots\ldots n$.

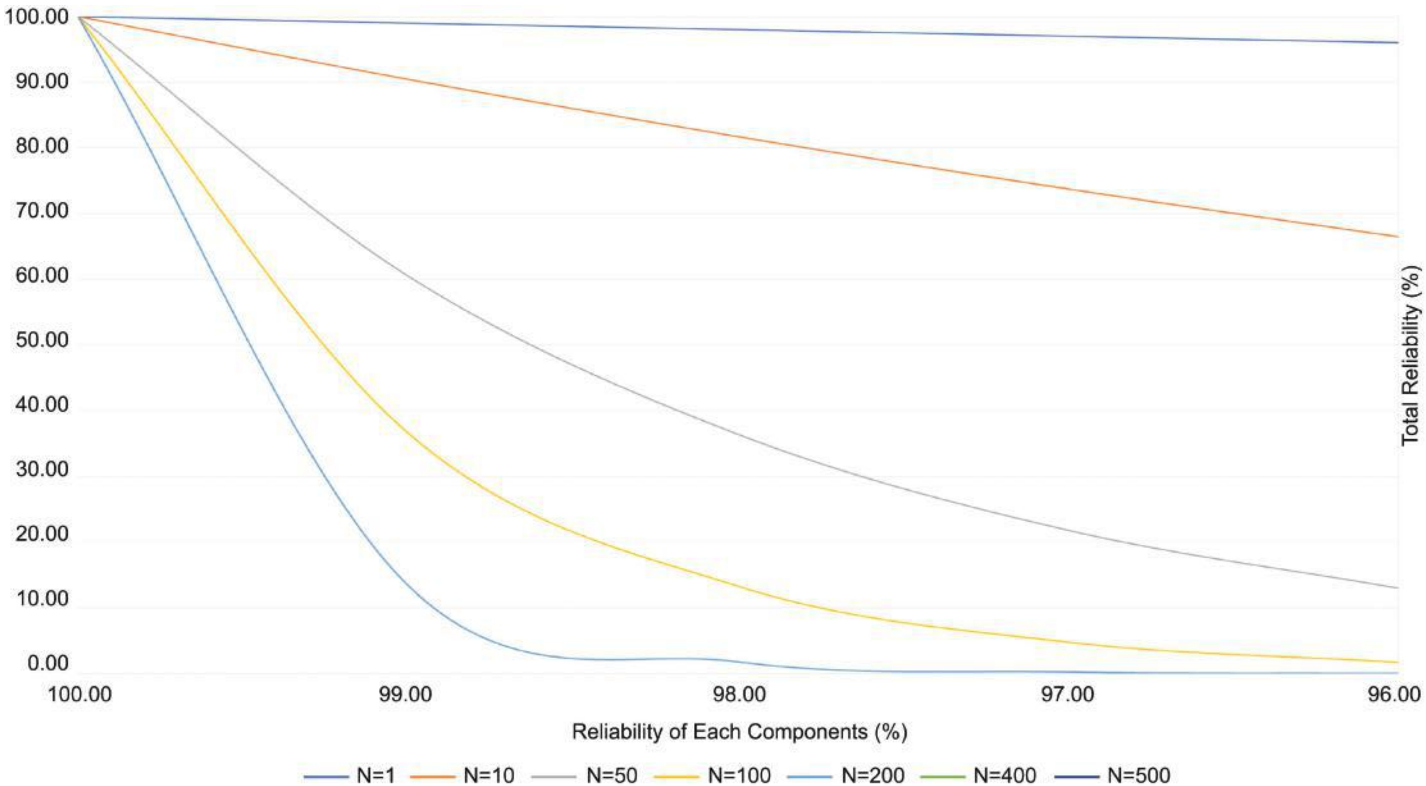


FIGURE 12.1 Number of components *n* and system reliability.

For instance, assume that you have a bulb with 95% confidence. It is understood that this bulb will work properly for 95% of its lifetime; 1 – 0,95 = 0,05 = 0,05% of its lifetime, it will be broken.

When defining the product's reliability, the function that the product must perform should be clearly stated, along with a description of the cause of the defect. It can be considered a failure if an electric light goes off, an electric motor draws too much current, or a breakdown occurs while driving a luxury car. Before measuring the life span of a product, the expected function of the product and what constitutes breakdown should be clearly defined. In addition, the working conditions of the product should be clearly defined. Reliability might vary depending on operating conditions (Jardine and Tsang 2013).

In addition, reliability should be emphasized as a function of time. At a specified time, a certain proportion of the product set maintains its current function intact. Reliability represents this rate that continues to operate after this specified time (Stephens 2010).

12.2.1 Backup

From time to time, system data is destroyed due to malfunctions in the systems. Backup is done in order to avoid data loss in case of possible malfunctions in the systems. Backup aims to ensure that the system has an alternative solution when a component or subsystem fails.

Use of spare component: Suppose a flashlight has a reliability of 75%. Assume that if this hand lamp breaks down, it can be replaced with another hand lamp with a reliability of 75%. In this case, our system reliability is equal to the sum of the probability of the first hand lamp working correctly and the likelihood of this component working correctly when the second hand lamp is needed and is obtained, with the help of the following equation 12.2:

$$R_s = \begin{pmatrix} \text{The probability that the} \\ \text{first component is durable} \end{pmatrix} + \begin{bmatrix} \begin{pmatrix} \text{The probability that the} \\ \text{second component is durable} \end{pmatrix} \\ \times \begin{pmatrix} \text{Possibility of needing} \\ \text{the second component} \end{pmatrix} \end{bmatrix} \tag{12.2}$$

$$(0{,}75) + [(0{,}75) \times (1 - 0{,}75)] = 0{,}93$$

Example 1: Studies have shown that the reliability of a new chipset design is higher than the previous generation because it contains parallel circuits, as shown in Figure 12.2. Find the reliability of this system.

Solution 1: First, the reliability of each subsystem is determined. The probability of failure of each subsystem is calculated. Then the product of these probabilities is subtracted from 1.

Reliability of the upper system = $R_1 \times R_2 = 0{,}72$
Reliability of the lower system = $R_4 \times R_5 = 0{,}52$

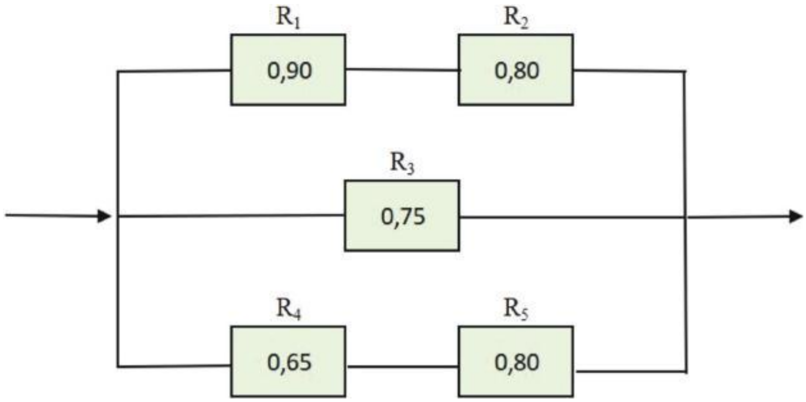


FIGURE 12.2 A chipset system demonstration.

Possibilities of failure of all subsystems = (1 − 0,72) × (1 − 0,75) × (1 − 0,52) = (0,28) × (0,25) × (0,48) = 0,0336

System reliability = 1 − (0,0336) = 0,9664

12.3 MAINTENANCE

The fact that companies are thriving to continue their activities following the schedules is strictly dependent on the work of the equipment and facilities without exposure to disruptions. There are two specific maintenance activities: before (preventive maintenance) or after (breakdown maintenance) the equipment is exposed to disruptions.

Preventive maintenance aims to keep the equipment and facilities of the companies in good working condition by making regular checks and maintenance works, such as cleaning, lubricating, and tightening. These procedures aim to avert potential malfunctions and stop the occurrence of new ones. This way ensures that equipment is able to continue to work as designed without decreasing its efficiency. However, in cases where preventive maintenance activities are not performed or regularly monitored, equipment failures are a common occurrence. The repair service received after failures is called breakdown maintenance.

As production facilities expand or production volumes increase, the significance of maintenance activities for companies increases day by day. Machine failures at workstations can cause the entire production line to bottlenecks or even stop.

Maintenance activities have much higher importance because highly trained maintenance personnel need to eliminate breakdowns in companies where automation is used more than the workforce. Companies are obliged to keep qualified personnel, especially for the maintenance of more complex machines.

12.3.1 Preventive Maintenance

Preventive maintenance activities are necessary for the equipment to continue working as designed before it breaks down. The foresight to predict when equipment will fail and perform necessary maintenance is not yet a developed skill for humans. For this reason, maintenance activities must be carried out at regular intervals before failures. Malfunctions may occur during different periods during the life of the equipment. Infant mortality, a frequently experienced situation in a piece of equipment, is also known as an early equipment failure. However, it is a well-known fact that most early failures occur not due to equipment but due to user error. For this reason, after-sales support departments have been established to carry out installation and usage training studies in many industrial sectors (Duffuaa and Raouf 2015).

The benefits of preventive maintenance activities for companies should be carefully analyzed by calculating the time between failures. According to the results of the analysis, if the statistical distribution of the time between failures is close to the normal distribution, that is, if the standard deviation is observed to be minor, no matter how high the maintenance costs are, the implementation of preventive maintenance will provide significant benefits to the companies. One of the most critical elements for preventive maintenance is determining when to apply it to be economical. As maintenance costs increase, the standard deviation in the time between failures is expected to be small. However, if the cost of repairing the broken system is cheaper than the preventive maintenance costs, the system can be allowed to fail and be repaired after the breakdown. In order for the second case to be applied, it should be thoroughly analyzed what the disruption of the system will cause. The second scenario can be applied if it does not lead to a major result. In a different scenario, preventive maintenance costs can sometimes be cheaper, but the standard deviation of the time between failures can be high. In this case, applying preventive maintenance activities can create positive results for companies.

In order for the production systems to continue to operate without interruption and at the same time to perform the breakdown maintenance operations, the companies need to increase their reliability in maintenance. The roadmap to be followed to achieve the increase has specific requirements.

The capacities of maintenance teams and equipment should be increased. With this development, companies will have a ready team that can respond immediately after a breakdown and equipment that can eliminate the problem. In this way, the idle time of the machines will be reduced to a minimum. Another specific requirement is that companies have backup production capacity. In cases of malfunction, the company's production will not be interrupted by taking the alternative use of the machine where the breakdown is experienced.

Increasing the robustness of the machines is another requirement of the roadmap. Procuring machines with high service life and low failure rates will have reduced breakdown maintenance rates and costs. Having work-in-process products between stations is the last requirement of the roadmap. In case of failure, work-in-process inventories can be created by producing more than needed so that production can continue without interruption. All these requirements for post-failure maintenance activities to be possible without disrupting production cause extra costs to companies. Companies should be cautious when determining their maintenance policies because of the extra high costs they bring and the benefits of post-failure maintenance activities. For this reason, companies should record and analyze the failures and failure frequencies. As a result of the analyzes made, it should be decided which of the preventive maintenance activities and breakdown maintenance activities will be selected. The following example shows the analysis of which maintenance activity to choose.

TABLE 12.1
The Observed Number of Breakdowns for a Number of Months

Number of Breakdowns	Number of Months That Breakdowns Occurred
0	4
1	2
2	8
3	6
4	4

Example 2: In a facility belonging to an automotive spare part manufacturer, CNC cutter machines have failed in the last two years, as shown in Table 12.1.

Each time the machines fail, the total cost to the company is €400 per breakdown. Alternatively, maintenance services have suggested preventive maintenance activities campaigns. According to the campaign, it has been stated that there may be an average of two malfunctions per month, and the price of preventive maintenance activities has been determined as €200.

Solution 2: The following four steps should be followed to decide whether to choose wait-till-breakdown or preventative maintenance:

Step 1. Calculate the expected number of breakdowns using equation 12.3 if the company does not participate in the preventive maintenance campaign by maintaining its current status.

$$\begin{aligned}&\text{Expected numbers of breakdowns}\\&=\Sigma\left[\left(\text{Number of breakdowns}\right)\times\left(\text{Corresponding Frequency}\right)\right]\end{aligned}\tag{12.3}$$

Step 2. Calculate the total cost when included in the preventive maintenance campaign using equation 12.4.

$$\begin{aligned}&\text{Expected breakdown cost}\\&=\left(\text{Expected number of breakdown}\right)\times\left(\text{Cost per breakdown}\right)\end{aligned}\tag{12.4}$$

Step 3. Calculate the total cost when included in the preventive maintenance campaign using equation 12.5.

$$\begin{aligned}&\text{Preventive maintenance cost}\\&=\left(\text{Expected cost of breakdown in the campaign}\right)\\&\quad+\left(\text{Cost of preventive service}\right)\end{aligned}\tag{12.5}$$

Step 4. Compare alternatives and choose the cheapest one.

TABLE 12.2
Frequency of the Observed Number of Breakdowns

Number of Breakdowns	Frequency
0	4 / 24 = 0,17
1	2 / 24 = 0,08
2	8 / 24 = 0,33
3	6 / 24 = 0,25
4	4 / 24 = 0,17

*Applying the steps to the question (*Table 12.2*):*

$$\text{Expected numbers of breakdowns}$$
$$= (0\times 0.17) + (1\times 0.08) + (2\times 0.33) + (3\times 0.25) + (4\times 0.17)$$
$$\text{Expected numbers of breakdowns} = 2.17 \text{ breakdowns / month}$$
$$\text{Expected breakdown cost} = (2.17)\times(€400) = €868 \text{ / month}$$
$$\text{Preventive maintenance cost} = (1 \text{ breakdowns per month}) + (\text{preventive service cost})$$
$$\text{Preventive maintenance cost} = (1\times 400) + (200) = €600$$

Preventive maintenance has been chosen as the primary maintenance activity of the company due to its lower cost.

With the example shown, it has been determined which of the preventive maintenance or breakdown maintenance activities is more appropriate for the company. However, it might not be possible to implement a perfect maintenance plan in real-life applications as expected. Companies can generally consider themselves sufficient when they have a certain level of maintenance capability. However, improvements, such as increasing maintenance equipment, enlarging their facilities, or updating the maintenance policy, provide a great advantage in making the production systems ready for production faster.

The majority of maintenance activities are carried out within the companies themselves. For this reason, another crucial issue that employers and managers need to decide on maintenance activities is at what stage of production and who should carry it out. Whether the operator, maintenance department, manufacturer maintenance support teams, or manufacturer service teams will undertake the maintenance activities should be decided. While the maintenance costs increase from the operator to the maintenance services, the maintenance competencies required by the companies decrease. However, the time to take action and the costs decrease as it goes from the maintenance service to the operator.

The operator's responsibility to undertake the activities within the scope of preventive maintenance activities is called autonomous maintenance. Operators can predict and prevent failures. In this way, the machine's service life will have been extended, and post-failure maintenance costs will have been eliminated. Autonomous maintenance activities might be evaluated as performance measurement criteria.

12.4 TOTAL PRODUCTIVE MAINTENANCE

A new concept, the total efficient maintenance approach, has emerged, with the inclusion of other departments other than maintenance in addition to the work that needs to be done on the equipment, such as preventive maintenance, in line with common goals. TPM aims to reduce the variables that may occur with autonomous maintenance and ideal maintenance procedures (Wireman 2004).

TPM is a system where everyone working throughout the company should take an active role. The entire factory team needs to be involved in the process, not only the maintenance or production departments. Companies desiring to implement the TPM concept entirely need to spend at least five to seven years. The TPM concept includes the following eight headings:

- 5S
- Autonomous maintenance
- Kobetsu kaizen
- Planned maintenance
- Early equipment management
- Quality management
- Education
- Office TPM
- Occupational health and safety

12.4.1 5S

The first thing to be implemented in TPM activities is 5S. 5S gets its name from the initials of five Japanese words (*seiri*, *seiton*, *seiso*, *seiketsu*, and *shitsuke*) that start with *S*. It is easier to detect and eliminate anomalies in an orderly fashion and clean work areas.

Seiri: What the activities are or what will be done should be determined, and the needs and purposes of these activities should be well understood. While performing these activities, what is needed and the problems experienced should be determined. As a result of the judgments made, unnecessary items should be eliminated. After that, necessary items should be placed according to the frequency of use.

Seiton: Tools should be stored appropriately to be ready for use when necessary. By making arrangements, such as the location of the tools and materials, and determining the location of the machines in the facility, it is ensured that the operator works more efficiently. In addition, visual stimuli and instructions are able to prevent deviations from standards.

Seiso: Seiri and *seiton* clean the space and organize it efficiently; *seiso* attacks the dirt that inevitably builds up under the clutter and works to keep it from coming back. Visual standard cleaning instructions should be created that are easy to follow, control, and teach. These instructions include cleaning every part of the work area on a regular (daily, weekly, monthly) basis.

Seiketsu: The first three steps of the 5S cover the basics of organizing and cleaning up a workspace. On their own, these steps will provide short-term benefits. However, *seiketsu* ensures the standardization of the activities in the first three steps of 5S. New applications can be incorporated into standard operating procedures by writing down what action is taken, where, and by whom. This method paves the way for long-term change.

Shitsuke: The idea in this step is to ensure the continuity of standardized activities. It is essential to implement the decisions made and continually return to the previous phases of the 5S in an ongoing cycle. The 5S approach is never a one-time event but repeats in a continuous process.

12.4.2 Autonomous Maintenance

Autonomous maintenance activities are some of the most critical applications for the TPM process. Today, many companies aim to bring operators to a level where they can perform autonomous maintenance activities and make them a necessary process in production. The fact that the operators only carry out production activities, do not care about the general condition of their machines, and ask for support from the maintenance department for even the most minor operation is one of the taboos that TPM wants to break. TPM is based on the principle that operators replace the philosophy "I produce, the maintenance department repairs" with the philosophy "I produce, I repair."

While autonomous maintenance ensures that production and maintenance departments work in coordination, it also expects operators to perform daily maintenance practices by being included in the maintenance processes. In this way, the operators both get to know their machines better, improve themselves, and provide the necessary time for the maintenance department to deal with more effective work. At this stage, the operators are expected to perform cleaning, lubrication, tightening, simple repair, and replacement of parts, and to detect anomalies in advance.

12.4.3 Kobetsu Kaizen

Kobetsu kaizen is a *kaizen* study to eliminate 16 losses on equipment. It is aimed to increase the overall equipment efficiency (OEE) with kaizen activities. It is necessary to collect data about the problems, examine the loss analysis, and make detailed improvement plans (Moore 2007). As a result of improvement efforts, all factors that cause inefficiency should be eliminated. Kobetsu kaizen includes loss removal activities, which are part of the OEE, as shown in Table 12.3.

12.4.4 Planned Maintenance

Planned maintenance is the maintenance work in which systematic applications increase equipment reliability, and efficiency is carried out by experienced specialist maintenance personnel. Planned maintenance activities have two main objectives: i. breakdown maintenance and preventive maintenance activities to correct and prevent errors and ii. improvement-based corrective maintenance and preventive maintenance activities to extend the machine's life, improve the maintenance time,

TABLE 12.3
Loss Types and Their Category

Loss	Category
1. Error and posture losses 2. Setup and adjustment of losses 3. Product return losses 4. First takeoff losses 5. Small stops, idle work 6. Speed losses 7. Wastage and rework losses 8. Planned maintenance losses	Losses affecting equipment efficiency
9. Administrative losses 10. Operational mobility losses 11. Line organization losses 12. Logistic losses 13. Measurement and adjustment losses	Losses affecting operator working efficiency
14. Energy losses 15. Die, jig, and apparatus losses 16. Yield losses	Losses affecting the effective use of production resources

and reduce the need for maintenance. In the TPM concept, two simple maintenance activities, autonomous and planned maintenance, must be done on the equipment side. With autonomous maintenance applications being carried out daily, mainly by the operators, it is expected that the maintenance department will perform the maintenance activities perfectly, in which, particular tools, apparatus, and techniques, which can be considered heavy maintenance, are used. This process is the top priority of the maintenance department. It must be done on time and perfectly.

Near-zero unplanned downtime is aimed by minimizing the possibility of equipment malfunction with planned maintenance activities. Maintenance activities are part of the production operation, and equipment must be stopped when the time comes for maintenance activities. In planned maintenance applications, it is expected that the original conditions of the equipment can be provided after maintenance. Each maintenance operation should be described in detail and in a standard way.

In order for the periodical planned maintenance process to be effective, which starts with the preparation of detailed maintenance and checklists for each piece of equipment, including what should be done daily, weekly, monthly, yearly, or in specific periods, such as 5,000, 10,000 hours; the points that should be included in the periodic maintenance form should generally be determined as follows:

Control and measurement points: It should be clearly defined where to check and measure the equipment.

Lubrication points: It should be clearly defined which points on the equipment will be lubricated with which type of oil, what quantity, and how.

Part controls and replacement: It should be clearly defined which parts will be checked on the equipment, with what frequency, and how.

In order to obtain effective results in the planned periodic maintenance application, the maintenance activities must be applied at the right time, with the proper technique and method; the suitable material or part should be used; and it should be done by competent maintenance personnel. In addition to these, parts of the equipment need to be changed periodically. Another essential element in planned maintenance practices is spare parts management. The maintenance department needs to prepare and budget a list of parts that need to be replaced annually and get approval. After the retrospective performance data of the machine, operator suggestions, and improvement activities during malfunction and maintenance, many improvements can be made to the equipment that facilitates maintenance or makes some maintenance operations unnecessary. These improvements are activities that improve operational maintenance efficiency every time and contribute positively to the next machine design.

12.4.5 Early Equipment

Lifecycle cost (LCC) is the sum of the design process costs, development process costs, pre-series commissioning process costs, mass production process costs, and maintenance and service process costs from the design phase of equipment to the end of its life.

In early equipment management, the goal is to reduce the LCC total cost. The more effectively the equipment is designed in the first three processes and developed and commissioned to require minimum improvement, the lower the production and maintenance costs will be. Continually focusing on improvements in the design and development phases, the aim is to transition to the series with minimum problems. Early equipment management is the whole of the improvement activities carried out at the early stage to reduce the cost of LCC in order not to leave too much improvement opportunity for the mass production phase as a result of the evaluation of production and maintenance difficulties experienced in the past, during the new product design and development phase.

12.4.6 Quality Management

TPM aims to establish an environment that will ensure error-free equipment production by eliminating errors and the causes that may lead to mistakes. At this stage, TPM focuses on parts non-compliance and equipment parts that cause or may cause failure. TPM aims to move from the "quality is controlled" idea adopted by the companies to the "quality is assured" idea. In this context, it is thought that quality should be produced in the process, and the operator should do this. According to this result, each process is responsible for two primary activities: not to produce a faulty product and not to transfer the defective product to the following process.

The poka-yoke approach is used to avoid and detect errors. Likewise, automation systems are used to prevent and detect equipment-related errors. Depending on the detection of the error in the processes, its effect on the company varies. To a large extent, process variability is caused by poor procedures, inadequate standards, machinery, unsuitable materials, unsuitable tools, and human errors.

At this step, all factors affecting quality issues are examined under the coordination of quality process engineers and try to be eliminated. The aim is to minimize the quality components' adverse effects that affect OEE.

12.4.7 Education

Human beings are at the center of most production processes; education of people, planning, and implementation of their development to meet expectations are among the indispensable rules for TPM to be successful.

In an exemplary operation, an operator is expected to be capable of performing multiple jobs as required. This is only possible by implementing a practical training and development program. Operator competencies are generally observed in four stages, and training needs are determined according to the results:

Stage 1: Doesn't know
Stage 2: Knows the theory but can't do it
Stage 3: Knows but cannot teach
Stage 4: Knows and can teach

While establishing the education system, some points should be considered, such as the following:

- Identification and planning of process-based training needs
- Identification and training of trainers
- Creation and standardization of training documents
- Establishment of the education evaluation system
- Establishment of the educational environment

12.4.8 Office TPM

As a result of many activities of managerial and communicative origin, there may be losses in the production area or general efficiency. At this stage, office TPM is mainly concerned with eliminating losses resulting from office work. The office TPM deals with the most significant losses, such as purchasing, sales, and marketing losses, that cause excessive stocks, losses due to internal and external communication, losses of inaccurate information transmission, loss of time in obtaining information, losses due to the inability of office equipment to work appropriately, failures in the urgent purchase and sales activities, and losses in office processes.

12.4.9 Occupational Health and Safety

It is more important than anything that the work can be done in healthy conditions without any work accidents. An indicator of the value given to people is how safe and secure the work environment is against the risk of accidents. The absence of work accidents should be perceived as the top priority criterion.

In this context, this issue should be primarily supervised by the management. Workplace risk maps should be prepared, and improvements should be made in all processes that guarantee worker health and work safety.

12.5 CASE STUDY

Many consultancy companies have been established in Turkey to provide the necessary training for lean production procedures. However, most of these companies do not have a competence or academic background in lean production from accredited institutions. In addition to these consultancy companies, model factories have been established by the Chambers of Commerce, which provides editing, training, and consultancy services within their structure. Consulting companies and model factories have not caught up with the digital age and still provide lean production consultancy using old methods.

Companies need to adapt to new technologies and approaches developing in the digital age to respond to increasing customer needs and speed and flexibility expectations, and to survive against the increasing competition, globalization, and cost pressures among rivals. In 2011, technologies that would define the era under Industry 4.0 were introduced in Germany for the first time to find solutions to such problems of companies. Industry 4.0 technologies have occupied an essential position in the production and service industry thanks to their ability to collect, process, analyze, modify, and report data that supports decision-making processes against the needs of companies.

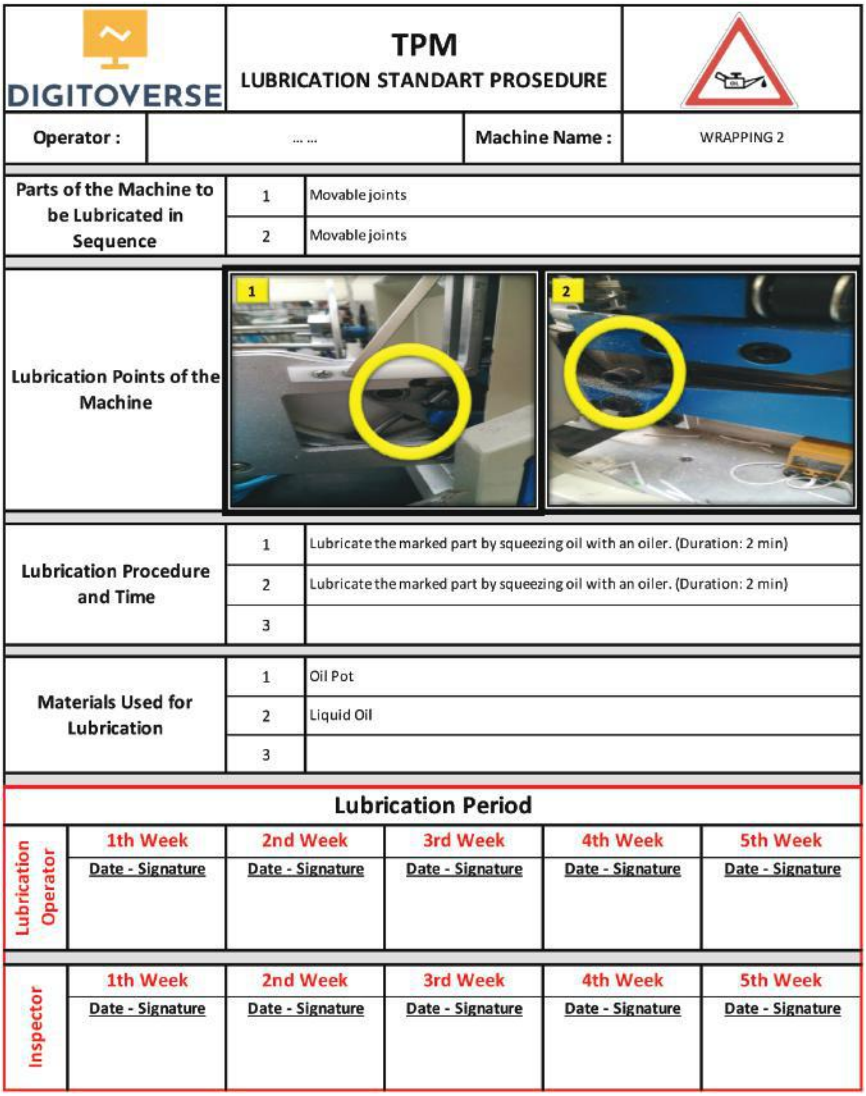
With the increasing digitalization trend in Turkey in recent years, government incentives and development agencies support companies with high-budget grants to improve themselves in digital transformation and lean production. Manufacturers in Turkey assume digital transformation only by using company resource planning software and increasing the use of automation devices. However, digital transformation tools, such as cloud technology, the Internet of Things, sensors, RFID, big data, mobile technologies, and additive manufacturing, can be applied in areas that can solve much more urgent problems for companies.

In this direction, the Dijital Evren Software and Consultancy company in Turkey has developed a lean digital transformation software with the brand Digitoverse. This software prevents the waste and errors that may occur during the training and implementation of lean production processes, which is one of the more urgent problems of companies, and enables them to integrate into more efficient lean production processes.

Lean manufacturing training given by consulting companies consumes at least six months of valuable time for companies. During this period, the training given to a group of employees from the company at regular intervals is not sufficient to spread the lean production philosophy to all employees. The enormous harm of this training is a waste of time and resources for companies. These days, when the government supports digital transformation, lean production processes are still implemented and followed through documents. Following the lean production processes with documentation is not limited to paper waste. Considering the most valuable raw material of our age, accessing the information will be a waste of time by analyzing these documents. In addition, the accuracy of the analyzed information can also be qualified as doubtful.

With the Digitoverse software, paper circulation and waste in the production environment are eliminated. Moreover, the data needed for lean production documents, such as kaizen success records, single-point courses, TPM, 5S, SMED, and *heijunka*, are collected with the help of kiosks in the digital environment. The data collected with the kiosks are processed and reported in a simple way to support the managers' decision-making.

The design of a TPM document in Digitoverse before the digitization of the lean production processes is shown in Figure 12.3. The document is the TPM standard procedure for the lubrication process. According to the document, it is shown that the operator should lubricate the lubrication points of the machine he uses correctly. After the lubrication process, it is necessary to fill in the blanks of the date and signature at the bottom of the document. If the TPM processes are done correctly, an



DIGITOVERSE	TPM LUBRICATION STANDART PROSEDURE		
Operator :	... ...	Machine Name :	WRAPPING 2

Parts of the Machine to be Lubricated in Sequence	1	Movable joints
	2	Movable joints
Lubrication Points of the Machine	1	2
Lubrication Procedure and Time	1	Lubricate the marked part by squeezing oil with an oiler. (Duration: 2 min)
	2	Lubricate the marked part by squeezing oil with an oiler. (Duration: 2 min)
	3	
Materials Used for Lubrication	1	Oil Pot
	2	Liquid Oil
	3	

Lubrication Period

	1th Week	2nd Week	3rd Week	4th Week	5th Week
Lubrication Operator	Date - Signature	Date - Signature	Date - Signature	Date - Signature	Date - Signature

	1th Week	2nd Week	3rd Week	4th Week	5th Week
Inspector	Date - Signature	Date - Signature	Date - Signature	Date - Signature	Date - Signature

FIGURE 12.3 Digitoverse TPM lubrication standard procedure document.

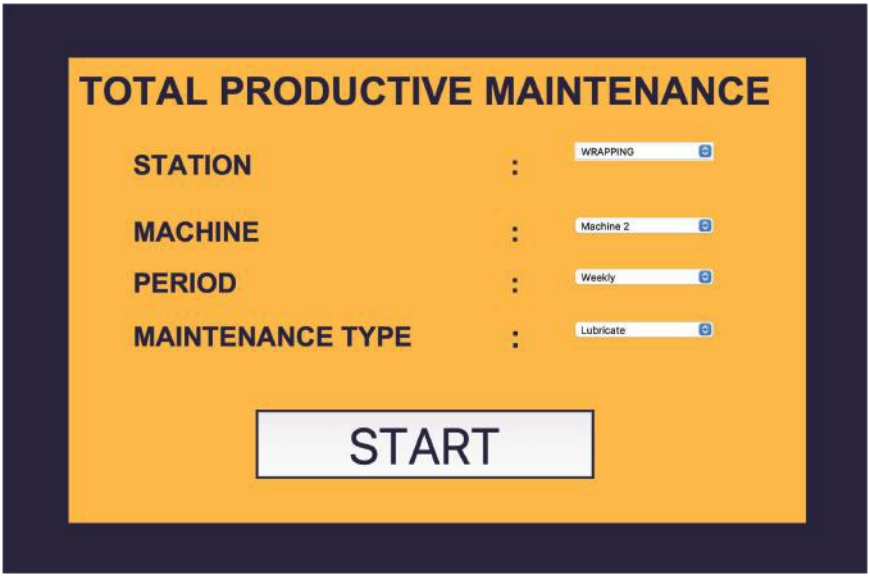


FIGURE 12.4 Digitoverse TPM software interface data entry page.

FIGURE 12.5 Digitoverse TPM software interface standard procedure display page.

inspector should check regularly. After the inspection, the signature and date gaps must be filled if no problems are encountered.

However, with the lean manufacturing software shown in Figure 12.4 and Figure 12.5, the places that need to be filled are simply shown. After filling the required boxes, the software shows the points where lubrication will be made. When you click on the button indicating that the maintenance activity has been completed on the software, when and by whom the maintenance activity was performed is kept in the database. At the same time, a notification is sent to the inspector, warning that the maintenance activity on that machine is done and should be checked.

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13 Supplier Selection and Management

Seda Turk

CONTENTS

13.1 INTRODUCTION

Supply chain management manages all activities from planning the supply of raw materials to delivering the end product and all coordination among partners consisting of vendors, manufacturers, third-party service providers and customers (Vitasek, 2010). Supply chain management is also defined as the management of all flow on distribution channels from suppliers to the end user (Thomas and Grifin, 1996). Suppliers have an important impact on the cost, quality and reputation of a company. For this reason, to enhance competitive advantages, supplier management is one of the most significant components in supply chain management (Turk et al., 2014).

In the global world, being in interaction quickly, an increase in specialisation on products and a decrease in lead time make companies face substantial risks arising from suppliers. Also, suppliers have raised the quality of a supply chain by providing quality raw materials, providing lead time efficiency and eliminating waste (Alimardani et al., 2014). These lead companies to focus on working with suitable suppliers, which has become a strategic challenge. Globalisation has also pushed companies in the industrialised world to have specific standards that provide worldwide trade. Sustainability is one of these standards that show the economic, environmental and social awareness of a company. Gaining and maintaining sustainability needs to handle and manage economic, environmental and social issues that arise from local, regional and global areas. Sustainable development for companies has become

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a significant challenge to deal with competitors and attain competitive advantages by addressing all issues (Gavrilescu, 2011). The achievement of a company in the perspective of sustainable development is an accomplished integration of sustainability into all processes (Zhan et al., 2021). One of the critical processes can be defined as sustainable supply chain management, and the importance of sustainable supply selection has been revealed in recent years. For instance, according to Hollos et al. (2012), several leading companies in electronics, such as Apple, Hewlett-Packard and Sony, have made a loss because of having Foxconn as one of their suppliers. Hence, to avoid any damage caused by their suppliers' environmental or ethical misconduct, companies have been focused on sustainable development in the supplier selection process (Govindan et al., 2018).

In addition, intelligent technologies are some of these standards that help gain competitive advantages for an organisation. Intelligent technologies, such as artificial intelligence (AI) techniques and the Internet of Things (IoT), come up with benefits for companies in a competitive environment because it provides detectable, identifiable, interpretable, foreseeable, controllable and optimisable supply chain systems (Chen et al., 2020). Intelligent technologies make activities in any process memorable, programmable, associable, addressable, sensible and communicable. Excluding these activities from supply chain management can change companies' interaction and collaboration among partners negatively (Nasiri et al., 2020). Although numerous benefits of digitalisation in supply chain management are accepted by many companies, their validation is shown in few studies (Büyüközkan and Göçer, 2018a). Hence, in this chapter, a smart sustainable supplier management is identified in terms of its main components. A supplier selection process is evaluated in terms of sustainability as a multicriteria decision-making problem for a plastic packaging company in Turkey.

13.2 SMART SUPPLIER SELECTION

Smart technologies, such as AI, IoT, cyber-physical systems (CPSs) and big data analytics, have spread around very quickly to make our lives easier, providing a new and improved way (Chen et al., 2020). Awareness of customers about innovative technologies has forced companies to shift their services from companies to individuals, and firms need to manage demands using well-equipped technologies to take advantage of this situation (Büyüközkan and Göçer, 2018a). Smart supply chain management is also vital to improving their capability in customer satisfaction and achieving the success of companies in the digital world (Gunduz et al., 2021). According to a review by Büyüközkan and Göçer (2018a), features that innovative technologies amend the supply chain management can be listed as follows:

- Speed to get their needs from vendors
- Flexibility in adapting to changing circumstances
- Global collaboration, which builds effective global hubs to supply goods and services locally
- Effective inventory management to monitor stock levels continuously
- Intelligent systems, which provide self-learning and self-giving decisions

- Transparent environments that make all processes manageable, understanding their behaviours and needs
- Cost-effective management
- Innovative perspective on processes in a supply chain management
- Proactive management that aims for effective planning and forward-thinking
- Eco-friendly structures

Since successful supply chain management went through successful supplier management, companies have been working on switching to innovative technologies in the supplier management process (Büyüközkan and Göçer, 2017). Although the supplier selection process has to be improved by implementing intelligent technologies to gain and maintain competitive advantages, the role of intelligent technologies in supplier selection is still in its beginning period, and limited research exists on the issues related to the implementation of smart supplier selection.

In addition, supplier selection is one of the most critical processes for managing a company, along with financial and operational opportunities. Working with an appropriate supplier can provide a decrease in cost and delivery time, and an improvement in quality (Alavi et al., 2021). While evaluating suppliers, their appearance, similarities to the company and perceptual inputs, such as auditory, also affect this evaluation process. In order to eliminate this effect, it may be necessary to control how effective the perceptions of decision-makers are. Cognitive judgments and behaviours have a significant influence on business relationships between buyers and suppliers (Blessley et al., 2018). In literature, there are several research on personal perception in several fields, such as consumer behaviour investigation (Byrd et al., 2021; Truong et al., 2021), brand influence on consumers (Long et al., 2019), buyer-supplier interactions (Blessley et al., 2018) and buyer-supplier attraction (Amino and Tanskanen, 2013). However, according to the literature, there is no study on the investigation of the personal perception of decision-makers during their evaluation process of suppliers. Thus, this study proposes to take into account the personal perception of decision-makers to investigate their influence on selecting suppliers.

13.3 SUSTAINABLE SUPPLIER SELECTION

Sustainable supplier selection (SSS), which considers social, economic and environmental aspects of actions during all processes, from buying raw materials and delivering end products to customers, can be defined as a typical multicriteria decision-making problem. Due to the significance of working with suitable suppliers, a number of multicriteria decision-making (MCDM) approaches have been proposed. According to the literature review, there are individual or integrated MCDM approaches applied to sustainable supplier selection in several different fields (Schramm et al., 2020). Recent literature and related works are summarised in Table 13.1 and show that the application area has been varied, from the telecom industry to the textile, and many MCDM approaches are used to solve each specific SSS problem. In this work, the sustainable supplier selection problem of a plastic packaging manufacturer is solved using interval-valued intuitionistic fuzzy sets, along with a consideration of many factors related to person perception.

TABLE 13.1
Some Applications of Sustainable Supplier Selection Using MCDM Methods, Showing Their Sectors and Specific Methods Applied

Sector	Year	Methods
Electronics company	2009	ANP (Hsu and Hu, 2009)
Telecom industry	2017	AHP with grey relational analysis (Ahmedi et al., 2017)
Food industry	2018	TOPSIS (Shalke et al., 2018)
Dairy company	2018	ANP-TOPSIS (Basset et al., 2018)
Automotive spare parts manufacturer	2019	Intuitionistic fuzzy TOPSIS method (Memari et al., 2019)
Widget manufacturing company	2020	Interval type-2 fuzzy set (Hendiani et al., 2020)
Automobile manufacturer company		
Transmission cables company		
Home appliance manufacturer	2020	Fuzzy best-worst method (Ecer and Pamucar, 2020)
Vehicle transmission market	2020	Fuzzy TOPSIS-DEMATEL model (Chen et al., 2020)
Textile industry	2021	Interactive fuzzy programming (Tayyab and Sarkar, 2021)

In addition, as seen in Table 13.1, sustainable supplier selection problems have been solved using different MCDM methods. The main idea behind MCDM methods is to determine the number of criteria believed to have an impact on the success of the supply chain management and evaluate vendors considering these criteria. For sustainable supplier selection problems, there are many criteria used in several types of research, and it is shown in Table 13.2. In this study, 16 criteria covering economic, environmental, social and smart aspects of sustainability are selected to evaluate suppliers. These criteria are quality, delivery, service, performance and cost from an economic perspective, environmental efficiency, green image, pollution reduction, green competencies from an environmental perspective and social perspective, OHSAS 18001 certification, rate of health and safety incidents, employee rights and staff training.

13.4 INDUSTRY APPLICATION

In our daily life, using plastics has taken an indispensable place. Plastics in various forms can be found for all the daily essentials, such as disposable dishware and personal care. Plastic packaging is the most crucial form of plastic, and without it, it has become impossible to visualise any products or goods for companies. Plastic packaging, especially in the food industry, which aims to provide food products safely along with easy handling and increasing shelf life, is the largest-growing industry (Sundqvist-Andberg and Akerman, 2021).

At the same time, the quantity of plastic waste has been enlarging when looking at it from an environmental perspective with each passing day. According to Plastics Europe, an association of the European plastics industry, while the production of plastics reached 359 million tonnes in 2018 in Europe, this number has been decreasing slightly due to the awareness of the negative impacts of using plastics and the

TABLE 13.2
Criteria Used for Sustainable Supplier Selection Problems

	Economic Sustainability								
Authors	**Cost**	**Quality**	**Service**	**Delivery**	**Loyalty**	**Technological Capability**	**Profit**	**Flexibility**	**Capacity**
Ahmedi et al. (2017)	X	X	X						
Shalke et al. (2018)	X	X		X	X	X			
Amindoust et al. (2012)		X	X	X			X		
Hsu and Hu (2009)		X	X	X					
Basset et al. (2018)	X	X				X		X	
Alavi et al. (2021)	X	X		X		X		X	
Hendiani et al. (2020)	X	X	X	X	X			X	X
Ecer and Pamucar (2020)	X	X	X	X					
Memari et al. (2019)	X	X	X						
Chen et al. (2020)	X	X	X					X	

(*Continued*)

TABLE 13.2 (Continued)

	Social Sustainability										
Authors	**Work Safety and Labor Health**	**Staff Training**	**Stakeholder Rights**	**Occupational Health and Safety Management Systems**	**Human Rights**	**Information Disclosure**	**Forced Child Labor**	**Social Commitment**	**Employee Rights**	**Adherence to Law and Policy**	**Smart Working Environment**
Ahmedi et al. (2017)	X	X	X								
Shalke et al. (2018)		X	X	X							
Amindoust et al. (2012)	X		X								
Hsu and Hu (2009)											
Basset et al. (2018)											
Alavi et al. (2021)				X	X	X	X	X			
Hendiani et al. (2020)		X	X	X		X	X		X	X	
Ecer and Pamucar (2020)	X	X	X			X			X		
Memari et al. (2019)	X	X						X			X
Chen et al. (2020)		X	X					X			X

	Environmental Sustainability										
Authors	**Green Corporate Image**	**Eco-Design**	**Environmental Management Systems**	**End-of-Pipe**	**Pollution**	**Environmental Competencies**	**Green Material Inventory Records**	**Defilement Production**	**Resource Exhaustion**	**Recycling Materials**	**Energy Conservation**
Ahmedi et al. (2017)	X	X	X	X							
Shalke et al. (2018)	X				X	X					
Amindoust et al. (2012)			X			X					
Hsu and Hu (2009)	X						X				
Basset et al. (2018)		X						X	X		
Alavi et al. (2021)			X		X					X	
Hendiani et al. (2020)	X		X		X	X					X
Ecer and Pamucar (2020)	X		X		X	X	X				
Memari et al. (2019)	X				X	X					
Chen et al. (2020)	X		X		X						X

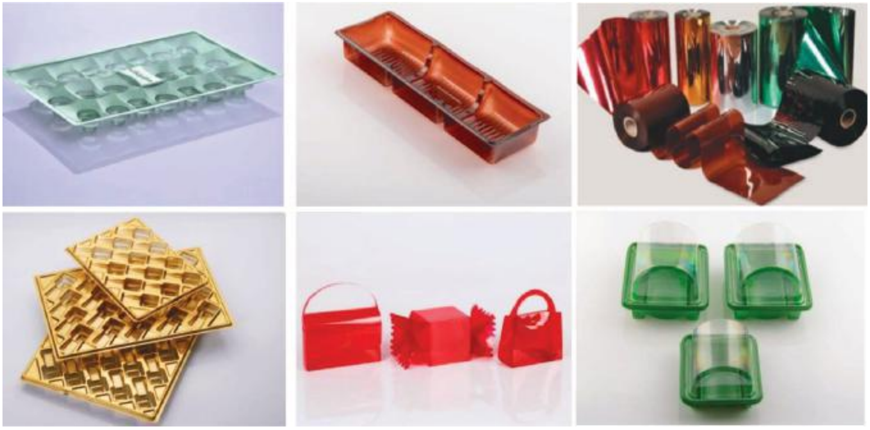

FIGURE 13.1 Some products of the plastic packaging company. (Armasan, 2022)

coronavirus pandemic (Plastics Europe, 2020). As a non-renewable resource with a high carbon footprint, plastics need to be kept under control by either downsizing or recycling them concerning the lifecycle of plastic for sustainability (Karanth et al., 2021). Hence, in this chapter, a plastic packaging company operating in Tekirdag, Turkey, is taken into consideration to identify, evaluate and encourage its suppliers in respect of sustainability. The company has a large production range, varying from vacuum thermoforming to folding boxes for more than 40 countries. Products are mainly in the fields of food, confectionery, cosmetics, medical, stationery and glassware sectors. The company also produces raw materials from recycled, and Figure 13.1 demonstrates a couple of products as examples (Armasan, 2022). Interval-valued intuitionistic fuzzy sets as a multicriteria decision-making approach are used to examine the performance of their vendors in terms of several criteria determined based on experts and literature review.

In order to form the problem, three suppliers are taken into account by three decision-makers, consisting of a quality manager, a production manager and a purchasing manager of the company. The suppliers' performances are evaluated in terms of 4 main criteria and 16 sub-criteria. Also, the personal perception of three decision-makers is investigated using eight criteria related to the personal perception of human beings. In this sense, collaboration with these suppliers, which provide the best performance in terms of sustainability, is believed to be capable of increasing recycling quality while decreasing the amount of total use of plastics. In addition, concerning the context of sustainable supplier selection in a developing bright environment, this study contributes to the literature.

13.4.1 Preliminaries

This section briefly introduces the main concepts of interval-valued intuitionistic fuzzy (IVIF) sets and the arithmetic operations of IVIF sets used in this study.

13.4.1.1 Interval-Valued Intuitionistic Fuzzy Sets

The concept of ordinary fuzzy sets introduced by Zadeh (1965) defines each element of a set with a membership value, and Atanassov (1986) proposed intuitionistic fuzzy sets, which consider both a membership value and a non-membership value of an element.

Definition 1. An ordinary fuzzy set *F* of Zadeh (1965) can be shown using a membership function $\mu_F(x)$, where $\mathrm{x} \to [0,1]$ as follows:

$$F = \{(x, \mu_F(x)) \mid \forall \mathrm{x} \in \mathrm{X}\} \tag{13.1}$$

where $0 \le \mu_F(x) \le 1$ in the universe of discourse *X*.

Definition 2. An intuitionistic fuzzy set *IF* of Atanassov (1986) can be expressed as follows:

$$IF = \{(x, \mu_{IF}(x), \vartheta_{IF}(x)) \mid \forall \mathrm{x} \in \mathrm{X}\} \tag{13.2}$$

where $\mu_{IF}(x)$ is a membership function of element x in between 0 and 1, and $\vartheta_{IF}(x)$ is a non-membership function of element x in between 0 and 1 in the universe of discourse *X*.

Definition 3. The degree of non-determinacy of an intuitionistic fuzzy, namely hesitation degree $\pi_{IF}(x)$ for an element x, can be shown as (Atanassov, 1986):

$$\pi_{IF}(\mathrm{x}) = 1 - \mu_{IF}(x) - \vartheta_{IF}(x) \tag{13.3}$$

Definition 4. An interval-valued intuitionistic fuzzy set *IVIF* is the extension of intuitionistic fuzzy sets (Atanassov and Gargov, 1989):

$$IVIF = \{(x, \mu_{IVIF}(x), \vartheta_{IVIF}(x), \pi_{IVIF}(x)) \mid \forall \mathrm{x} \in \mathrm{X}\} \tag{13.4}$$

where $\mu_{IVIF}(x) = [\mu_{IVIF}{}^{l}, \mu_{IVIF}{}^{u}] \subset [0,1], \vartheta_{IVIF}(x) = [\vartheta_{IVIF}{}^{l}, \vartheta_{IVIF}{}^{u}] \subset [0,1]$ and $\pi_{IVIF}(x) = [\pi_{IVIF}{}^{l}, \pi_{IVIF}{}^{u}] \subset [0,1]$. It is also demonstrated as follows:

$$IVIF = \{[\mu_{IVIF}{}^{l}, \mu_{IVIF}{}^{u}], [\vartheta_{IVIF}{}^{l}, \vartheta_{IVIF}{}^{u}], [\pi_{IVIF}{}^{l}, \pi_{IVIF}{}^{u}]\} \tag{13.5}$$

Algebraic operations used in this chapter are explained as follows. Let's define two interval-valued intuitionistic fuzzy sets: $A = \{[\mu_A{}^{l}, \mu_A{}^{u}], [\vartheta_A{}^{l}, \vartheta_A{}^{u}]\}$ and $B = \{[\mu_B{}^{l}, \mu_B{}^{u}], [\vartheta_B{}^{l}, \vartheta_B{}^{u}]\}$ in the universe of discourse *X*.

1. $$A \otimes B = \{[(\mu_A{}^{l} \times \mu_B{}^{l}), (\mu_A{}^{u} \times \mu_B{}^{u})], [(\vartheta_A{}^{l} + \vartheta_B{}^{l} - (\vartheta_A{}^{l} \times \vartheta_B{}^{l}), (\vartheta_A{}^{u} + \vartheta_B{}^{u} - (\vartheta_A{}^{u} \times \vartheta_B{}^{u}))]\} \tag{13.6}$$

2. $$A \oplus B == \begin{Bmatrix} \left[\left(\mu_A{}^l + \mu_B{}^l - \mu_A{}^l \times \mu_B{}^l\right), \left(\mu_A{}^u + \mu_B{}^u - \mu_A{}^u \times \mu_B{}^u\right)\right], \\ \left[\left(\vartheta_A{}^l \times \vartheta_B{}^l\right), \left(\vartheta_A{}^u \times \vartheta_B{}^u\right)\right] \end{Bmatrix} \tag{13.7}$$

3. $$\rho \times A = \left\{\left[\left(1-\left(1-\mu_A{}^l\right)^\rho\right), (1-\left(1-\mu_A{}^u\right)^\rho\right], \left[(\vartheta_A{}^l)^\rho, (\vartheta_A{}^u)^\rho\right]\right\} \tag{13.8}$$

4. $$A^\rho = \left\{\left[(\mu_A{}^l)^\rho, (\mu_A{}^u)^\rho\right], \left[\left(1-\left(1-\vartheta_A{}^l\right)^\rho\right), \left(1-\left(1-\vartheta_A{}^u\right)^\rho\right)\right]\right\} \tag{13.9}$$

Definition 5. The score function used in this study is formulated as follows (Xu and Chen, 2007):

$$S(A) = \mu_A{}^l + \mu_A{}^u + \left(1-\vartheta_A{}^l\right) + \left(1-\vartheta_A{}^u\right) + \mu_A{}^l \times \mu_A{}^u - \sqrt{\left(1-\vartheta_A{}^l\right)\left(1-\vartheta_A{}^u\right)} \tag{13.10}$$

In addition, the interval-valued intuitionistic fuzzy weighted averaging (IFWA) operator is used for aggregation (Xu and Cai, 2012), and the formulation of IFWA is illustrated as follows:

$$IIFWA_K = \begin{Bmatrix} \left[\left(1-\prod_{k=1}^{K}\left(1-\mu_A{}^l\right)^{\frac{1}{K-1}}\right), \left(1-\prod_{k=1}^{K}\left(1-\mu_A{}^u\right)^{\frac{1}{K-1}}\right)\right], \\ \left[\prod_{k=1}^{K}\left(\vartheta_A{}^l\right)^{\frac{1}{K-1}}, \prod_{k=1}^{K}\left(\vartheta_A{}^u\right)^{\frac{1}{K-1}}\right] \end{Bmatrix} \tag{13.11}$$

where K is the number of decision-makers.

13.4.2 Methodology

In this section, a sustainable supplier selection problem is solved by creating two scenarios. In the first scenario, the weights of 3 decision-makers are defined using linguistic evaluation, then 3 suppliers are examined in terms of 4 main criteria and 16 sub-criteria, along with a consideration of the weights of decision-makers. In the second scenario, 3 decision-makers are investigated to manage the adverse impacts of personal perception on their decisions using 8 criteria related to personal perception, and based on this investigation, the weight of each decision-maker is assigned, and then 3 vendors are evaluated using criteria selected (4 main criteria and 16 sub-criteria) by 3 decision-makers whose weights are calculated. In this section, the definition of each criterion used in this study and the approach proposed are given.

13.4.2.1 Definition of Criteria

In the first step of the second scenario, eight criteria are used to examine the perspective of decision-makers on the behaviour of suppliers. These criteria are selected based on the extended literature review and detailed as follows (Salminen et al., 2020):

1. **Clarity (*N*1)** is the quality of being clear and precise. For suppliers, it is related to the clarity of information that suppliers provide to the experts.
2. **Completeness (*N*2)** is the state of being complete and entire without unrelated information, providing only the information needed.
3. **Consistency (*N*3)** is about receiving the same information as previously taken.
4. **Credibility (*N*4)** is being worthy of trust and belief.
5. **Empathy (*N*5)** is the ability to understand and sense others' emotions and be able to think like the other party to understand the reason behind the action.
6. **Likability (*N*6)** is about having qualities that make one like this person.
7. **Similarity (*N*7)** is having similar aspects to someone and feeling close to this person.
8. **Willingness to use (*N*8)** is the keenness of the user to have something. This criterion has a negative impact on the evaluation processes of suppliers.

Decision-makers are asked how important these criteria are for them, and based on the answers, the perception of decision-makers is investigated, and the weights of decision-makers are calculated. The weights are carried into the next step as the weights of decision-makers. Then the sustainable supplier selection problem is solved using interval-valued intuitionistic fuzzy sets under 4 main criteria and 16 sub-criteria (shown in Table 13.3) determined by experts.

Economic sustainability (M1) is the ability of economic development in a company in the long term without any negative impact on ecological sustainability, and

TABLE 13.3
The List of Criteria and Sub-Criteria Selected Related to Sustainability

Criteria	Abb.	Sub-Criteria	Abb.
Economical	M1	Quality	C1
		Delivery	C2
		Service Performance	C3
		Cost	C4
		Green image	C5
Environmental	M2	Pollution reduction	C6
		Green competencies	C7
		Environmental efficiency	C8
		OHSAS 18001 certification	C9
Social	M3	Rate of health and safety incidents	C10
		Employee rights	C11
		Staff training	C12
Smart	M4	Using AI	C13
		Having Autonomous systems	C14
		Using cloud technologies	C15
		Controlling via IoT	C16

it covers five sub-criteria, namely quality (C1), delivery (C2), service performance (C3) and cost (C4).

C1. **Quality** can be defined as meeting customer expectations by providing either a good or a service (Abdolshah, 2013).
C2. **Delivery** is related to three terms in a supply chain; inventory, cost and time. A successful delivery policy of a company is to negotiate among these three terms to get a good or service at the right time and the right amount to customers along with a minimum cost (Taherdoost and Brard, 2019).
C3. **Service performance** is the performance of suppliers while providing a good or service. Service covers these issues: i) to customise the product according to customer demands, ii) to make possible the small size of an order, iii) to be able to respond quickly to any change, and iv) to meet customer expectations during communication (Taherdoost and Brard, 2019).
C4. **Cost** is the sum of the expense incurred in the production process, from the raw materials to the end product (Abdolshah, 2013).

Environmental sustainability (M2) is related to the protection of natural resources to ensure the continuity of ecosystems for now and the future (Memari et al., 2019). In this study, four sub-criteria are taken to account, namely green image (C5), pollution reduction (C6), green competencies (C7) and environmental efficiency (C8), and the brief definition of each criterion is given respectively as follows (Memari et al., 2019):

C5. **Green image** is the supplier's ability to produce eco-friendly products and actions for the long term.
C6. **Pollution reduction** is about mitigating greenhouse gas emissions along with keeping under control of wastewater, air emissions, carbon footprint, solid wastes and use of harmful materials.
C7. **Green competencies** are the capability of a supplier to use clean technologies, such as green packaging and recycling capability.
C8. **Environmental efficiency** is the ability of a supplier to combine external environmental policies and internal ones with respect to environmental protection.

Social sustainability (M3) is a perspective of a supplier looking at sustainability in terms of protecting its employees. This criterion consists of having an OHSAS 18001 certification (C9), rate of health and safety incidents (C10), employee rights (C11) and staff training (C12) (Ecer and Pamucar, 2020).

C9. **Having an OHSAS 18001 certification** is a way to measure the awareness of a supplier across the protection of employees.
C10. **Rate of health and safety incidents** shows us the implementation of policies to protect employees in a company.
C11. **Employee rights** are about how a supplier respects and protect all rights and interests of employees in the company.

C12. **Staff training** is related to the attitude of a supplier toward the continuous training and education of employees.

Smart sustainability (M4) is related to smart technologies used to maintain sustainability to increase efficiency along with a decrease in the need for workers (Gunduz et al., 2021). This criterion has four sub-criteria: using AI (C13), having autonomous systems (C14), using cloud technologies (C15) and controlling via IoT (C16).

C13. **Using AI** covers how a company is using AI-enhanced tools throughout supply chains.
C14. **Having autonomous systems** is about the ability and capacity to manage all processes during the production of a good or service without a single human intervention.
C15. **Using cloud technologies** provides a platform combining the physical processes and software to manage the supply chain remotely.
C16. **Controlling via IoT** is the ability to manage a supply chain via drones to monitor and control remotely (Gunduz et al., 2021).

13.4.2.2 The Proposed Approach

In this study, three decision-makers, DM1, DM2 and DM3, evaluate three suppliers, A1, A2 and A3, according to several criteria related to sustainability. Two scenarios are created: i) the weight of decision-makers is determined using linguistic terms, and ii) the weight of decision-makers is decided by considering eight personal perception criteria and evaluating each decision-maker in terms of these eight criteria and, based on this evaluation, assign a weight to the decision-maker. Therefore, each scenario includes two main parts: first, determine the weight of decision-makers, and then second, solve the multicriteria decision-making problem. The approach proposed consists of eight steps that cover two main parts of the problem, explained as follows:

Step 1: The weight of each decision-maker is calculated based on each scenario and assigned.
Step 2: The importance of the three main criteria and their corresponding sub-criteria are determined by three decision-makers. Table 13.4 indicates the linguistic terms and the corresponding interval-valued intuitionistic fuzzy numbers used.
Step 3: Global score for the importance of each criterion is found by multiplying the main criterion and its corresponding sub-criterion. In order to provide a better understanding, let's define economic sustainability (M1) as very important, and one of its sub-criteria quality (C1) as important, and the global score of C1 can be found as follows:

$$M1 \otimes C1 = \Big\{\Big[\big(\mu^{l}{}_{M1} \times \mu^{l}{}_{C1}\big), \big(\mu^{u}{}_{M1} \times \mu^{u}{}_{C1}\big)\Big], \Big[(\vartheta^{l}{}_{M1} + \vartheta^{l}{}_{C1} - \big(\vartheta^{l}{}_{M1} \times \vartheta^{l}{}_{C1}\big), \\ \big(\vartheta^{u}{}_{M1} + \vartheta^{u}{}_{C1} - \big(\vartheta^{u}{}_{M1} \times \vartheta^{u}{}_{C1}\big)\big)\Big]\Big\} = [0.76, 0.85], [0.05, 0.10] \tag{13.12}$$

TABLE 13.4
Linguistic Variable to Define the Importance of Each Criterion

Linguistic Variables	IVIF Values		
	$[\mu^l, \mu^u]$	$[\vartheta^l, \vartheta^u]$	$[\pi^l, \pi^u]$
Extremely important (EI)	[0.95, 1.00]	[0.00, 0.00]	[0.00, 0.05]
Very important (VI)	[0.80, 0.85]	[0.05, 0.10]	[0.05, 0.15]
Important (I)	[0.60, 0.65]	[0.10, 0.15]	[0.20, 0.30]
Medium (M)	[0.30, 0.35]	[0.25, 0.30]	[0.35, 0.45]
Unimportant (U)	[0.20, 0.25]	[0.30, 0.35]	[0.40, 0.50]
Very unimportant (VU)	[0.00, 0.05]	[0.45, 0.50]	[0.45, 0.55]

(Büyüközkan and Göçer, 2018b)

TABLE 13.5
Linguistic Variable to Evaluate Alternatives

Linguistic Variables	IVIF Values		
	$[\mu^l, \mu^u]$	$[\vartheta^l, \vartheta^u]$	$[\pi^l, \pi^u]$
Extremely good (EG)	[0.99, 1.00]	[0.00, 0.00]	[0.00, 0.01]
Very, very good (VVG)	[0.90, 0.95]	[0.01, 0.04]	[0.01, 0.09]
Very good (VG)	[0.80, 0.85]	[0.05, 0.10]	[0.05, 0.15]
Good (G)	[0.70, 0.75]	[0.15, 0.20]	[0.05, 0.15]
Medium good (MG)	[0.60, 0.65]	[0.25, 0.30]	[0.05, 0.15]
Medium (M)	[0.50, 0.55]	[0.35, 0.40]	[0.05, 0.15]
Medium bad (MB)	[0.40, 0.45]	[0.45, 0.50]	[0.05, 0.15]
Bad (B)	[0.30, 0.35]	[0.55, 0.60]	[0.05, 0.15]
Very bad (VB)	[0.20, 0.25]	[0.65, 0.70]	[0.05, 0.15]
Very, very bad (VVB)	[0.10, 0.15]	[0.75, 0.80]	[0.05, 0.15]

(Büyüközkan and Göçer, 2018b)

Step 4: The performance of each supplier is assigned for each criterion using the linguistic terms shown in Table 13.5, and the global score for the performance of suppliers is found by multiplying the main criterion and its corresponding sub-criterion.

Step 5: The aggregate interval-valued intuitionistic fuzzy decision matrix is formed by multiplying the importance of each criterion by the performance of each supplier.

Step 6: The IFWAA operator is used to obtain the aggregate weighted intuitionistic fuzzy super decision matrix.

Step 7: To calculate the scores of alternatives, the score function explained in equation 13.10 is used.

Step 8: Based on the score found, alternatives are ranked.

13.4.3 Preliminary Experiments and Results

The proposed method is applied to the sustainable supplier selection problem of a plastic packaging manufacturer as a real-world problem, and the application of each step is explained as follows:

Step 1: Calculation of the weight of each decision-maker for each scenario is shown as follows:

a. **Scenario 1:** The importance of decision-makers is determined using the linguistic terms shown in Table 13.3, and the weights of decision-makers are calculated using the following formula:

$$w_i = \frac{w_i^l + w_i^u}{2} = \left(\frac{\mu_i^l + \pi_i^l \times \dfrac{\mu_i^l}{\left(\mu_i^l + \vartheta_i^l\right)}}{\sum_{i=1}^{n} \left(\mu_i^l + \pi_i^l \times \dfrac{\mu_i^l}{\left(\mu_i^l + \vartheta_i^l\right)} \right)} + \frac{\mu_i^u + \pi_i^u \times \dfrac{\mu_i^u}{\left(\mu_i^u + \vartheta_i^u\right)}}{\sum_{i=1}^{n} \left(\mu_i^u + \pi_i^u \times \dfrac{\mu_i^u}{\left(\mu_i^u + \vartheta_i^u\right)} \right)} \right) / 2 \quad (13.12)$$

The importance of Decision-Maker 1 (DM1) is assigned as extremely important, where DM2 and DM3 are assigned as very important. Based on this formula, the weights are found as 0.354, 0.323 and 0.323, respectively.

b. **Scenario 2:** The personal perceptions of decision-makers are investigated in terms of the eight criteria explained in Chapter 13.4.2.1 “Definition of Criteria”. The view of decision-makers is revealed through evaluating these criteria. In respect of their opinions, Table 13.6 shows how important each criterion is for decision-makers. The score of each criterion is found using equation 13.12, and then the mean value of the scores achieved for all criteria is calculated and assigned as the weights

TABLE 13.6
Evaluation of Criteria According to Decision-Makers

Criterion	DM1	DM2	DM3	Criterion	DM1	DM2	DM3
N1	VI	I	M	N5	M	M	VI
N2	VI	I	M	N6	VI	M	U
N3	I	I	I	N7	VI	VI	M
N4	VI	VI	VI	N8	I	I	M

of decision-makers. Decision-makers' weights are found as 0.312, 0.317 and 0.371, respectively.

Step 2: The importance of the three main criteria and their corresponding sub-criteria are determined by three decision-makers, as indicated in Table 13.7.

Step 3: The global score for the importance of each criterion is found by multiplying the main criterion and its corresponding sub-criterion, as explained in Chapter 13.4.2.2, and Table 13.8 demonstrates the global scores for each criterion.

TABLE 13.7
Importance of Criteria Based on Decision-Makers

Decision-Makers	M1	M2	M3	M4	C1	C2	C3	C4	C5	C6
DM1	EI	I	I	EI	EI	EI	I	EI	I	I
DM2	EI	EI	I	I	EI	I	EI	I	I	EI
DM3	I	I	I	EI	I	I	I	M	I	VI
Decision-Makers	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
DM1	I	I	I	I	I	I	I	VI	I	VI
DM2	I	EI	EI	EI	I	I	M	M	VI	VI
DM3	I	I	M	VI	VI	VI	I	I	M	I

TABLE 13.8
Global Score of Criteria for Their Importance

Criteria	μ^l	ϑ^l	μ^u	ϑ^u
$C1_g$	0.293	0.190	0.423	0.278
$C2_g$	0.185	0.271	0.275	0.386
$C3_g$	0.185	0.271	0.275	0.386
$C4_g$	0.093	0.393	0.148	0.494
$C5_g$	0.074	0.410	0.116	0.556
$C6_g$	0.156	0.307	0.233	0.447
$C7_g$	0.074	0.410	0.116	0.556
$C8_g$	0.117	0.344	0.179	0.478
$C9_g$	0.037	0.508	0.062	0.635
$C10_g$	0.098	0.377	0.152	0.530
$C11_g$	0.062	0.439	0.099	0.601
$C12_g$	0.062	0.439	0.099	0.601
$C13_g$	0.470	0.134	0.573	0.188
$C14_g$	0.564	0.105	0.683	0.163
$C15_g$	0.557	0.107	0.675	0.165
$C16_g$	0.676	0.063	0.803	0.114

Step 4: The performance of each supplier is determined for each criterion using the linguistic terms shown in Table 13.5, and Table 13.9 demonstrates their linguistic evaluation.

Step 5: The aggregate interval-valued intuitionistic fuzzy decision matrix is formed by multiplying the importance of each criterion by the performance of each supplier and demonstrated in Table 13.10.

TABLE 13.9
Suppliers' Performance Assigned by Decision-Makers

Criteria	A1			A2			A3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
M1	VVG	VVG	VVG	G	G	VG	G	G	VVG
M2	G	G	VG	VG	VG	VG	VG	VG	VG
M3	VG	VG	G	VG	VG	VG	VG	VG	VG
M4	G	G	MG	MG	MG	G	G	VG	G
C1	VVG	VVG	VVG	G	G	VG	G	G	VVG
C2	VG	VG	VG	VG	G	VG	G	VVG	G
C3	VVG	G	VG	G	G	VG	VVG	VG	VG
C4	G	G	VG	G	G	VG	VVG	VVG	VG
C5	VG	VG	G	VG	VG	VG	VG	VG	VG
C6	VG	G	G	VG	VG	VG	VG	VG	VG
C7	VG	VG	G	VG	VG	VG	VG	VG	VG
C8	G	G	G	VG	VG	VG	VG	VG	VG
C9	VVG	VVG	VVG	VG	VG	VG	VG	VG	VG
C10	VG	VG	G	VG	VG	VG	VG	VG	VG
C11	VG	VG	VG	VG	VG	VG	VG	VG	VG
C12	VG	VG	VG	VG	VG	VG	VG	VG	VG
C13	M	MG	MG	MG	MG	MG	MB	M	MB
C14	VG	VG	G	G	G	MG	MG	MG	G
C15	M	M	MB	MB	M	M	M	MB	MB
C16	VG	VG	VG	G	VG	G	MG	G	G

TABLE 13.10
The Aggregate Interval-Valued Intuitionistic Fuzzy Decision Matrix

Criteria	Alternative 1				Alternative 2				Alternative 3			
	μ^l	ϑ^l	μ^u	ϑ^u	μ^l	ϑ^l	μ^u	ϑ^u	μ^l	ϑ^l	μ^u	ϑ^u
C1	0.810	0.020	0.903	0.078	0.543	0.199	0.621	0.294	0.623	0.121	0.725	0.224
C2	0.720	0.060	0.808	0.136	0.569	0.169	0.649	0.265	0.623	0.121	0.725	0.224
C3	0.739	0.050	0.836	0.127	0.543	0.199	0.621	0.294	0.666	0.089	0.765	0.183

(*Continued*)

TABLE 13.10 (Continued)

Criteria	Alternative 1				Alternative 2				Alternative 3			
	μ^l	ϑ^l	μ^u	ϑ^u	μ^l	ϑ^l	μ^u	ϑ^u	μ^l	ϑ^l	μ^u	ϑ^u
C4	0.663	0.114	0.749	0.193	0.543	0.199	0.621	0.294	0.691	0.078	0.791	0.166
C5	0.569	0.169	0.649	0.265	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C6	0.545	0.196	0.624	0.291	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C7	0.569	0.169	0.649	0.265	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C8	0.516	0.239	0.591	0.328	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C9	0.695	0.081	0.782	0.160	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C10	0.596	0.138	0.677	0.235	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C11	0.618	0.118	0.700	0.213	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C12	0.618	0.118	0.700	0.213	0.640	0.098	0.723	0.190	0.640	0.098	0.723	0.190
C13	0.510	0.617	0.320	0.088	0.480	0.668	0.255	0.145	0.320	0.535	0.370	0.202
C14	0.695	0.081	0.782	0.160	0.537	0.279	0.554	0.215	0.468	0.467	0.392	0.226
C15	0.423	0.520	0.413	0.088	0.373	0.537	0.372	0.145	0.322	0.538	0.368	0.202
C16	0.720	0.060	0.808	0.136	0.589	0.150	0.670	0.244	0.492	0.331	0.504	0.263

Step 6: The IFWAA operator is used to obtain the aggregate weighted intuitionistic fuzzy super decision matrix.

Step 7: The score for each alternative supplier is calculated using equation 13.12 and shown in Table 13.11.

Step 8: Based on the score found, alternatives are ranked, as indicated in Table 13.12.

The results achieved for the two scenarios are summarised in Table 13.12, and the rank of suppliers differs for the two scenarios. On the one hand, for the first scenario, where the weights of decision-makers are assigned using linguistic evaluation, the first supplier is the best alternative, with a score of 0.325, and supplier A2 is placed second with a score of 0.322. At the same time, the third one achieved a score of 0.321. On the other hand, for the second scenario, where the calculation of weights is done evaluating eight criteria related to personal perception, the first supplier is still found as the best performing supplier. In contrast, the second and the third supplier are placed in the same order found in the first scenario, with a larger difference, achieving scores of 0.342 and 0.335, respectively. This leads to the conclusion that the weight of a decision-maker has a significant influence on the evaluation process of suppliers.

In this chapter, the choice of decision-makers with their knowledge and experience on vendors causes the companies to be successful or unsuccessful in supply chain management. Personal perceptions of decision-makers on vendors make some decisions unfair. Thus, in this study, it is seen that measurement of decision-makers' perceptions can help to reflect impartiality, uncertainty and hesitancy on human thoughts as the actions of small changes on the weights of decision-makers

TABLE 13.11
Scores of Alternatives for Two Scenarios

Criteria	Scenario 1			Scenario 2		
	A1	A2	A3	A1	A2	A3
$C1_g$	0.353	0.324	0.320	0.349	0.320	0.317
$C2_g$	0.316	0.308	0.305	0.312	0.303	0.301
$C3_g$	0.316	0.309	0.306	0.314	0.306	0.304
$C4_g$	0.309	0.305	0.305	0.302	0.298	0.299
$C5_g$	0.299	0.291	0.291	0.298	0.291	0.291
$C6_g$	0.300	0.295	0.295	0.300	0.295	0.295
$C7_g$	0.299	0.291	0.291	0.298	0.291	0.291
$C8_g$	0.300	0.289	0.289	0.299	0.288	0.288
$C9_g$	0.289	0.287	0.287	0.288	0.286	0.286
$C10_g$	0.299	0.296	0.296	0.300	0.296	0.296
$C11_g$	0.304	0.302	0.302	0.304	0.302	0.302
$C12_g$	0.304	0.302	0.302	0.304	0.302	0.302
$C13_g$	0.462	0.469	0.390	0.484	0.501	0.432
$C14_g$	0.309	0.351	0.404	0.469	0.459	0.452
$C15_g$	0.421	0.412	0.396	0.453	0.454	0.441
$C16_g$	0.315	0.315	0.364	0.488	0.484	0.469
Total Score	**0.325**	**0.322**	**0.321**	**0.348**	**0.342**	**0.335**
Normalised Score	**0.335**	**0.332**	**0.332**	**0.339**	**0.334**	**0.327**

TABLE 13.12
Scores of Alternatives for Two Scenarios

Alternatives	Scenario 1		Scenario 1	
	Score	Rank	Score	Rank
A1	0.325	1	0.348	1
A2	0.322	2	0.342	2
A3	0.321	3	0.335	3

contribute substantially to the rank of vendors. According to Table 13.12, based on the approach to determine weights, Scenario 1 and Scenario 2 provide the same rank for three suppliers. In addition, the proposed approach, which considers the personal perception of decision-makers, is capable of dealing with MCDM problems along with additional flexibility. An interface can be designed to provide an automated system to measure the weights of decision-makers for two scenarios and solve the problem of assigning their weights. This study will be a good attempt to fill the gap in the applications of smart sustainable supply chain management.

All over the world, although people face the adverse environmental effects of plastics on nature, the demand for using plastics is increasing day by day. This makes plastics manufacturers a global concern and reveals the need to educate them on sustainability. This study is an attempt to keep vendors of a plastics manufacturer aware and to emphasise the harmful impact of plastics, giving them several criteria which aim to improve the awareness of perspective for sustainability.

13.5 CONCLUSION AND FUTURE RESEARCH

The selection and evaluation of suppliers from a sustainability perspective has turned into a vital issue for many companies in smart environments. Hence, this chapter is aimed to provide a detailed overview of the sustainable supplier selection process with respect to developing a smart environment. The chapter presents the study that proposed a multistage implementation framework that highlights the impacts of the personal perception of experts in the plastic packaging industry. As a future study, a genetic algorithm can generate an autonomous supply selection integrating the personal perception of decision-makers on the evaluation of suppliers. Because of the lack of research on smart sustainable supplier selection, this study can be applied to different industries, and other MCDM methods will also be used for comparison.

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14 The Internet of Things and Cyber-Physical Systems

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CONTENTS

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14.1 DEFINITION OF IOT

In the age of digitization, the concept of IoT has attracted great interest from all walks of life. As a result, it has become a popular topic for both academics and businesses. Semantically, the phrase IoT consists of the words "Internet" and "thing" (Tuysuz and Trestian, 2020). The Internet is the global network of interconnected smart devices, and a thing is any object that can connect to the Internet with some modifications if needed (Tuysuz and Trestian, 2020). Examples are smartphones, smartwatches, ovens, production lines, and machines. Figure 14.1 demonstrates an integration of the IoT process.

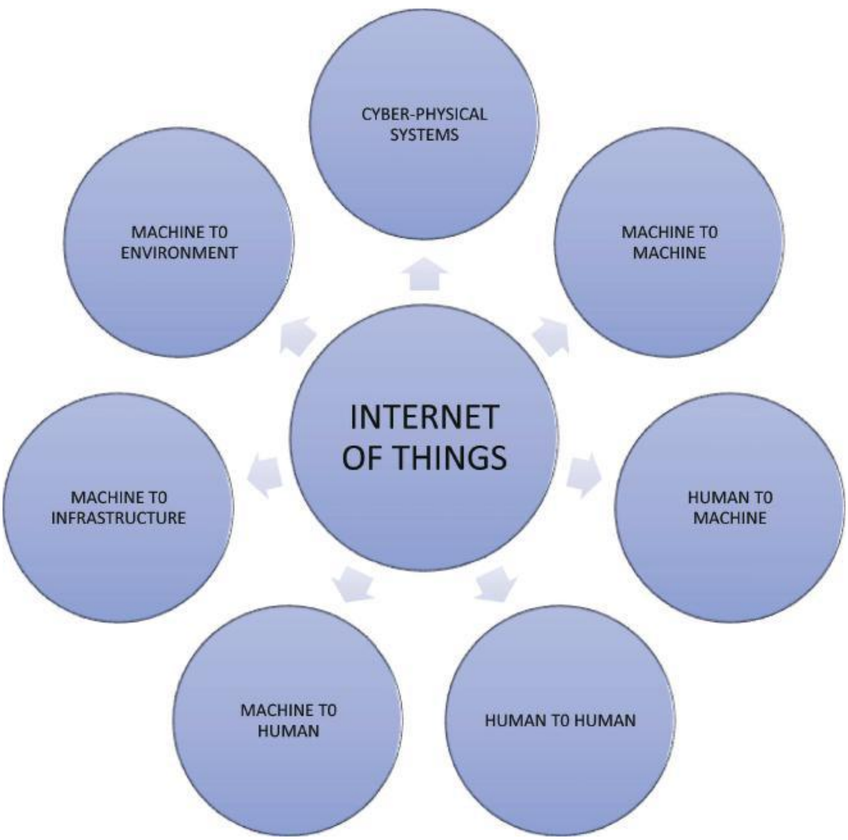

FIGURE 14.1 IoT integration. (Vermesan et al., 2016)

IoT consists of objects uniquely interconnected via sensors, wired connections, wireless channels, or hybrid systems based on interoperable Information and Communications Technologies (physical and virtual) and communication protocols with self-configuration capabilities, and provides advanced services that are controllable and optimizable. It is defined as a worldwide network for the information society (Istepanian and Woodward, 2017).

The core infrastructure components of IoT create an intelligent environment to make the collected information interactive and well-performing. It also provides an efficient way of communication between people and objects on a network at any time and place. IoT creates an intelligent and well-performing communication environment with an identifier, address, information processing, sending and receiving of messages, and sensing and communication functions (Tuysuz and Trestian, 2020).

In the context of SCM, IoT has been defined as a network of digitally connected physical objects used for control and coordination, sensing, monitoring, and interaction of supply chain processes, enabling agility, visibility, monitoring, and information sharing to facilitate timely planning. As a path to operational excellence, IoT has played a critical role in various aspects of SCM.

As a result of the continuous advances in the technologies that form the basis of IoT, the cost of IoT applications has decreased, and they have become less energy-consuming. With IoT technologies, businesses gain many advantages, such as counterfeit detection, real-time monitoring, predicting maintenance and repair times, more accurate sales data, reduction in over- and under-production, personalized marketing, competitiveness, more accurate carbon tracking, and sustainability (Hopkins, 2021).

14.2 EVALUATION OF IOT

IoT, one of the most important innovations brought by the digital age, emerged as a result of the advancement of technologies. The IoT was introduced as the network of things, transforming the world into a new era where billions of objects can perceive, communicate, and share information.

Historically, different individuals, academic institutions, and companies have played an important role in applying IoT technologies to their needs and have invested in the IoT field at different times but at regular intervals. Table 14.1 shows the developments that the IoT concept has experienced in the process from its birth as the first idea to its most recent usage today.

Since its emergence, objects connected to the Internet have become widespread and regularly used in events. With the impact of multiple factors, such as new Internet protocols like IPv6, support from major network providers (Amazon, GE, IBM, and Cisco), and decreasing connection costs, IoT is estimated to generate 15 trillion of global GDP and reach 50 billion devices in 20 years.

14.3 IOT SYSTEM ARCHITECTURE

As the number of connected devices increases and their use becomes more widespread, the need to create smarter systems has arisen (Ansari et al., 2021). A critical requirement of IoT is that things on the network must be interconnected. This

TABLE 14.1
Evolution of IoT

In 1832, for the first time in history, Michael Faraday stated that, with the IoT, two devices/machines could be connected through the exchange of electrical signals by the electromagnetic principle.
In 1969, the US Defense Advanced Research Projects Agency (DARPA) introduced ARPANET, the precursor to the Internet, and was seen as part of the IoT. The first message in history was sent via ARPANET.
In 1982, the first connected gadget, the Coca-Cola vending machine, was introduced by members (students and professors) of Carnegie Melon University. For the first time in history, designers used a type of network starter that worked by combining small switches with machines to check whether the chiller was keeping drinks cold enough and if they were accessible. This device is recognized as pioneering the advancement of machinery all over the world (Bansal et al., 2021).
In 1989, the Internet/World Wide Web (www) was first introduced by Tim Berners-Lee. From the moment the Internet was introduced, it quickly spread around the world. Since the birth of the Internet, the first application of the trend of connecting various things to the Internet has been the Trojan Room coffee pot.
In 1990, John Romkey introduced the first Internet-controlled and web-based toaster.
In 1993, researchers at the University of Cambridge introduced the first webcam model that took pictures of the coffee machine at work and sent the pictures to nearby computers.
In 1994, Steve Mann introduced the WearCam, the first wearable device with real-time performance on a 64-processor system.
In 1995, the US government introduced its GPS application that provides location detection.
In 1997, Paul Saffo gave the first brief description of sensors and their future applications (Ghasempour, 2019).
In 1998, Mark Weiser introduced the concept of ubiquitous computing, which makes computing appear anytime and anywhere.
In 1999, the term "Internet of Things" was introduced by Kevin Ashton, director of MIT Auto-ID. Kevin Ashton described IoT as the next-generation Internet. Also in 1999, an IoT project designed as a global radio frequency identification (RFID)–based product identification system for supply chain optimization of Procter & Gamble was introduced (Chandra et al., 2014).
In 1999, Neil Gershenfelt (MIT Media Lab) talked about the concept of IoT in his book *When Things Start to Think* (Tzafestas, 2018).
In 2000, LG announced its Internet-connected refrigerator design/manufacturing plan that tracks the usage amounts of stored foodstuffs.
In 2003, the US Army/US Department of Defense used RFID technology as part of the Savi Program.
In 2003, the retail giant announced that Walmart was starting to use RFID technology to a greater extent in all its stores worldwide.
In 2004, the Japanese Ministry of Interior introduced the u-Japan concept of "Anytime, Anywhere, Everything, Everyone".
In 2004, the Korean government introduced the u-Korea "Digital Age of Humanism: IT839 strategy" strategy.
In 2005, mainstream publications, such as the *Guardian*, *Scientific American*, and the *Boston Globe*, cited many articles about the IoT and its future course.
In 2005, at the World Summit of the Information Society (WSIS), it was stated that the use of four important IoT technologies, such as radio frequency identification (RFID), sensor technology, nanotechnology, and smart technology, will increase (Liu and Lu, 2012).
In 2007, at the Macworld conference, Apple's CEO Steve Jobs introduced the iPhone, the first touchscreen mobile phone connected to the Internet.

In 2008, a group of companies formed the IPSO Alliance to encourage the use of Internet Protocol (IP) in the smart object network and enable the Internet of Things in energy, consumer, healthcare, and industrial applications (Suresh et al., 2014).

In 2008, the US Federal Communications Commission (FCC) approved the use of the “white space spectrum” in a 5–0 vote (Suresh et al., 2014).

In 2008, the First International European IoT conference on the Internet of Things was held in Switzerland with the participation of employees from 23 different countries.

In 2008, IBM proposed the concept of a smart planet (IoT + Internet = Smart Planet) as a strategy for economic stimulus (Liu and Lu, 2012).

In 2008, the US National Intelligence Council (NIC) included the IoT among six disruptive civilian technologies with a potential impact on US interests by 2025 (Tzafestas, 2018).

In 2009, the first IoT medical device, the Internet-connected pacemaker, was launched by Saint Jude Medical Center.

In 2009, the European Commission announced that they would provide substantial financial support to IoT technology, in line with the existing network of regulatory oversight programs.

In 2009, Cisco’s IoT Business Solutions Group was established.

In 2010, Chinese Premier Wen Jiabao described IoT as an important industry for China and announced plans to invest heavily in the Internet of Things as part of their Five-Year Strategic Plan.

In 2010, Google introduced the StreetView service/app, which allows one to take 360-degree photos and also stores tons of data on people’s Wi-Fi networks (Lueth, 2014).

In 2010, Nest released a smart thermostat that can automatically adjust a home’s temperature based on the user’s habits. It was considered one of the first steps of the smart home concept.

In 2010, 90 crore devices were invested in IoT technology in the world, and it was increased to 125 crores.

In 2010, the concept of IPv6 protocol was introduced, which plays a vital role in the expansion of IoT (Bansal et al., 2021).

In 2011, the Internet of Things Global Standards Initiative (IoT-GSI) promoted a unified approach to the development of technical standards that enable IoT on a global scale (Tzafestas, 2018).

In 2011, Gartner added the nascent Internet of Things phenomenon to their list of “the hype cycle for emerging technologies” (Gartner, 2020).

In 2012, IPv6 (Internet Protocol version 6) was released, which made it possible to assign IP addresses to every atom in the world without any restrictions, thus enabling connectivity between millions of devices.

In 2012, the theme of Europe’s largest Internet conference, LeWeb, was the Internet of Things.

In 2012, popular tech-focused magazines, like *Forbes*, *Fast Company*, and *Wired*, started using IoT as a vocabulary to describe the phenomenon (Gonzalez, 2019).

In 2013, IDC released a report stating that the Internet of Things will be an $8.9 trillion market by 2020 (Gonzalez, 2019).

In 2013, Google Glass, a wearable technology, was launched.

In 2014, the term “Internet of Things” reached mass-market consciousness when Google announced its acquisition of Nest for $3.2 billion. At the same time, the Consumer Electronics Show (CES) in Las Vegas was held with the theme of IoT (Lueth, 2014).

In 2014, Amazon launched the smart speaker Echo, a big step forward for smart home technologies.

Between 2017 and 2021, the IoT market has become more and more popular.

connection takes place over the IoT system (Gokhale et al., 2018). IoT systems are often developed as large-scale systems because they have to deal not only with cyberspaces but also with physical spaces. To fully define an IoT system, three different visions must be considered (Tran et al., 2021):

- Object-oriented vision is a way of focusing on the thinking ability of physical objects with embedded sensors, computation, and communication activities.
- The Internet-focused vision focuses on addressing the consequences of the flow of physical devices connected to TCP/IP networks.
- Semantic-driven vision is about exchanging, displaying, and addressing information produced by physical objects.

IoT system architecture can be done in two different ways, top-down and bottom-up layers exploration. The top-down research idea focuses on the software architecture of the IoT system, addressing the importance of delivering and sharing services over the Internet with the participation of physical objects. The bottom-up research idea focuses on the ways objects connect to the IoT, the relationships between objects, and the expansion of the scope of the Internet (Lv et al., 2017).

The IoT system architecture must connect the physical and virtual worlds with the operations of the IoT. The design of the IoT architecture includes process steps involving many factors, such as networking, communication, extensibility, and scalability. In addition, device interoperability should be especially taken into account when designing the IoT architecture. To enable devices to interact dynamically with others and to support communication between them, the IoT architecture must be adaptive. In addition, IoT should ensure lower energy consumption by optimizing costs and being decentralized, heterogeneous, and sustainable (Gokhale et al., 2018).

IoT system is a closed-loop to produce custom and personalized products to meet the needs of end users. IoT system consists of four main layers and sub-layers, namely perception, network, processing, and application layer (Sengupta et al., 2020). Figure 14.2 demonstrates the system of IoT.

In the Internet of Things architecture, the perception layer is the basic layer created for the system to perceive the outside world (Lei, 2022). This layer is essentially a network of many sensor nodes. The perception layer is integrated with all available objects to detect dynamic states of the outside world (Gokhale et al., 2018). Devices

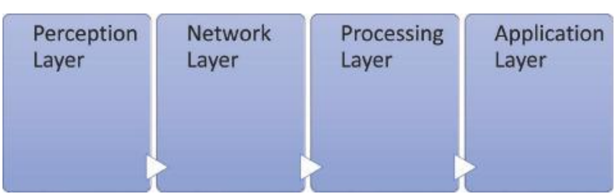

FIGURE 14.2 IoT system. (Sengupta et al., 2020)

used in this layer are divided into detection devices and execution devices (Singh et al., 2021).

Detection devices are devices that directly access the smart device and convert the external physical signal into a signal that can be recognized by the smart device and the physical information into digital information and then transmitted to smart devices (Lv et al., 2017). Detection devices are different types of sensors, RFID scanners, surveillance cameras, GPS modules, and more. Execution devices are devices that can receive control signals sent by smart devices and control the behavior of objects based on control signals (Lv et al., 2017). Execution devices are propulsion devices, automatic guided vehicles (AGVs), conveyor systems, industrial robots, and more (Sengupta et al., 2020).

The smart device layer consists of devices that can collect information about objects and directly access the Internet. IoT terminals, computers, and LANs are the most basic smart devices. The IoT terminal is a system with a smart chip; the computer is a general-purpose computer, industrial computer, or personal mobile device; and it is a network that provides information to objects with LAN monitoring and control equipment (Lv et al., 2017).

The processing layer enables services and applications in the IoT. The processing layer consists of servers and databases (Sengupta et al., 2020). It is responsible for the execution of various tasks, such as information exchange, decision-making, computational and optimization algorithms, storage, and management of large amounts of data.

In the application layer, activities, such as combining the Internet of Things with related technologies, providing the integration of information technology in different industries, and providing solutions to problems, are carried out for the end users (Lei, 2022). The application layer provides a visual process interface, such as monitoring, process optimization, alarm management, statistical analysis, control logic, logistics, and consumer models (Rajmohan et al., 2022). Smart home, Smart city, e-health, vehicle ad hoc network (VANET), smart grid, smart factory, smart robotics, supply chain, Amazon's reinvented warehouse, and so on are some of the important applications based on IoT (Sengupta et al., 2020).

14.4 IOT APPLICATIONS AND SERVICES IN SUPPLY CHAIN MANAGEMENT

The application of IoT technologies in industry will increase efficiency in procurement, production, and distribution processes, and enable more efficient communication and networking between operators and machines (Ghasempour, 2019; Nižetić et al., 2020). Figure 14.3 demonstrates IoT applications.

As an emerging market, the usage areas of Internet of Things (IoT)–based applications are shown subsequently.

14.4.1 Smart Agriculture

Under the influence of problems such as climate change and global warming, efficient agricultural production is a necessity to prevent the lack of potential food resources caused by population growth and different factors in the future (Nižetić et al., 2020).

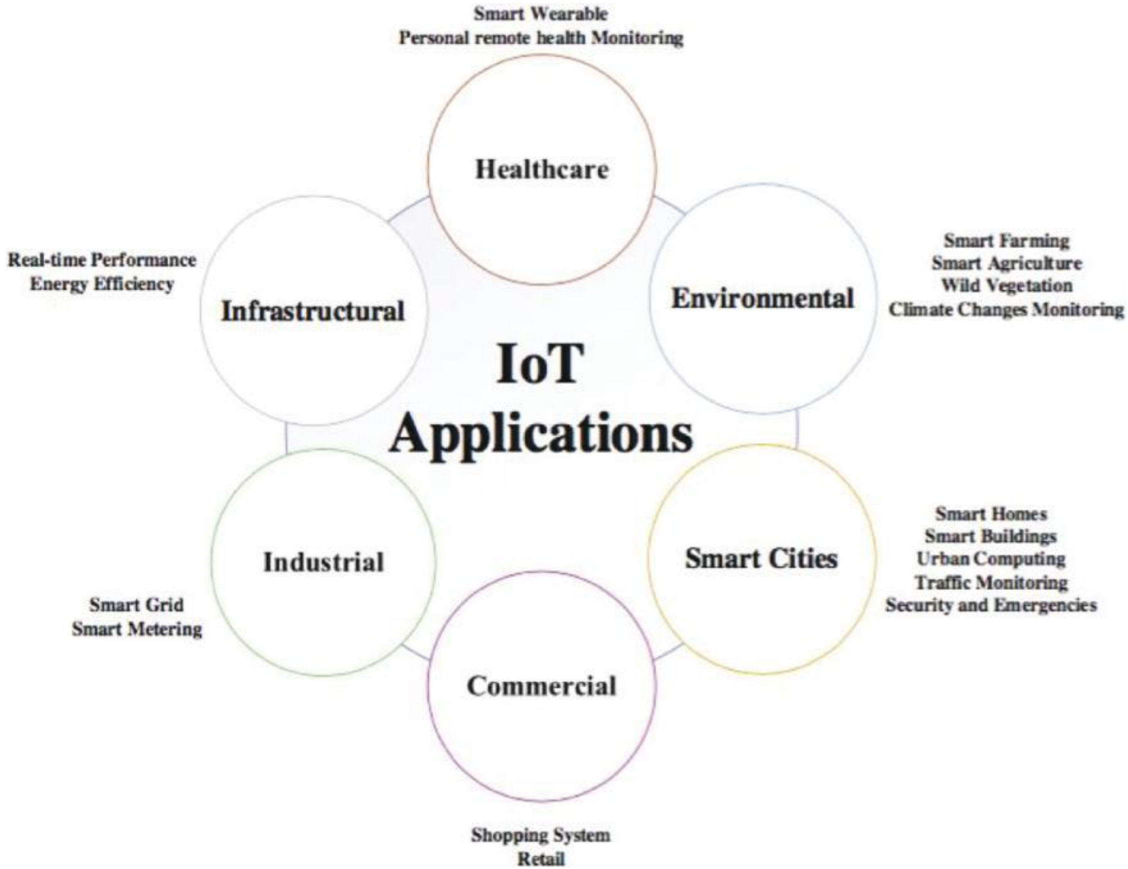

FIGURE 14.3 IoT applications. (Hassan et al., 2020)

Therefore, the application of IoT technologies in the agriculture sector will lead to advances that could drastically change the current production procedures in agriculture (Nižetić et al., 2020).

The concept of Agriculture 4.0 or Future Agriculture is a system in which air, water, soil, energy, and other natural resources are used effectively with the data they need for health and productivity by using smart and IoT technology (Tabaa et al., 2020).

In smart agriculture, the IoT application is implemented for professionals, farmers, consultants, and researchers, with equipment and sensors placed on the field, creating a large database over a virtual network platform. The following are applications of IoT technologies in agriculture (Tabaa et al., 2020; Nižetić et al., 2020):

- A better understanding of a situation allows one to take advantage of the behavior of crops or animals according to the seasons and weather.
- The maturity status of the land, the appearance of disease in plants, the health status of an animal, and so on provide instant tracking of activities.
- It can help secure food demands and increase the efficiency of agricultural production processes in general.
- It provides water savings by optimizing the water used with smart irrigation systems.

14.4.2 Smart Health

According to recent research, the Internet of Things in the healthcare market is expected to grow from $41.22 billion in 2017 to $158.07 billion in 2022 (Tabaa et al., 2020). The main purpose of IoT applications is to maximize all pharmacy and clinical functions, from healthcare and drug information delivery to physician advice; ensure patient safety; create a cost-effective service experience for patients, clinics, and pharmacies, with the ability to synchronize and connect data; and predict diseases.

The smart health IoT system consists of hardware platforms, wearable devices, network technologies, and cloud platforms. Smart medical devices monitor various vital and valuable human functions, such as heart rate and skin temperature; tracks motion, monitors general health and nutritional status of the patient; monitors home rehabilitation procedures after a serious illness; and predicts different symptoms and potentially life-threatening conditions and diseases (Nižetić et al., 2020). IoT activities, such as prevention, are implemented.

One of the main problems and challenges for the application of IoT technologies in the health sector is to provide effective cybersecurity against possible attacks on patient tracking and monitoring systems. With IoT technologies, the collection of patients' data can improve the service quality of the healthcare system. It can also lead to an increase in the likelihood of patients' survival by improving patient safety and care. Costs can be reduced as it allows early detection of medical devices and equipment malfunctions. In global epidemic situations, it can benefit medical personnel resources and triage as a result of the rapid collection of various needed data (Nižetić et al., 2020).

14.4.3 Smart City

Today, smart life and the environment have become a part of everyone's life. IoT technologies enable the emergence of what we call the smart city by encompassing and improving our cities. IoT will embody this concept by connecting computers, smartphones, and the Internet to our daily activities (Suresh et al., 2014). A smart city is a city where everything is managed automatically over the Internet, using new Information and Communications Technology to improve people's quality of life. It necessitates urbanization and world-class infrastructure development.

It uses linked objects to collect data necessary for the city government. This huge amount of data is gathered from various sources that make up various applications. Processing the obtained data makes life easier for citizens by optimizing urban operations and services. This data is used for processing and analysis, and management and control of data at many points, such as schools, hospitals, power plants, waste management, water supply networks, traffic, and transportation (Tabaa et al., 2020). In smart cities, IoT technologies are used to prevent problems such as power failure, help in disaster recovery, monitor pollution levels, monitor seismic vibrations in buildings, manage waste, distribute water, control traffic signals, monitor radiation levels, help with urban security, monitor vehicle parking regulations, and manage traffic (Suresh et al., 2014).

IoT technologies in smart cities would increase the quality of life and efficiency as different daily services in cities, such as transportation, security (surveillance), measurement, energy systems, water management, health, warehouses, transportation, and waste management, become smart (Nižetić et al., 2020).

As a result, the use of IoT in smart cities will contribute to the economic and social development of businesses and communities. Here are examples:

- The Smart Buick app sends an alert to city services when a trash can needs to be emptied.
- People can find free parking spaces in the neighborhood using sensors and the Internet.

14.4.4 Smart House

Smart homes will become widespread in residential areas in the modern world in the near future. It gives us instant control over our homes by automating activities in the home ecosystem, such as electrical equipment, sound systems and security, and lighting system. IoT technologies connect all the devices and equipment in our homes so they can communicate. Smart homes work as a very simple system that includes receiver and transmitter elements (Lawal and Rafsanjani, 2021).

14.4.5 IoT in Waste Management

Today, in densely populated cities, IoT technologies that can help to recycle and provide efficient waste management have become a part of the circular economy. This application allows smart monitoring of the GPS location of garbage bins in cities, bin vibration occurrence and bin tilt, bin fill level, and waste temperature. In this way, municipalities ensure that the harmful emissions (pollutants) created by garbage trucks are reduced with efficient traffic management. In the coming years, it is expected to develop innovative IoT-based technological solutions that can support smart waste management systems and the circular economy concept, especially from the perspective of the smart city concept (Nižetić et al., 2020).

14.4.6 IoT in Smart Grids and Power Management

Today, energy transformation movements have started to reduce the pollution effects created by the energy obtained from fossil fuels. Renewable energy and smart metering technologies should be used for efficient, advanced, and smart management of electricity grids. The most important role of IoT technologies in smart grids is to save electricity through an efficient distribution of electricity. Collecting and analyzing network data through IoT devices and software can help improve network reliability and efficiency. IoT technologies also support efficient and intelligent estimation of the amount of electricity required for households (Nižetić et al., 2020).

14.4.7 Smart Factory

The smart factory has emerged as a connected, fully automated, flexible production system supported by robots to improve the existing production systems in the industrial sector (Ameri and Sabbagh, 2016). Smart factories will be the center of industry transformation with their potential.

The interconnection and cooperation of every value (employees, machines, products) in the factory system is provided through the Internet of Things/connected systems. Smart factories are seen as a value point where all actors can communicate with each other, analyze, and understand a certain production level with the automation of production lines to solve problems with minimal human participation. IoT plays a key role in the development of smart factories (OECD, 2016).

14.4.8 Smart Transportation

Information technology, and especially the IoT, allows real-time traceability throughout the supply chain, increasing visibility and control. Transportation is a good example of how IoT technologies can bring value (Nižetić et al., 2020). In the coming years, transportation modes will change significantly, thanks to autonomous and electric vehicles that will take place in practice.

IoT technologies, such as RFID, near-field communication (NFC), Global Positioning System (GPS) technologies, sensors, embedded and mobile devices, and cloud storage systems provide businesses with supply chain monitoring, vehicle tracking, inventory management, secure transportation, process automation, and route optimization (Wadhwan, 2018; Nižetić et al., 2020). It can perform activities, such as tracking stolen vehicles, tracking lane violations, tracking vehicles that do not comply with traffic rules, tracking vehicles for drug smuggling, doing emergency assistance, collecting fees with smart transit, and helping with smart highway lighting in smart transportation processes.

The IoT application will improve the driver experience, increase comfort and safety, provide better service and added value for customers, create an efficient supply chain, deliver goods from the manufacturer to the end user at the agreed time and under specified conditions, and reduce time and personnel costs and increase their competitiveness by producing on time (Nižetić et al., 2020).

14.4.9 Radio Frequency Identification (RFID)

RFID is defined as a technology that automatically identifies an object and collects information with the help of a reader using electromagnetic signals from a tag without mechanical or optical contact with wireless communication technology (Ljung and Capadrutt, 2020). RFID technology consists of three elements: a chip-based tag connected via an antenna, a radio signal reader that receives data and information from the tags, and software (Anitha et al., 2021). Three types of RFID tags are used in the application, namely Active RFID, Passive RFID and Semi-Passive RFID. Generally, RFID tags contain electronic information.

The benefits of RFID technology (Anitha et al., 2021):

- Efficient use of cost, raw materials, equipment, and tools
- Increased supply chain visibility
- Integration between supply chain participants
- Enhanced performance
- Increased quality of information
- Reduction in inventory losses
- Facilitation in recognizing, monitoring, and associating products and equipment with real-time data databases and networks

14.4.10 Smart Sensors

It is used to detect, monitor, control, and manage changes in values, such as quality conditions, vibration, temperature, pressure, and humidity throughout the supply chain, with the help of sensors. It is also a technology that allows the data in logistics processes to be shared instantly between supply chain partners (Anitha et al., 2021).

14.4.11 Real-Time Global Positioning System

The Real-Time Global Positioning System using the Internet of Things has a significant impact on ensuring a safe and intelligent transportation process (Katarahweire et al., 2021). Real-Time Global Positioning System (RTGPS) is an IoT technology used to monitor vehicles, trucks, trains, ships, and containers used in supply chain and logistics processes in real time (Ziegler and Ladid, 2016). The benefits of RTGPS technology for the implementers are as follows (Ljung and Capadrutt, 2020):

- More transparent transport chain
- Higher delivery performance through faster problem identification
- Pre-identification of problems and more reliable data for planners

- Faster reaction times in case of delays and increased customer satisfaction
- Transparent information sharing
- Increased efficiency in making accurate decisions
- Increased logistics capacity
- Optimization in city logistics
- Instant reporting of data and real-time tracking of shipments within the supply chain network
- Online decision support

14.4.12 Automatic Identification System

It is a widely used technology for collecting information about vehicles in transportation activities. The Automatic Identification System (AIS) automatically provides information about vehicles' identity, type, location, route, speed, and cruise status. This information is then used to provide advanced tracking in the supply chain and to estimate the arrival times of shipments. Information gathered from AIS is increasingly used to monitor environmental impacts, which may enable the creation of a sustainable transport economy (Ljung and Capadrutt, 2020).

14.5 ADVANTAGES AND DISADVANTAGES OF IOT

The evolution of automation and digitalization technologies has begun to carry out the necessary change, transformation, and development activities for the production needs of companies and modernization. In IoT technologies, one of the modernization activities, such as automation and digitalization, provide significant advantages to businesses. In this context, businesses can achieve the following benefits by adopting IoT technologies (Brous et al., 2020):

- Basic resources, such as personnel, machinery, and equipment, can be used more efficiently and economically.
- Integration of just-in-time delivery and route optimization preferences with IoT technologies can optimize fuel consumption, which can increase revenue.
- It can improve the supply and logistics value chain as a whole and reduce its complexity.
- It can improve operational efficiency, customer experience, and safety and security.
- It facilitates the recording of export, import, purchase, and other transportation information.
- It can significantly reduce human-induced errors and accidents, improve delivery safety, and reduce waste and labor costs.
- It can optimize production, reduce energy consumption, improve slot management, and reduce empty containers.
- Analytical information can be provided to managers on weaknesses and strengths in supply chains.
- Coordination between people, products, and vehicles can be improved.

- Business operations can be started and terminated without human intervention.
- The performance of assets can be tracked without evaluation costs.
- Real-time measurement and analysis of sensor data efficiency can provide several benefits related to improved efficiency of services and improved flexibility of services based on trend analysis of historical data over time.
- It provides ease of collection, sharing, and use of data and information automatically.
- By linking data from different sources, insight is provided, enabling more effective communication with customers.
- It can provide corporate transparency with instant sharing of data and information.
- By monitoring what is happening in the real world, time management increases service flexibility and efficiency, enabling better decision-making.
- The massive volume of data enabled by the IoT can increase organizations' performance, improve operational planning, and enhance the ability to respond quickly to unforeseen events.
- It can increase the potential for intelligent governance and collaboration among supply chain actors.
- Instant and detailed tracking of product lifecycle information can be done.

However, there are some potential barriers that digital and smart technologies, such as IoT, can create. There are potential barriers to the Internet of Things (IoT) applications for businesses. These obstacles are as follows (Tzafestas, 2018; Brous et al., 2020; Chukwudebe et al., 2021):

- Lack of government regulation: Governments, institutions, and organizations must provide the enabling environment, policies, and laws for the realization of IoT applications and services. Specifically, communication protocol standards should set industry-wide standards for IoT, such as 4G and Wi-Fi, or device addressing standards, such as IPv6. It is thought that consumers can trust IoT applications with government regulations.
- Lack of standardization: The obstacles created by the lack of standardization in IoT implementation processes negatively affect businesses. Setting global standards for network, identification and communication security on the Internet of Things (IoT) platforms and intelligent technologies (object and system) that integrate into the implementation process will enable businesses to adopt, invest, and implement the Internet of Things (IoT).
- High energy consumption: Proactive evaluation of energy consumption processes of enterprises and making them sustainable is seen as the main competence of the Internet of Things. The increase in the adoption and application of smart objects and systems by businesses will increase the need for energy consumption and cause costs to rise. In this context, it is important to use smart objects, RFID tags, and power units that can charge themselves and use renewable energy.
- Security and privacy: A major disadvantage is that businesses are not transparent about how data collected from large numbers of users is stored and

used. There are disadvantages to the Internet of Things (IoT) platform/network, such as resilience to attacks, data leaks, unauthorized access, and misuse of sensitive personal information, such as personal habits and personal financial information.

- High operating and return costs: High initial investment, usage, and maintenance and repair costs, and lack of knowledge of return-on-investment processes prevent businesses from implementing the Internet of Things (IoT).
- Lack of Internet infrastructure: The Internet infrastructure of every supply chain partner may not be suitable for real-time data monitoring, evaluation, and decision-making. Investing in Internet infrastructure will be able to remove this obstacle.
- Lack of trained personnel: The Internet of Things (IoT) system requires highly trained personnel with advanced technical and functional skills. In this context, businesses may have difficulties in employing personnel with technology-based skills.
- Integration and compatibility issues: Different software, hardware, tools, machinery, and equipment systems used among supply chain partners can create IoT integration and compatibility problems.
- Scalability issues: As businesses expand the applicability of Internet of Things (IoT) technologies, problems related to the complexities created by the scalability of data from smart devices may be hindered.
- Lack of validation and detection: Businesses lack knowledge of the potential benefits of the Internet of Things (IoT).

14.6 SMART AND SUSTAINABILITY IN SUPPLY CHAIN THROUGH IOT

The Internet of Things, which has left its mark on the past decades, has had a huge impact on people's living standards and behavior, such as pollution and degradation of the natural environment of everyday life. The European Commission Program states that by 2050, issues such as environmental sustainability and digital technologies will increase in importance for society and that adopting sustainable practices will enable the circular economy, the restoration of biodiversity, the reduction of pollution, and the strengthening of control over digital transformation (EU, 2021).

Sustainability is a practice that continues to evolve and be considered. Sustainability requires efficient management of millions of objects and optimization of energy and resource use. IoTs play an important role in helping users to manage resources wisely; control the availability and consumption of water and energy; protect wildlife; understand sustainable development, use, redistribution, and recycling of more accurate resources; and increase sustainability with real-time data collected data.

The Internet of Things allows people and things to be connected anytime, anywhere, with anything, and anyone, ideally using any network and any service (Gonzalez, 2019). The purpose of using IoT technologies is to create a "better world for humans," where objects around us know what we like, want, and need, and act accordingly without clear instructions (Perera and Zaslavsky, 2014).

IoT technologies contribute to changing and improving people's lives, reducing gas consumption and CO_2 emissions intelligently and sustainably. The drivers required for IoT technologies to support sustainable solutions and services are interrelated and overlapping. The drivers required for IoT and sustainability are monitoring, process optimization and automation, awareness-raising and behavior change, data collection and analysis, and alerting. These drivers and their uses are briefly described subsequently (Schneider, 2019):

- Monitoring is defined as a routine, ongoing measurement activity used to gather information about a program's activities, outputs, status, and results. Therefore, monitoring represents a form of data collection and analysis with a prominent presence. Tracking is strongly associated with technologies such as RFID and Global Positioning System (GPS).
- Process optimization and automation are defined as the automatic execution of tasks that were previously performed manually. Optimization of processes is about increasing the efficiency of a particular process and reorganizing processes to achieve a specific goal. In the context of IoT, automation and optimization are defined as awareness of what an IoT system should do, how to do it, and what results can be achieved without clear instructions.
- Awareness raising and behavior change rely on humans to perform the tasks suggested by data analysis. This represents a training function achieved by providing users with individual data on their behavior in the context of a sustainability-related feature. The necessary data is obtained through the monitoring of IoT systems.
- Data collection and analysis is a summative feature. Data collection can be accomplished by any sensing or sensing technique. An alert consists of a combination of monitoring with the sending of an automated message to a defined individual, organization, or group if a particular variable or combination of variables exceeds a defined threshold.

Figure 14.4 shows the 9R framework in the context of sustainable IoT.

The 9R framework, the approach taken by the circular economy, focuses mostly on pre-deployment and post-deprecation production. Sustainability aspects are largely overlooked during deployment and operation (Janicke et al., 2020).

The 9R framework steps are shown subsequently (Janicke et al., 2020):

- The first stage is to establish strategies for efficient and effective use and production of IoT devices for smart product use and production. The reject strategy argues that consumers and manufacturers ignore the functionality of IoT devices and argue that they are unnecessary. IoT usage is unlikely to be reduced. Because the prevalence and growth of the use of IoT for sustainability strategy prevent this. However, manufacturers can use the functionality of IoT devices to achieve energy efficiency (rethink). The second strategy can create multipurpose IoT devices using integrated environmental sensors to track variables instead of using single and different sensors in the rethink phase. It is also necessary to integrate with other devices and applications

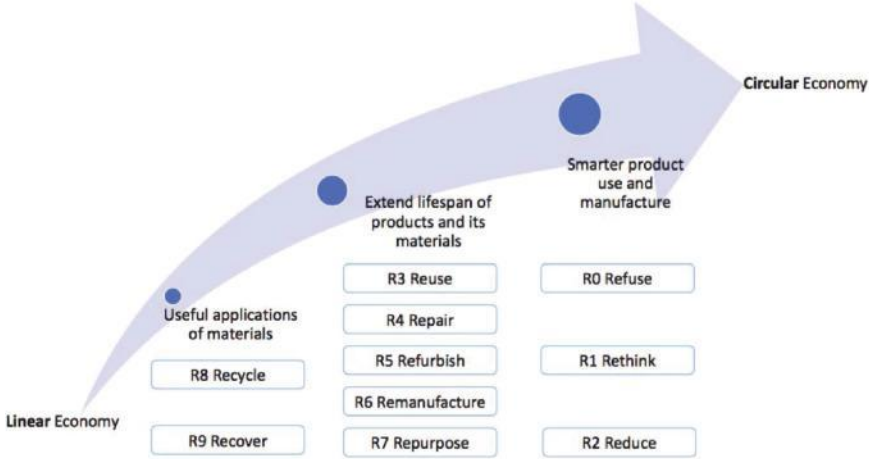

FIGURE 14.4 The 9R framework for the circular economy. (Janicke et al., 2020)

to increase the use of IoT technologies. This could involve, for example, a manufacturer replacing battery-powered IoT devices with solar-powered IoT devices. Another example is the use of IoT sensors, which reduce the distribution density to reduce the total amount of devices used. Such sustainability considerations will increase the utility, function, or quality of the IoT system. The third strategy, reduction, focuses on reducing the total amount of devices used and energy consumption by using environmental energy. These applications can increase the utility, function, and quality of the IoT system.

- The second phase consists of five different strategies for extending the life of IoT devices. The first strategy, during the reuse phase, focuses on reusing IoT devices for different applications or customers rather than discarding them. However, because the sensors are so cheap, customers may know to reuse them. Therefore, the reuse of IoT devices can be encouraged by creating innovative and second-hand markets.
- The next strategy is in the repair phase, supporting the original functionality of IoT devices by repairing and maintaining defective and obsolete devices. But because these devices are cheap nowadays, the cost of repair and maintenance is often higher than buying new ones.
- In the third strategy, the refurbishment phase, the focus is on renewing the necessary parts of IoT devices. However, there is no evidence of these strategies on the market for IoT devices yet. This strategy will become more important for the market if the prices of IoT devices increase soon.
- The next strategy, the remanufacturing phase, focuses on the use of good parts of end-of-life devices in new ones with the same functionality. This strategy is mostly not applied successfully and practically in the industry. The final strategy at this stage is similar to remanufacturing, in the reuse

process, by reusing parts in devices used for different functions. For example, parts of pollution sensors can be used to manufacture temperature sensors.

- The final stage consists of two strategies, recycling and recovery. These strategies are widely used for sustainability in industries. Recycling paper and plastic and recovering valuable materials from electronic products are examples of these strategies. However, the implementation of these strategies for IoT devices has not received great support from industry and government.

14.7 DIGITAL INNOVATION IN SUPPLY CHAIN MANAGEMENT: PRACTICES, PRINCIPLES, AND GUIDELINES

In the contemporary world with economic globalization, enterprises compete more than before to achieve their goals. Traditional management is no longer of great help to companies. In this regard, more enterprises are embarking on the path of the utilization of supply chain management (SCM) in their integrated structure. With the advent of SCM utilization in companies, customers' satisfaction and companies' competition have been influenced. In other words, the competitiveness of the company has intensified dramatically.

In modern SC, the effective operation of the supply chain and the effective sharing of information are of great importance for integrating the business processes, covering the entire process from upstream enterprise suppliers to end customers, and eventually palliating the bullwhip effect and increasing market share. Innovative solutions of a diverse nature can be introduced as an outcome of digitalization in SCM. This will result in improvements in the cost, quality, and time, which are the main pillars of SCM activities.

SCM with digital technologies aggregation is the main driving force of change in the modern world. The application of digital technologies, such as SMAC and blockchain, artificial intelligence and 4D printing, social media, mobile technologies, big data analytics, and cloud computing, is becoming widespread. Businesses have achieved a level of business efficiency that was previously impossible while reducing costs, thanks to the interoperability, networking, and relatively low cost of accessing any level of computing power needed anywhere in real time provided by these technologies.

The concept of digital innovation emerged as a result of extensive changes in the management of commercial organizations. Svahn et al. (2009) state that digital innovation is the use of digital technology in a product that is emerging for the first time.

Åkesson (2009) defines digital innovation as a solution promoted by digital technologies, complementing it in terms of new ICT products. In a narrow sense, digital innovation is the implementation of a new or significantly improved ICT product (solution). In a broad sense (based on the definition of innovation set out in the Oslo Manual), it is an innovation promoted by technology through the use of ICT in the implementation of a new or significantly improved product or process, a new marketing method, or an organizational method.

14.7.1 Blockchain

In today's world, due to the complexity of modern supply chains, disjointed entities compete to serve customers. Some factors, such as regulatory policies, various interactions in SC, and globalization, to name but a few, made the information evaluation process impossible. Furthermore, managing risks has become an intricate task to do in these supply chains.

Inefficient transactions, fraud, pilferage, and poorly performing supply chains lead to greater trust shortages and, therefore, a need for better information sharing. In this regard, traceability is a vital force that differentiates supply chains from each other; for instance, the agri-food sector (Costa et al., 2013), pharmaceutical and medical products (Rotunno et al., 2014), and high-value goods (Maurer, 2017). In the case of luxury items that rely heavily on paper certificates and receipts, the loss of these certificates can prevent supply chain entities and customers from verifying and validating the true value of those items. With all the previously mentioned examples, risks and lack of transparency will be imposed on decision-makers (DMs) in SC. In this regard, inefficient transactions, fraud, pilferage, and poorly performing supply chains will culminate in removing the trust between SC actors.

Blockchain technology is a distributed database of records of all digital events or shared public/private ledgers that can be executed and instantly shared between agents participating in the blockchain (Crosby et al., 2016). The first point of departure for this technology is distributed ledger technology. Blockchain technology differs from the designs of existing information systems with its four main features, such as non-localization (decentralization), security, auditability, and smart execution (Domingue et al., 2015). These transactions occur as a result of a network consensus rule-compliant verification procedure. Once a new record has been validated and added to the blockchain, several copies of the record are produced in a decentralized way to build a trustworthy chain.

A new transaction initiated by an intermediary on the blockchain constitutes the first step of implementation. This process, which is shared instantly on the network, is included in the verification and auditing process. This new transaction is added to the chain as a new block after it has been confirmed by the majority of the nodes in the chain according to predetermined authorized rules. For security reasons, a record of that transaction is kept on multiple dispersed nodes. Meanwhile, the smart contract, which is a key element of blockchain technology, enables the execution of trustworthy transactions without the participation of third parties. The Internet was meant to transmit information (not value) and copies of things, which is one of the fundamental differences between it and blockchain technology (not original information). Value is represented in blockchains by transactions recorded in a shared ledger, which are protected by giving a verifiable, time-stamped record of transactions. The workflow of the blockchain is shown in Figure 14.5.

14.7.2 Artificial Intelligence (AI)

Bhatele et al. (2019) have defined AI as machine intelligence that implements activities related to an intelligent being. In this technology, human knowledge can be applied to decision-making in multifarious fields such as medical diagnosis.

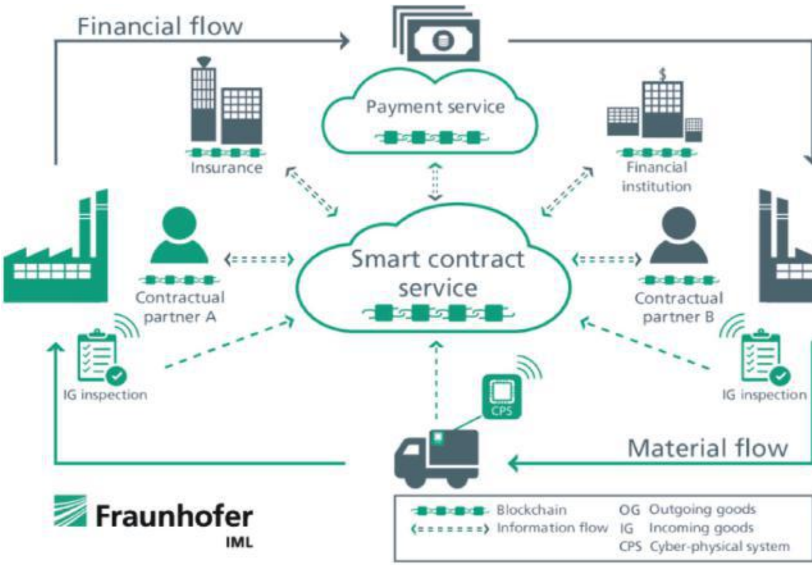

FIGURE 14.5 Blockchain. (Schütte et al., 2018)

Organizations have begun to implement AI with technological advances, such as computing power, exponential growth in data, and new machine learning techniques. Netflix's decisions about movie topics, directors, and actors (Grant, 2018); Unilever's talent acquisition process (Marr, 2018); and Pfizer's drug discovery and development activities (Fleming, 2018) are examples of currently applied AI applications.

14.7.3 Cloud Computing

14.7.3.1 Cloud Computing–Based Supply Chain Information Collaboration System Architecture

The supply chain information collaboration platform consists of four layers (Zhang and Gong, 2021):

- The infrastructure layer, which includes computer servers, network equipment, cloud servers, and cloud storage devices, is the first layer. It acts as the center of all application operations, providing parallel processors, large-capacity storage, and other cloud IaaS infrastructure services.
- The cloud system service layer is the second layer that provides system service, including interfaces for system development, a software operating environment, user management, access codes, permissions, records, and traffic statistics. Cloud computing and information-sharing system for organizations is a service platform that provides corporate collaboration.

- The third layer is the cloud computing application service or virtualization service platform layer, which provides SaaS online software services, such as order, production, and inventory information, and different functional units. Information sharing is the main purpose of cooperation in supply chain management processes.
- The fourth layer is where information is transmitted, processed, received, and responded to quickly using personal computers, mobile phones, and other terminal devices.

The architecture of the cloud computing supply chain collaboration and information-sharing platform consists of these four layers.

14.7.3.2 Construction of Supply Chain Information-Sharing Mode of EPC Internet of Things

EPC is an electronic product code consisting of a question number and digits containing domain name management, object classification, and serial number. It is a list of numbers that correspond to each physical thing (retail units, containers, and cargo identification). It enables organizations to establish a worldwide label standard and track and identify items with EPC. The EPC system is a physical Internet that can automatically identify and exchange information in real time on a global scale and is created from the Internet using technologies such as RFID and wireless data communication. EPC is an information report (directory) running on the physical Internet, consisting of a card reader, EPC tags, medium-sized EPC software, Internet, ONS server, EPC information Service (EPC IS), and many databases (Zhang and Gong, 2021).

This information is about finding the IP address and retrieving the relevant information stored in the address. Because there is only one EPC code on the label, the computer should be able to recognize other information that matches the EPC. This requires the provision of automated network database services by the National Bureau of Statistics. The medium EPC software sends the EPC code to the ONS, and the ONS instructs the medium EPC software to look for the product files on the server (EPC IS) (Zhang and Gong, 2021). The workflow of the EPC system is shown in Figure 14.6.

14.7.4 Big Data Analytics

Big data is characterized as tremendous or complex sets of information, which incorporates a run of exabytes and more. It surpasses the space of a specialized capacity framework, preparing, overseeing, translating, and visualizing a conventional framework (Kaisler et al., 2013).

As of now, information is expanding exponentially and is predicted to reach a zettabyte per year in a number of a long time. The concept of big data was presented by Cox and Ellsworth in October 1997 (Park and Leydesdorff, 2013). Since that point, it has pulled in extraordinary consideration from both the scholarly world and professionals.

The scholarly world and professionals concur that the surge of information makes unused openings; subsequently, numerous organizations tried to create and improve

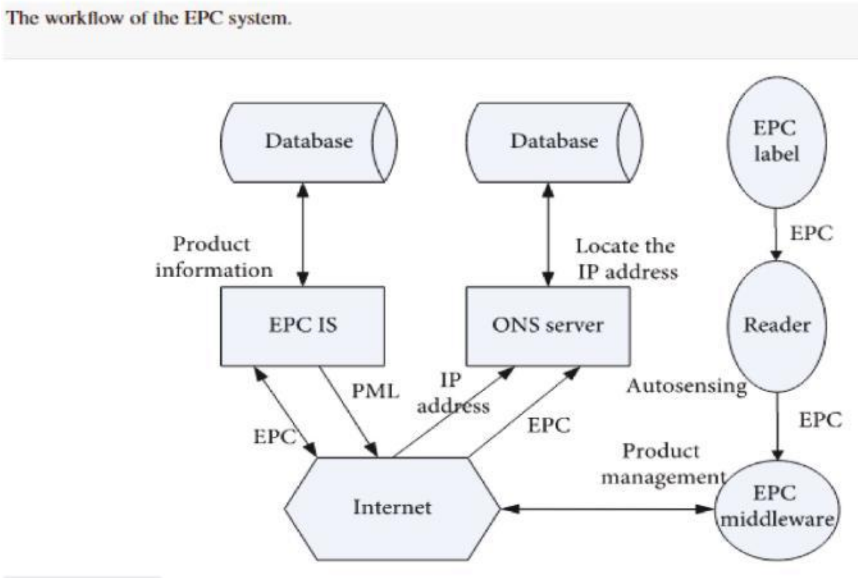

FIGURE 14.6 EPC system.

their huge information analytics capability to reveal and pick up distant understanding from their huge information covered-up values. The consideration of enormous information is ceaselessly advanced and extended, and most qualities of huge information are presently extended into the 5V concept, comprising volume, velocity, variety, verification/veracity, and value (Tiwari et al., 2018).

Organizations have been using analytical applications in supply chain management for many years (Souza, 2014). Organizations have used statistics and operations research to achieve their goals of balancing supply and demand in supply chain management. Business analytics affect supply chain performance with the help of information systems (Trkman et al., 2010). However, as the application of big data evolves, new possibilities are emerging. Advanced big data analytics in supply chain management is called supply chain analytics (Dai et al., 2020). This analytics is divided into three, descriptive, predictive, and prescriptive analytics (Tiwari et al., 2018):

- Descriptive analytics explores what happened in the past, what is happening now, and why. It uses an online analytical processing (OLAP) system to find possibilities and problems (e.g., GPS, RFID, transaction barcode) with visualization tools and real-time information and reporting technology. Descriptive statistics can be used to show total inventory, average customer spending, and sales fluctuations from year to year. Reports that provide historical information about a company's production, financials, operations, sales, finances, inventory, and customers are common examples of descriptive analytics.
- Predictive analytics uses statistics, simulation, and programming to try to determine what will happen with data models. It tries to accurately predict

the future and find out why. It is very important to keep in mind that no statistical technique can accurately predict the future. With predictive analytics, organizations can predict consumer behavior and purchasing patterns and detect trends in sales activity. They also assist in forecasting demand for supply chain, operations, and inventory inputs. Predictive analytics can be used to make predictions or to fill data gaps.

- Prescriptive analytics addresses the topic of what should happen and how to affect it by pushing alternative decisions, utilizing descriptive and predictive analytics, mathematical optimization, simulation, and multicriteria decision-making approaches. Prescriptive analytics is difficult to implement, and most businesses have yet to employ them in their day-to-day operations. When properly implemented, they may have a significant influence on how organizations make choices. Prescriptive analytics is being used successfully by some of the bigger corporations to improve production, scheduling, and inventory in the supply chain.

14.7.5 3D Printing and 4D Printing

There have been significant developments in the field of additive manufacturing since the first system was presented in the late 1980s. There are several uses for additive manufacturing (AM), also known as three-dimensional (3D) printing or rapid prototyping (RP) (Han et al., 2019). Fabrication of physical prototypes, such as mock-ups, functional evaluation of product designs, healthcare goods, and living biological structures, are among these uses. Furthermore, 3D printing has been utilized to create end-use goods, like component or object duplication, 3D printed electronics, fashion and jewelry, and sophisticated multifunctional honeycomb. Figure 14.7 shows the 3D printing process.

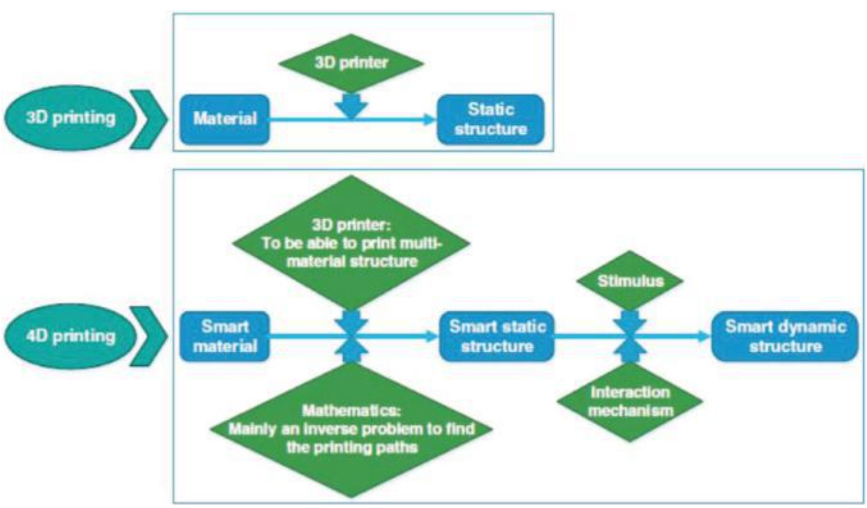

FIGURE 14.7 3D printing.

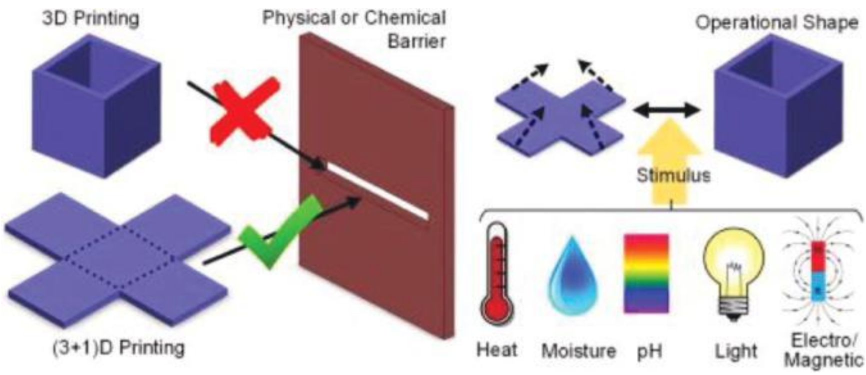

FIGURE 14.8 4D printing.

Smart materials' capacity to evolve in a specified fashion over time allows 3D printed components made of such materials to evolve in a predefined manner. As a result, the phrase "4D printing" has been coined. However, not all 3D printing techniques that create animate components, such as printed live hinges, are classified as 4D printing since they lack smart features, like self-sensing, self-actuation, and shape change. Furthermore, advances in 4D printing have been aided by recent advances in multimaterial printing employing PolyJet technology. Furthermore, recent breakthroughs in multimaterial printing utilizing the PolyJet technology (Stratasys Ltd) and the production of metallic components using the Selective Laser Melting (SLM) technology have aided the development of 4D printing (SLM Solutions) (Han et al., 2019). Figure 14.8 shows the 4D printing process.

14.7.6 Social Network Analysis in Supply Chain

During the last decade, social networks (SN) have drawn the attention of scholars in multifarious fields, such as sociology, epidemiology, economy, computer engineering, telecommunication, and many others. Communication networks, the World Wide Web, and systems with the interaction of numerous individuals (actors) with complicated structures are great instances of SN. Based on Scott (1988), SN is defined as a set of actors or groups of entities and relationships. The first step to capturing the properties of SN is to show it as a graph in which nodes are called actors of the SN and links are relations between the actors. Figure 14.9 indicates a portrayal of SN (Gruszczyński and Arabas, 2011).

SN was used first in the field of sociology, in which scholars didn't use mathematical graph theory. It was indicated that aggregating the concept of SN and mathematical graph theory led to social network analysis (SNA) methods. SNA is defined as graph theory–based techniques that are applied to extract noteworthy information from the networks. Since social platforms have been used widely by people, the application of SNA is more widespread than before. With the advent of platforms such as Facebook, Twitter, Foursquare, nk.pl, to name but a few,

FIGURE 14.9 Social network.

retrieving information has become easier and more applicable than in previous years ago. SNA is commonly used to analyze interpersonal connections in different subjects, which will culminate in paving the path of invaluable knowledge extraction.

14.8 STANDARDS AND REGULATIONS IN IOT: SECURITY IN IOT PRIVACY, SECURITY, SAFETY

Fundamental IoT standards are being created all over the world to meet the need to understand IoT and provide a strategic foundation for IoT standardization across all industries. The absence of common IoT standards for all countries and industries makes IoT construction unable to meet the needs of the final application and directly limits the implementation and development of IoT. For this case, some general and specific standards have been developed for interoperability between entities in the IoT ecosystem. A cross-industry IoT structure maximizes IoT benefits while minimizing IoT risks.

The creation of a new social, political, economic, and ethical environment of IoT has forced political and economic decision-making bodies to develop appropriate regulations to control the fair use of IoT in society. Therefore, the legal and ethical framework of IoT should include the following (Tzafestas, 2018):

- Legislation/regulations
- Ethical principles, rules, and codes
- Standards/guidelines
- Contract arrangements

IoT regulations should include the following (Tzafestas, 2018):

- Regulations for connected devices
- Regulations for networks and their security
- Regulations for data associated with devices

The ISO/IEC NP 19654 standard provides a reference architecture (RA) as the generalized system-level architecture of IoT systems that share common areas. IoT RA also includes rules, guidelines, and policies for building a specific IoT system architecture. IoT RA aims to help develop interoperable IoT systems that interact seamlessly. IoT RA includes three key enablement technology areas (Meddeb, 2016):

1. IoT interest system
2. Communication technology
3. Information technology

Conclusion: It is very important to establish a standardized information publishing platform based on IoT application technology and to coordinate the relationship between national standards and industry standards. Strengthening exchange and cooperation between IoT standards technology organizations, increasing support for international standards, paying attention to the convergence of national and international standards, and promoting the level of international standardization participation will enable countries and industries to be successful in IoT implementations.

14.9 CONCLUSIONS AND FUTURE DIRECTIONS

With the emergence of the Industry 4.0 concept, such as IoT, cloud computing, big data analytics, use of smart sensors, robotics, and more, various industries, such as organizations, are implementing innovative technologies in IoT for competitive advantage and future sustainable supply chain applications. IoT creates an intelligent environment that uses collected information to make critical infrastructure components more informed, interactive, and well-performing. With IoT applications, organizations can respond quickly to customer demand, increase productivity, enable stakeholders to make faster decisions in real time, and improve the production process.

In addition, the energy consumed by ICTs and their impact on the environment are important issues. However, current trends, such as rising electricity costs, reserve limitations, and increasing carbon dioxide (CO_2) emissions, are shifting the IoT's focus to energy-efficient and well-performing solutions.

Therefore, IoT should have a significant impact on global economic, social, and environmental sustainability, as well as provide support for sustainable industrialization. Governments and companies should reduce carbon emissions and direct their energy needs toward renewable energy sources. All in all, IoT is a digital technology that will open up new opportunities for organizations in various industries.

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15 Machine Learning and Data Analytics

Mehmet Şahin

CONTENTS

15.1 INTRODUCTION

Operations management (OM) is responsible for planning, organizing, and managing all resources, such as labor, equipment, materials, technology, and information, needed for product or service production (Sanders 2020). Supply chain management (SCM) combines core business processes from end users to suppliers, providing services, products, and information that add value (Lambert 2008). Hence, the main difference between OM and SCM is that OM deals with intra-company processes, while SCM deals with inter-company processes, such as obtaining materials and delivering products. However, OM and SCM are essential for more efficient processes, adding value to the business and ultimately generating better revenue.

Sustainability assures adequate development standards in the future while focusing on short-term goals (Belvedere and Grando 2017). In this regard, sustainable OM is the management of the process of maximizing benefits to workforces, customers, and societies, and minimizing resource consumption, pollution, and waste in order to minimize risks and maximize revenue in the long term (Sanders and Wood 2019). Sustainable SCM is the design, coordination, control, and organization of processes

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in a way that does no damage to the environment and social systems in the long run with minimum economic requirements (Pagell and Shevchenko 2014).

The success of operations and supply chain management today depends mainly on the degree of digital technology adopted. Digital technology and transformation have enabled intelligent (smart) factories or adaptive production and logistics networks. Besides, the Internet, data analytics, industrial robots, additive manufacturing, augmented reality, and tracing and tracking technology are contributing factors to smart operations and supply chain management (Ivanov, Tsipoulanidis, and Schönberger 2019). Data analytics and machine learning concepts are integral parts of smart and sustainable operations and supply chain management in this context.

The massive expansion of machine learning and data-based information technologies has enabled the emergence of a "new industrial revolution" (Li et al. 2017). This new Industrial Revolution has triggered radical models, methods, procedures, and systems in operations and supply chain management (Liu, Zhu, and Seuring 2020). In this way, modern organizations can collect vast amounts of data. However, data must be analyzed and processed to be valuable and meaningful to organizations. In other words, data need to be transformed into insights that can be used to make optimal decisions. Extracting insights from data is the task of data analytics. Different tasks may be needed in data analytics, including forecasting, classification, and hybridization. Machine learning is capable of performing such tasks efficiently and effectively, as can be seen in real-life applications. In general terms, machine learning can be described as extracting patterns from data. More specifically, the algorithm of machine learning systematizes the learning process, which can determine the relationship between the descriptive features in a dataset and the target feature.

The rest of the present study is structured as follows. The following section provides background information. Chapter 15.3 reviews the recent and related literature. Chapter 15.4 details data analytics and machine learning. Chapter 15.5 explains operations and supply chain management in terms of smart and sustainable perspectives. Then Chapter 15.7 presents the details of the case study and the obtained results. Finally, Chapter 15.8 concludes the study.

15.2 BACKGROUND

Advances in technology and science lead to changes in the way people work and the business environment. The changes can be explained as follows in four industrial phases (revolutions). In the First Industrial Revolution, the production processes were mechanized. The use of steam and water power started to improve efficiency for the creation of goods. In the Second Industrial Revolution, division of labor principles was introduced, and electrical energy innovations that powered machines led to mass production as a new production method. Then in the Third Industrial Revolution, computer technology was used in the value creation processes. In other words, information-oriented production emerged. Progresses in electronics, information technology, and automation led to new approaches, including computer-integrated manufacturing. During these three revolutions, milestone advances were achieved in terms of efficiency and productivity (Ivanov, Tsipoulanidis, and Schönberger 2019).

New approaches and developments triggered the Fourth Industrial Revolution (Industry 4.0), which now exists and is based on digitalization. Industry 4.0

incorporates an intelligent production network where machines, tools, materials, and products interact with needless human control. Operations and supply chains in such networks have dynamic features evolving over time. Flexible customized production, high output, real-time capacity utilization control, and low stock levels, risks, emissions, and transportation are enabled by Industry 4.0. Industry 4.0 necessitates reconsidering and changing the mindset in how products and services are produced, used, distributed, supplied, and sold in the supply chain. Therefore, it has triggered substantial structural theoretical development and revolution for operations and supply chain management.

The Industry 4.0 concept facilitates the use of smart sensors, devices, and machines to enable smart factories that constantly collect production-related data. Transforming data into a usable form to make optimal decisions is accomplished through data analytics. It can be stated that data and data analytics are found in all dimensions of the Industry 4.0 ecosystem, and machine learning is an essential component of this ecosystem. In this context, machine learning methods enable the generation of actionable intelligence and the intelligent decision support system in various fields such as OM, predictive maintenance, quality improvement, intelligent and continuous inspection, process optimization, and supply chain management by processing the obtained data to increase productivity and efficiency. As a result, some distinct advantages are achieved in operations and supply chain management through data analytics and machine learning. Some of the advantages are optimized transportation and delivery; minimized losses associated with delayed, damaged, or lost goods in transit; advanced real-time asset management, increased assembly-line efficiency; reduced errors and repairs during product development and improved product quality; advanced customization and increased customer satisfaction; extended asset life and avoided downtimes through predictive maintenance; and increased visibility in the supply chain and operations management (Rai et al. 2021).

15.3 LITERATURE REVIEW

The business environment has been dynamic, and competition between companies has been stiff. As mentioned previously, the earlier phases of the Industrial Revolution provided various signs of progress. However, there were some issues related to productivity, timeliness, customization of products, demand, and delivery (Nagar et al. 2021). Developments and changes in different areas, changing customer expectations and demands over time, and scarce resources have triggered new trends, methods, and developments. Nowadays, end users constantly demand highly customized products in small batches (Wang et al. 2016). The industries must consider flexibility, innovation, and complexity (Nagar et al. 2021). In this regard, Industry 4.0, which was first introduced in 2011 and can meet such expectations and needs, is a strategy that enables the customization of products with highly flexible mass production (Wang et al. 2017). It allows flexibility in the organization's operational activities, facilitating the production system's adaptation into mass customization and improving quality and productivity (Almada-Lobo 2015).

Industry 4.0 is accepted as the new Industrial Revolution. Industry 4.0 integrates different methods and technologies, such as the Internet, data analytics, cloud computing, and machine learning (Duan, Edwards, and Dwivedi 2019). Industry 4.0 or smart manufacturing is grounded on the interconnectedness of processes and machines using the technologies mentioned previously to self-correct and self-adapt to environmental requirements (Fatorachian and Kazemi 2021). Connected machines and processes through network sensors to the Internet generate a vast amount of data (Kotsiopoulos et al. 2021). Machine learning is used to examine, evaluate, and interpret the generated data and produce valuable information about different aspects of operations and supply chain management, such as optimizing products and processes, reducing waste, minimizing costs, and automating the production process (Min 2010). In addition, such technologies and methods enable industries to transform production resources and capabilities into production services that can be managed and operated in an intelligent and integrated manner to ensure the full sharing and circulation of production resources and production capabilities (Zhang et al. 2014).

The implementation of Industry 4.0 technologies provides substantial performance enhancements in supply chain management by providing comprehensive integration, information sharing, and transparency in all supply chain processes. In addition, these technologies enable significant performance improvements in supply chain processes, such as inventory management, procurement, and manufacturing, by providing automation, process integration, digitization, and innovative analytical capabilities (Fatorachian and Kazemi 2021). Considering the supply chain concept, in which resources flow from one location to another to meet customer expectations and demand, it is understood that a vast amount of data based on various parameters, including geographic, demographic, and behavioral, are obtained (Hsu et al. 2009).

Industry 4.0 technologies provide substantial improvements in OM as well. Some improvements are enhanced process flexibility, cost reduction in production, time reduction in product processing, better customer service, highly customized production, and reduced product waste and defects (Fettermann et al. 2018). Thanks to automation, product quality has been improved, and production processes have been more efficient (Lasi et al. 2014). Industry 4.0 has gained new decentralized and digitized production standards in the manufacturing industry and added value to the entire product lifecycle (Koh, Orzes, and Jia 2019). Industry 4.0 technological innovations ensure the effective use of resources, making sustainable performance a vital component in smart factories (Strozzi et al. 2017). Industry 4.0 improves the connection and interaction between systems, processes, and input sources, resulting in more interactive production systems (Mourtzis et al. 2019). As a result, vast amounts of data are generated at all levels of production systems and operations.

Data analytics plays a crucial role in achieving improvements. In Industry 4.0, possible machine malfunctions can be diagnosed, and maintenance processes can be optimized with the large amount of data collected from the production process (Duan and Da Xu 2021). In addition, data analytics can be adopted to improve all processes, including manufacturing components, assembling products, quality control of products, distributing products to customers, and managing customer relationships (Xu et al. 2007). Industry 4.0 and Industrial Internet of Things (IIoT) technologies generate big data and spread software solutions in various areas, especially industrial automation and production systems (Kabugo et al. 2020). Overall, considering all connecting and communicating machines and processes in all aspects of smart factories, a vast amount of data has been generated. To extract insights from the data, data analytics plays a crucial role.

Using such data, machine learning is a robust and powerful method concentrating on optimizing all resource utilization throughout the value chain and operations (Helo and Hao 2021). Machine learning is among the most effective tools in today's perspective since it focuses on optimizing the entire resource usage throughout the value chain (Fasli and Kovalchuk 2011). Machine learning often provides reliable information as it accurately predicts the situation and helps find the most feasible solution from the alternative course of action developed in the analysis (Sindhwani et al. 2019). Overall, big data has been affecting the process industries significantly, providing significant opportunities in smart manufacturing, which requires machines to be efficient at taking on intellectual labor, innovating independently, and freeing people from intense physical work. In this context, data analytics and machine learning are indispensable (Shang and You 2019).

15.4 DATA ANALYTICS AND MACHINE LEARNING

In this section, the details of data analytics and machine learning are presented. In this context, the importance of data analytics is explained. Next, different stages of data analytics are described. Then the purposes of using machine learning, types of machine learning, and machine learning algorithms are explained, respectively.

15.4.1 Data Analytics

One of the most distinctive features of Industry 4.0 is the high availability of data. Such a large amount of data is generated through machines and processes connected to the Internet via network sensors. Data analytics and machine learning, needed to analyze, interpret, process, and model data to ultimately achieve machine intelligence, have played a decisive and essential role in constantly moving beyond traditional operations and supply chain management boundaries. These methods have permeated various areas and processes of operations and supply chain management to handle tasks such as process monitoring and critical decision-making.

Data processing enables the integration of analytical systems to develop sustainable decision-making processes in production management and supply chain management (Ahmad et al. 2020). Such sustainable decision-making processes are vital for improving operational efficiency, minimizing faults and defects, minimizing costs, improving quality, and increasing productivity. In this context, data can be considered both input and output in smart and sustainable production and supply chain operations. In other words, data represents one of the vital inputs for decision-making processes in sustainable manufacturing and supply chain operations. In addition, data is one of the most fundamental outputs for smart manufacturing and supply chain operations, as it is an essential component of the real-time feedback system necessary to achieve the ultimate goals in OM and supply chain management, such as maximizing revenue and minimizing costs. Considering the importance of big data and the necessity of data analytics in transforming this data into a meaningful one, the importance of data analytics is seen more clearly.

Different stages of data analytics can be formed with machine learning methods. These can be (i) predictive analytics, (ii) diagnostic analytics, (iii) prescriptive analytics, and (iv) descriptive analytics. Predictive analytics utilizes statistical models for several purposes, including estimating the possible production size and the remaining useful life of the machinery. Diagnostic analytics analyze and report malfunctions in the machine and product. Prescriptive analytics recommends undertaking movements to optimize production and determine the effect of such actions. Descriptive analytics review and define the situations in the production process and production environment (Kotsiopoulos et al. 2021).

15.4.2 Machine Learning

Machine learning is described as an automated process that extracts patterns from data. Machine learning can also be defined as the science of getting machines to act without explicit programming. The basic logic underlying machine learning is case-based reasoning, the procedure of reasoning the problem by relating to preceding comparable situations. In this context, machine learning algorithms systematize a model learning process that maps the relationship between the descriptive features and the target features in a dataset.

It can be stated that a machine learning approach comprises three main components that are data, representations, and models. First, the data is used to train, validate, and test the model. The size of the data significantly determines the accuracy of the output the model provides. Given that actual big data can be costly to acquire, the data may be the weakest component. Second, it is essential to how the data is represented in the model. Data can be in numeric and non-numeric formats. In this context, determining the variables that make up the model input is decisive for the model performance. Last, a modeling strategy is vital. Various machine learning models can be applied to a particular problem. Models can be classified differently according to the purpose (classification, regression, clustering, or hybrid tasks) or learning methodology (supervised, unsupervised, semi-supervised, or reinforcement learning). Machine learning models can be implemented for any problem where correlations within datasets are indirectly modeled (Dobbelaere et al. 2021).

The purposes of using machine learning can be grouped as follows (Jo 2021):

- *Classification* involves assigning each entry to one or more of the predetermined classes.
- *Regression* is the process of predicting an output depending on various features. The difference between regression and classification is the continuous output value in regression and discrete in classification.
- *Clustering* involves the process of dividing a cluster of objects into smaller groups, each containing similar ones.
- *Hybrid tasks* involve integrating classification, regression, or clustering. For instance, allocating a categorical value to each category in the form of a continuous value can be considered a combination of classification and regression.

15.4.2.1 Types of Machine Learning

15.4.2.1.1 Supervised Learning

To minimize the misclassification or the difference between the computed and target outputs, the parameters are optimized in this learning concept. To illustrate this expression, it can be stated that there are two types of outputs: the target output that is firstly labeled to each training example, and the calculated output that is calculated through the learning algorithm—the KNN (k-nearest Neighbor), decision tree, and naïve Bayes belong to this group. Regression and classification are application fields of this kind of learning algorithm.

15.4.2.1.2 Unsupervised Learning

In the unsupervised learning concept, the cluster prototypes are optimized based on the resemblances among the training examples. All training examples are unlabeled, and prototypes, each characterizing its own set, are randomly started in unsupervised learning. Unlabeled training samples are used to optimize cluster prototypes based on their similarity. As explained earlier, supervised learning focuses on minimizing misclassifications or errors between calculated outputs and target outputs, while unsupervised learning focuses on maximizing resemblances between cluster prototypes and data objects. In this context, it can be stated that unsupervised learning algorithms are functional for clustering.

15.4.2.1.3 Semi-Supervised Learning

In this learning concept, the error between the target label and the computed one and the unlabeled samples are minimized, based on their similarities, as the combination of supervised learning and unsupervised learning. Semi-supervised learning is implemented for classification and regression purposes by adding unlabeled examples. The unsupervised learning algorithm is integrated with the supervised learning algorithm in semi-supervised learning.

15.4.2.1.4 Reinforcement Learning

The parameters are restructured to maximize the reward and minimize the punishment. The input is obtained from the external environment, and the output is produced as the action. As a critic, the reward or punishment is assigned from the environment, and parameters are updated to receive the reward and avoid punishment (Jo 2021).

15.4.2.2 Machine Learning Algorithms

Some common machine learning algorithms are described in this section. In this context, decision tree, support vector machine, Gaussian process regression, ensemble methods, nearest neighbor, naïve Bayes, and logistic regression are explained as follows:

1. ***Decision tree*:** The fundamental concept of a decision tree is to iteratively split a training set till each partition completely or mainly comprises examples from one class. The decision tree algorithm uses a decision tree to

observe the data of a case and generate a concise and precise report on the case's target value. To do so, decision tree algorithms generally construct an opening tree from the training data with each leaf node being pure and then prune the tree to rise generalization and, thus, the forecast accuracy of the test data. Decision trees are used to predict categorical values. One of theadvantages of the decision tree is that it requires less data preparation in the preprocessing stage (Sharda, Delen, and Turban 2020).

2. ***Support vector machine (SVM)*****:** Support vector machine is a commonly used machine learning method due to its superior predictive capabilities and theoretical foundations. As a supervised learning technique, they form input-output functions from labeled training datasets. The function between the input and output vectors may be either regression or classification. In this context, regression is applied to predict the continuous numerical value of the desired output, and classification is applied to allocate cases into predefined classes. Support vector machines can process high-dimensional multivariate datasets and provide significant accuracy and remarkable performance (Bredensteiner and Bennett 1999).
3. ***Gaussian process regression (GPR)***: Gaussian process regression is a nonparametric supervised machine learning technique applied to multivariate regression and classification cases. Gaussian process regression is used to define the initial distribution for flexible classification and regression models, where regression or class probability functions are not limited to primary parametric forms. Some of the advantages of the Gaussian process regression include having high flexibility and accurate prediction for processing small and high-dimensional datasets and assessing the successive deterioration of nonlinear regression by limiting the previous distribution to match the existing training data (Ažman and Kocijan 2011).
4. ***Ensemble methods***: Ensemble learning combines several weak machine learning algorithms into a robust algorithm. Ensemble methods belong to the family of machine learning algorithms in which a weighted committee of learners is utilized to solve classification or regression problems. The ensemble's base learners can be the nearest neighbor, neural networks, or decision trees. It is believed that ensemble methods allow a better generalization model compared to a single model. One of the main advantages of ensemble methods is that they improve the machine learning results by combining multiple models, which leads to formulating a better predictive model than a single model (Wuest et al. 2016).
5. ***Nearest neighbor*****:** The nearest neighbor (or k-nearest neighbor) algorithm is a straightforward machine learning algorithm applied to classification and regression problems. The nearest neighbor algorithm is a kind of instance-based learning algorithm, where all calculations are postponed until the actual forecast. To determine the optimal value of the *k* parameter, which denotes the number of neighbors to use in a given prediction problem, a cross-validation–type experimentation is needed (Sharda, Delen, and Turban 2020).
6. ***Naïve Bayes*****:** Naïve Bayes is a probability-based machine learning method implemented for classification-kind prediction problems derivative from the

Bayes theorem. A naïve Bayes classifier assumes that the input variables are not interdependent and that the existence or absence of a specific variable among the estimators has nothing to do with the absence or presence of other variables. Because of the independence assumption, naïve Bayes models can be constructed without strictly following the instructions and requirements of Bayes's theorem (Sharda, Delen, and Turban 2020).

7. ***Logistic regression*:** Logistic regression is like linear regression in that it focuses on regression to a mathematical function that defines the relationship between the output variable and input variables in historical data. However, logistic regression diverges from linear regression because the output is a class rather than a numerical variable. Although logistic regression can deal with multidimensional feature spaces, logistic regression output is discrete (Şahin 2021).

15.5 SMART OPERATIONS AND SUPPLY CHAIN MANAGEMENT

In addition to enabling remarkable changes and developments in production, the Industrial Revolution has formed and shaped vital infrastructures to create intelligent factories by providing comprehensive process integration (Rashid and Tjahjono 2016). In the environment provided by Industry 4.0, networked communication between machines, processes, and systems has enabled the creation of smart factories and fully automated production systems. Thus, a high level of automation can provide enhanced operational performance. The steady increase in business systems' automation and the subsequent productivity and efficiency benefits and quality enhancements are driving organizations to expand the Industry 4.0 operational perspective into other organizational fields, such as operations and supply chain management.

Industry 4.0 and its enabling technologies influence every part of factories and organizations and lead to significant advances in management levels such as operations and supply chain management (Blau 2014). Adapting the technologies within the scope of Industry 4.0 to operations and supply chain management is accepted as a promising strategy for solving the incorporation problems because these technologies have been revolutionizing operations and supply chain management by providing enhanced connectivity, comprehensive integration, and thus, significant performance improvements in processes.

15.6 SUSTAINABLE OPERATIONS AND SUPPLY CHAIN MANAGEMENT

Thanks to the consolidation and integration of production technologies, machines and devices, information and communication systems, and database with the network structure, production facilities are better positioned in such essential matters as interactivity, security, productivity, efficiency, and sustainability. Succinctly, factories have become more intelligent.

The impact of smart factory technologies on sustainability dimensions is significant. The application of the Internet of Things technologies in the smart factory can be exemplified as follows. Sensors integrated with artificial intelligence, providing predictive and intelligent maintenance, can automatically detect and diagnose faults in advance. Thus, preventive measures can be taken to minimize downtime and increase components' utilization rate and their remaining useful life. Predictive maintenance is vital for sustainable and smart manufacturing (Çınar et al. 2020). Cloud computing systems allow data to be stored in a network-based sharing environment. It can be stated that the stored and shared data is generally a valuable input in many critical situations, such as decision-making and taking preventive actions. Mobile and augmented reality devices process information in real time, enabling employees to improve the efficiency and performance of their operations. The flexibility and reconfigurability of production and interaction with customers in the smart factory allow cost-effective personalized, high-quality products. Considering all these situations, the technologies implemented within the scope of Industry 4.0 allow the efficient use of resources and, thus, make sustainability the focus and output of smart factories (Strozzi et al. 2017).

15.7 CASE STUDY

Energy affects a variety of crucial fields, such as health, quality of life, industrial manufacture, access to water, agricultural production, and education (Suganthi and Samuel 2012). It is an indispensable input for production, and it has a critical role in the development of societies and economies. Therefore, governments and industry must pay attention to the following subjects (Sánchez-Durán, Luque, and Barbancho 2019): (1) energy equity (energy supply's availability and affordability for the population), (2) energy security (reliability of energy infrastructure, and capacity of energy suppliers to meet present and future demand), and (3) environmental sustainability (energy productivity and the potential of energy provided by renewable and clean sources). Considering the criticality of the subject, in this study, the case of demand forecasting of the energy supply chain in the era of Industry 4.0 is considered.

Demand forecasting is essential in addressing uncertainties in operations and supply chains (Blackburn et al. 2015; Boulaksil 2016). In the era of Industry 4.0, with the enhanced computational efficiencies and developments in information technologies, real-time data gathering, data analytics, and machine learning methods provide more accurate predictions that enable more efficient processes in operations and supply chain, a better understanding of customer needs, reduced reaction times, facilitated evaluations, and better risk assessments (Seyedan and Mafakheri 2020).

The main objectives of the present case by implementing data analytics/machine learning algorithms include facilitating accurate data-driven demand prediction and aligning operations and supply chain processes with these forecasts to maximize satisfaction and efficiency while minimizing costs. Also, considering that demand uncertainty has a noticeable impact on supply chain performance with extensive effects on production and inventory planning, demand forecasting is vital for determining such uncertainties.

To demonstrate the applicability of machine learning methods, the prediction of electricity consumption in Turkey is considered as a case study. As mentioned earlier, electricity is a vital input for production systems. Therefore, it has a crucial role in effectively ensuring and operating smart and sustainable operations and supply chain management. In addition, considering that electricity is a scarce resource, predicting its consumption is vital in many aspects, such as planning and sustainability. In this context, real data is collected and used (EMRA 2021). The input variables are year, month, licensed generation, unlicensed generation, licensed installed capacity, unlicensed installed capacity, import, and export. The output variable is invoiced electricity consumption. The five-year data is used for training the models. The models are used to predict the 2021-year data. In other words, to provide a realistic comparison, the predicted values are compared with the actual values (invoiced electricity consumption (MWh)). In this context, the models' analysis, training, testing, and calculation processes are conducted on MATLAB (2020) (MathWorks 2020).

The prediction results and actual values are shown in Table 15.1. The prediction results were obtained from exponential Gaussian process regression (EGPR), linear regression (LR), robust linear (RL), fine tree (FT), coarse Gaussian support vector machine (CGSVM), medium Gaussian support vector machine (MGSVM), ensemble boosted trees (EBT), and ensemble bagged trees (EBGT) models.

To compare the performance of the models, mean absolute percent error (MAPE) values are calculated as shown in Table 15.2.

The MAPE results revealed that the robust linear model provided the best prediction results, followed by exponential Gaussian process regression, fine tree, coarse Gaussian support vector machine, ensemble bagged trees, medium Gaussian support vector machine, linear regression, and ensemble boosted trees models. However, it can be seen that all models provided effective results since all MAPE values were less than 10%. It can be inferred that all these models can be used for the prediction

TABLE 15.1
The Predicted and Actual Consumption Values in MWh

EGPR	LR	RL	FT	CGSVM	MGSVM	EBT	EBGT	Actual Values
20051000	24282000	20399000	19424000	19795000	19664000	18649000	20401000	19969814
18719000	20856000	19034000	18556000	19169000	18668000	17697000	18660000	19088175
20403000	20908000	21183000	20848000	20090000	19613000	19969000	21108000	20882048
19720000	20748000	20112000	20322000	19639000	19457000	18893000	19764000	20457549
19082000	20448000	20016000	18556000	19409000	18795000	17588000	18570000	19511124
20064000	21643000	21095000	20322000	19856000	19551000	18808000	19766000	20936645
21255000	23137000	23295000	20848000	20711000	19274000	20519000	21108000	21998241

TABLE 15.2
MAPE Values Based on the Prediction Results of the Models

EGPR	LR	RL	FT	CGSVM	MGSVM	EBT	EBGT
2.57%	6.54%	2.12%	2.77%	2.95%	5.34%	7.52%	3.33%

of electricity consumption (demand). If a model is to be selected, it must be the robust linear model.

The present case results are essential in different aspects. The outperforming machine learning was determined to predict electricity demand, and prediction results were obtained from different machine learning models within the scope of the analysis that allowed the methods to be compared and evaluated. However, it should be noted that the case and the variables were chosen to show the applicability of the methods to the problem. Despite the effective and acceptable prediction results, the accuracy of the prediction could be improved by including additional variables, such as weather, day of the week, and week of the month. These kinds of variables might allow a more detailed analysis. Also, a larger size of data might improve the accuracy of the prediction results.

15.8 CONCLUSIONS

Thanks to the possibilities provided by Industry 4.0, an ever-increasing amount of data containing valuable information can be gathered and archived. The importance of data has been increasing day by day. Data analytics and machine learning are essential tools to unlock and harness the benefits of data. Data analytics and machine learning methods can help sense the environment, extract information, and thus, enable automated and intelligent decisions using relevant data as input. Therefore, it can be stated that data analytics and machine learning are integral parts of smart and sustainable operations and supply chain management.

An energy demand forecasting case was considered in the present study to demonstrate the applicability of machine learning methods. As well-known, electricity is an integral input of any manufacturing system. Considering the fact that the manufacturing system is the backbone of operations and supply chain management, forecasting the demand for the scarce input (electricity) is valuable. It is needless to mention the criticality of electricity and the significance of forecasting its consumption in general. Based on real data, all machine learning methods used have been shown to provide accurate and effective predictions. As highlighted, more accurate predictions could be achieved by using a larger dataset and including additional variables.

The fact is that data analytics and machine learning models have been successful in various fields for different purposes. In particular, data analytics and machine learning have been facilitators and crucial infrastructure components for smart and sustainable operations and supply chain management. It may not be easy to summarize the benefits they provide, but it can be concluded that the benefits they provide are undeniably significant. However, there may be some concerns and difficulties in obtaining, storing, understanding, and processing big data. In addition, cybersecurity problems can threaten the success, continuity, and sustainability of smart manufacturing.

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16 Fuzzy Decision-Making

Belkız Torğul and Turan Paksoy

CONTENTS

16.1 INTRODUCTION

Fuzzy expressions and fuzzy logic are used quite often in our daily life, and no one notices them. Natural language is full of vague and imprecise notions, such as "he's tall" or "it's very cold today." Information originating from natural spoken language, which people frequently use, is ignored in the classical decision-making processes. However, it is very significant that the decisions to be made in the conditions of verbal uncertainty expressions result in consistent and correct choices too (Ross 2005).

In cases where the information is not complete or precise, the use of mathematical methods, which require clear data to model a complex system, is insufficient. The fuzzy logic concept was demonstrated by Lotfi A. Zadeh in 1965 to define the uncertainties arising from expressions used in daily life, and a new era was opened in the world of science and technology. The idea of fuzzy logic is similar to the human

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emotion and inference process (Bai and Wang 2007). Its main purpose is to enable the use of imprecise propositions, which are the basis of fuzzy set theory. L. A. Zadeh developed the fuzzy set theory as a tool for representing uncertainty. Through fuzzy set theory, uncertainty could be expressed linguistically in forms such as "more or less" and "a little." It considers the partial membership relations and, thus, allows the memberships that are difficult to define since they have no definite boundaries, such as the set of blue or bluish colors, to be explained mathematically, too, and to be expressed with the help of a function.

Since the 1970s, various fuzzy set types have been introduced: type-1 (classic fuzzy set), Type-2, Rough, Intuitionistic, Grey, Vague, Neutrosophic, Hierarchical, Axiomatic, Hesitant, Pythagorean, 2-tuple, Z-numbers, and Fermatean fuzzy sets. In addition to these, many other fuzzy set extensions have been presented and continue to be acquainted. Due to space limitations, all different fuzzy sets and their applications could not be covered in a single chapter, so the fundamentals of fuzzy logic presented in the next section are on classical fuzzy sets.

16.2 FUZZY SETS

Fuzzy sets described in 1965 by Lotfi A. Zadeh have been used to model decision-making operations dependent on vague and uncertain information, such as the judgments of decision-makers. It handles uncertainty in decision-making via quantification to qualitative values (Zadeh 1965; Lima Junior, Osiro, and Carpinetti 2014).

The classical set theory permits the membership of the elements in the set with binary statements; that is, it is expressed as either an element of the set (1) or not (0). The fuzzy set, in other respects, is an object class with continuous membership degrees; that is, it is expressed as such grade belongs to the set or such grade does not belong to the set, allowing a membership function valued in the range of [0,1] (Zadeh 1965).

16.2.1 Membership Functions

A fuzzy set $\tilde{A}$ is expressed by a characteristic function in interval [0,1] defined from the universal set E. The function in question is called the membership function. A membership function to be defined for the fuzzy set $\tilde{A}$ is shown in equation 16.1 (Höhle and Rodabaugh 2012).

$$\mu_{\tilde{A}} : E \rightarrow [0, 1] \tag{16.1}$$

The degree of membership of x, which is a member of fuzzy set $\tilde{A}$, $\mu_{\tilde{A}}(x)$ is an indicator that the element x is a member of fuzzy set $\tilde{A}$ with how much degree, and it provides the calculation of the correctness of the sentence "x is a member of fuzzy set $\tilde{A}$" (Höhle and Rodabaugh 2012).

If $\mu_{\tilde{A}}(x) = 0$, x isn't an element of fuzzy set $\tilde{A}$. If $\mu_{\tilde{A}}(x) = 1$, then x is definitely an element of fuzzy set $\tilde{A}$. In other cases, the fact that x is in the set is defined as fuzzy. As the value of $\mu_{\tilde{A}}(x)$ gets closer to 1, the membership of x increases in the set.

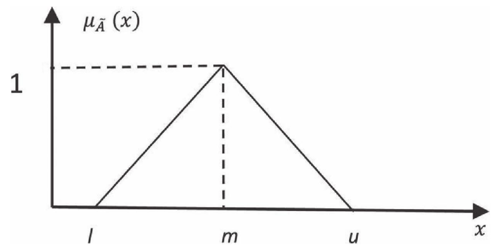

FIGURE 16.1 Triangular membership function.

There are different notations for describing a fuzzy set. Equation 16.2 shows the expression of a fuzzy set $\tilde{A}$ as ordered pairs. The first expression in the ordered pairs represents the element whose membership degree is calculated, and the second expression indicates the membership degree of the element (Li and Yen 1995).

$$\tilde{A} = \left\{\left(x_1, \mu_{\tilde{A}}(x_1)\right), \left(x_2, \mu_{\tilde{A}}(x_2)\right), \ldots, \left(x_n, \mu_{\tilde{A}}(x_n)\right)\right\} \tag{16.2}$$

Fuzzy numbers can be expressed in different ways and can be represented by continuous or piecewise continuous membership functions. The mostly used membership functions are triangular and trapezoidal. The triangular fuzzy number and membership function are presented later.

A triangular fuzzy number is denoted as (l, m, u), with $1 < m < u$, and shown in Figure 16.1 (Shaw et al. 2012; Lima-Junior and Carpinetti 2016b).

A triangular membership function and its elements are presented in equation 16.3, as follows:

$$\mu_{\tilde{A}}(x; l, m, u) = \begin{cases} 0 & for\, x < l, \\ \dfrac{x-l}{m-l} & for\, l \le x \le m, \\ \dfrac{u-x}{u-m} & for\, m \le x \le u, \\ 0 & for\, x > u, \end{cases} \tag{16.3}$$

16.2.2 Arithmetic Operations on Fuzzy Numbers

Arithmetic operations on fuzzy numbers could be performed with different techniques, such as interval arithmetic operations, approximation arithmetic operations, arithmetic operations with confidence intervals, or arithmetic operations with membership functions, which vary according to the fuzzy number type. In this section, the arithmetic operations that give approximate results on triangular fuzzy numbers are presented.

Let there be two triangular fuzzy numbers $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$.

Equality: The equality of *A* and *B* fuzzy numbers means the equality of all mutual elements (membership functions). Mathematically:

$\tilde{A} = \tilde{B} \Leftrightarrow (a_1, a_2, a_3) = (b_1, b_2, b_3) \Leftrightarrow a_1 = b_1,\ a_2 = b_2,\ a_3 = b_3$

Summation: It is expressed as $\tilde{A}(+)\tilde{B} = (a_1 + b_1,\ a_2 + b_2,\ a_3 + b_3)$, and the result is again a triangular fuzzy number.

Subtraction: It is expressed as $\tilde{A}(-)\tilde{B} = (a_1 - b_3,\ a_2 - b_2,\ a_3 - b_1)$, and the result is again a triangular fuzzy number.

Symmetric: The symmetry of $\tilde{A} = (a_1, a_2, a_3)$ triangular fuzzy number will be $-(\tilde{A}) = (-a_3,\ -a_2, -a_1)$.

Multiplication: It is expressed as $\tilde{A}(\times)\tilde{B} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3)$, and the result is again a triangular fuzzy number.

Division: It is expressed as $\tilde{A}(/)\tilde{B} = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right)$, and the result is again a triangular fuzzy number.

Operations of multiplication and division are identified only on positive fuzzy numbers. A positive fuzzy number is a number whose lower limit is a positive number (Bector and Chandra 2005; Lee 2004).

16.2.3 Defuzzification

The defuzzification process performs the conversion of fuzzy numbers to classical numbers by expressing a fuzzy set with a single representative numerical value (Sousa and Kaymak 2002). There are different methods, such as the center of sums method, center of gravity method, maximum membership method, average maximum membership method, and weighted average method, to perform the defuzzification process. The following defuzzification technique, one of the weighted average methods, is widely used.

Graded mean integration representation:

The graded mean integration representation $R(\tilde{A})$ of a triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3)$ can be calculated by equation 16.4 (Chen and Hsieh 2000).

$$R(\tilde{A}) = \frac{a_1 + 4a_2 + a_3}{6} \tag{16.4}$$

16.3 FUZZY DECISION-MAKING

Both in daily life and business life, people often face the problem of choosing one among various options. The choice of an activity or set of activities from among the possible options is defined as a decision. A traditional decision problem consists of six components: decision-maker, goal, decision criteria, options, and result. The decision model is established for the evaluation and selection of alternatives (options). Evaluation measures are one or more objectives and criteria to be determined by the decision-maker. From this point of view, mathematical decision-making techniques could be examined in three categories: single-objective single-criteria, single-objective multicriteria, and multi-objective multicriteria decision-making techniques. Single objective decision-making techniques are based on the logic of optimizing a single objective function of the decision-maker, which can be maximum or minimum, under specified constraints. Multi-objective decision-making techniques have been developed for situations where there are multiple objectives to be achieved simultaneously. Multicriteria decision-making techniques are utilized to solve selection or ranking problems involving multiple criteria and alternatives.

In real-life problems, question components may not always be modeled precisely (Massad et al. 2009). During decision-making, many quantitative and qualitative criteria could be involved in the process, as well as taking into account the experience, personal ideas, and strategic goals of the decision-makers.

The decision-making process becomes a difficult process, especially in areas where there is incomplete or ambiguous information and where factors containing verbal and linguistic uncertainties are frequently used. These factors are an indication that the decision-making process should take place in a fuzzy environment (Massad et al. 2009). The stages of a fuzzy decision process work similarly to a classical decision process. What is different is the cases where there is no fuzziness in the decision-maker and the set of options (universal set), but the goal, decision criteria, and parameter components may contain fuzziness. The fuzzy logic approach is used when it isn't feasible to measure the uncertainty of information or judgments with deterministic techniques.

Based on the fuzzy set concept, Bellman and Zadeh introduced the fuzzy decision theory in 1970. A decision to be made in a fuzzy environment is described by a decision set that combines the fuzzy objective function and fuzzy constraints (Bellman and Zadeh 1970). Following the decision theory of Bellman and Zadeh, fuzzy linear programming is developed by Zimmermann.

Fuzzy set theory is commonly used in conjunction with multicriteria decision-making (MCDM) methods to deal with vagueness in decision-making, as it ensures a convenient language for handling fuzzy criteria that could integrate analysis of qualitative and quantitative factors (Amid, Ghodsypour, and O'Brien 2006; Kumar, Vrat, and Shankar 2006). The commonly used fuzzy MCDM approaches are fuzzy AHP (analytic hierarchy process), fuzzy ANP (analytic network process), fuzzy TOPSIS (a technique for order of preference by similarity to ideal solution), fuzzy VIKOR (multicriteria optimization and compromise solution), fuzzy ELECTRE (elimination and choice expressing reality), fuzzy DEA (data envelopment analysis), fuzzy DEMATEL (decision-making trial and evaluation laboratory), fuzzy PROMETHEE (preference ranking organization method for enrichment of evaluations), fuzzy MOORA (multi-objective optimization by ratio analysis), and more.

In this section, fuzzy AHP and fuzzy linear programming methodologies, which are frequently utilized for the solution of fuzzy decision-making problems, are presented.

16.3.1 Fuzzy AHP

The earliest work on fuzzy AHP was seen in Van Laarhoven and Pedrycz's 1983 study comparing fuzzy ratios defined with triangular membership functions. Buckley (1985) stated the fuzzy priorities of comparison ratios with trapezoidal membership functions. Chang (1996) presented a new approach to handling fuzzy AHP using triangular fuzzy numbers for the pairwise comparison scale of fuzzy AHP and the use of the degree analysis method for synthetic degree value of pairwise comparisons (Büyüközkan, Kahraman, and Ruan 2004).

The Buckley approach is presented in this section. Buckley (1985) utilized the geometric mean method to receive fuzzy weights and performance scores. This method could be readily generalized to fuzzy cases, and it receives a single solution from comparison matrices. The steps of the method are presented subsequently (Hsieh, Lu, and Tzeng 2004):

1. According to the decision-maker's opinion, a comparison matrix is acquired. Let the fuzzy positive comparison matrix be presented as follows:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{16.5}$$

2. To calculate w_i fuzzy weights, for each row, the geometric mean is calculated.

$$Z_i = \left[\prod_{j=1}^{n} a_{ij}\right]^{1/n}, \quad \forall i. \tag{16.6}$$

3. w_i is calculated using equation 16.7.

$$w_i = \frac{z_i}{z_i + \ldots + z_n}, \quad \forall i. \tag{16.7}$$

   w_i can be shown as $w_i = (lw_i, \mathrm{m}w_i, \mathrm{u}w_i,)$, where lw_i is the lower fuzzy value, mw_i is the middle fuzzy value, and uw_i is the upper fuzzy value.
4. The defuzzification value of w_i could be found using equation 16.8.

$$F_i = \frac{\left[\left(\mathrm{u}w_i - lw_i\right) + \left(\mathrm{u}w_i - lw_i\right)\right]}{\left(3 + lw_i\right)}, \quad \forall i. \tag{16.8}$$

Each alternative is ranked according to the calculated F value.

16.3.2 Fuzzy Linear Programming

In 1976, Zimmermann first proposed to model traditional linear programming problems using fuzzy set theory; the fuzzy linear program with fuzzy objectives and constraints could be solved as a linear programming problem. Zimmermann (1978) suggested a traditional linear programming problem as follows (equations 16.9–16.11):

$$\text{Minimize } Z = Cx \tag{16.9}$$

Subject to

$$Ax \le b \tag{16.10}$$
$$x \ge 0 \tag{16.11}$$

After fuzzification, the equation could be described as equations 16.12–16.14:

$$\tilde{C}x \precsim Z \tag{16.12}$$
$$\tilde{A}x \precsim \mathrm{b} \tag{16.13}$$
$$x \ge 0 \tag{16.14}$$

The symbol ≤ in the set of constraint indicates smaller than or equal to and lets one reach some aspiration level where $\tilde{C}$ and $\tilde{A}$ indicate the fuzzy values.

A fuzzy objective $\tilde{\mathrm{Z}} \in \mathrm{X}$ is a fuzzy subset of X and is characterized by a membership function $\mu_{\mathrm{Z}}(\mathrm{x}) : \mathrm{x} \to [0,\ 1]$. Each objective function is separated as maximum and minimum, and the membership function of the objectives is formulated according to this. The linear membership functions for maximization and minimization objectives are developed as follows:

$$\mu_{Zj}(x) = \begin{cases} 1 & if\ Z_j(x) \le Z_j^{min} \\ \dfrac{Z_j^{max} - Z_j(x)}{Z_j^{max} - Z_j^{min}} & if\ Z_j^{min} \le Z_j(x) \le Z_j^{max}, where\ j = 1, 2, \ldots, j \\ 0 & if\ Z_j(x) \ge Z_j^{max} \end{cases} \tag{16.15}$$

(for minimization)

$$\mu_{Zj}(x) = \begin{cases} 0 & if\ Z_j(x) \le Z_j^{min} \\ \dfrac{Z_j(x) - Z_j^{min}}{Z_j^{max} - Z_j^{min}} & if\ Z_j^{min} \le Z_j(x) \le Z_j^{max}, where\ j = 1, 2, \ldots, j \\ 1 & if\ Z_j(x) \ge Z_j^{max} \end{cases} \tag{16.16}$$

(for maximization)

In equations 16.15 and 16.16, $\mathrm{Z}_{\mathrm{j}}^{\mathrm{min}}$ is $min_j\, Z_j(\mathrm{x}^*)$ and $\mathrm{Z}_{\mathrm{j}}^{\mathrm{max}}$ is $mix_j\, Z_j(\mathrm{x}^*)$ and x^* is the optimum solution.

In the Zimmermann (1978) approach, each objective function must be solved as a single objective function, only using one objective at a time and ignoring the others. For different *j* objective functions, this procedure is repeated *j* times. Whole solutions are used to create a payoff matrix of size *j* to *j*. Then the lower limit ($\mathrm{Z}_{\mathrm{j}}^{\mathrm{min}}$) and the upper limit ($Z_j^{max}$) are predicted from the payoff matrix for Z_j as follows (Behera and Nayak 2011):

$$Z_j^{min} \le Z_j \le Z_j^{max} \qquad for\ all\ j, j = 1,2,\ldots,J \tag{16.17}$$

The basic logic of the max-min approach is to maximize the minimum membership function values of each objective function.

$$Max[\text{Min}\,\mu_z(x)] \tag{16.18}$$

The fuzzy programming model for all *j* objectives is converted into the crisp formulation as follows (Kumar, Vrat, and Shankar 2006; Shaw et al. 2012; Kumar, Rahman, and Chan 2017):

$$\text{Maximize } \lambda \tag{16.19}$$

Subject to

$$\lambda(Z_j^{max} - Z_j^{min}) + Z_j(x) \le Z_j^{max} \qquad for\ all\ j, j = 1,2,\ldots,J, \quad (\text{for minimization}) \tag{16.20}$$

»$$(Z_j^{max} - Z_j^{min}) + Z_j^{min} \le Z_j(x) \qquad for\ all\ j, j = 1,2,\ldots,J, \quad (\text{for maximization}) \tag{16.21}$$

$$Ax \le \text{b} \qquad for\ all\ the\ deterministic\ constant, \tag{16.22}$$

$$x \ge 0 \text{ and integer,} \tag{16.23}$$

$$0 \le \lambda \le 1 \tag{16.24}$$

Furthermore, the weighted additive model could be used to reflect the relative importance of the objectives. In the weighted additive approach, the decision-maker designates different weights as coefficients of the specific terms in the simple additive fuzzy function to represent their comparative importance; namely, the objective function is formulated by multiplying each fuzzy goal membership function with a convenient weight and then summing them together. The approach's formulation is presented in equations 16.25–16.30:

$$\text{Maximize} \sum_j W_j \lambda_j \tag{16.25}$$

Subject to

$$\lambda_j(Z_j^{max} - Z_j^{min}) + Z_j(x) \le Z_j^{max} \qquad for\ all\ j, j = 1,2,\ldots,J, \quad (\text{for minimization}) \tag{16.26}$$

$$\lambda_j(Z_j^{max} - Z_j^{min}) + Z_j^{min} \le Z_j(x) \qquad for\ all\ j, j = 1,2,\ldots,J, \quad (\text{for maximization}) \tag{16.27}$$

$$Ax \le b \qquad for\ all\ the\ deterministic\ constant, \tag{16.28}$$

$$x \ge 0 \text{ and integer,} \tag{16.29}$$

$$0 \le \lambda_j \le 1. \tag{16.30}$$

Where W_j is the relative weight of the jth fuzzy objective. The significant challenge of the method is the duty of decision-makers to accurately evaluate the relative importance of the objectives (Tiwari, Dharmar, and Rao 1987).

16.4 SMART AND SUSTAINABLE SUPPLY CHAIN MANAGEMENT

Sustainable supply chain management is seen as a solution to the avoided environmental, economic, and social impacts of supply chains and a facilitator of the adoption of appropriate production methods within product lifecycles. However, while a sustainable supply chain needs integration between the diverse sustainability dimensions, in some cases, they can be contradictory to each other. For example, environmentally friendly materials can increase procurement costs. In addition, uncertainties in supply chain processes make it difficult to operationalize the concept of sustainability, so visibility is crucial for the management and integration of sustainable supply chains (Shokouhyar, Pahlevani, and Sadeghi 2019). Monitoring and controlling supply chain operations and flows have always been intended to reduce vagueness via information access and process interferences. Information and Communications Technology now operate as a facilitator by lowering the activity costs via automation. Embedded chips and sensors help design intelligent products and processes throughout the global supply chain (van Nunen, Zuidwijk, and Moonen 2005). These technologies, which came to the rescue of businesses, first emerged under the Industry 4.0 name.

Digitization and the integration of the Internet into production processes have also led to a global transformation in supply chain management, revealing the concept of a smart supply chain as a new connected business system ranging from local, isolated, and single firm applications to systematical smart applications. The smart supply chain would have intelligent technologies, such as IoT, RFID, 3D printing, robotics and autonomous systems; intelligent infrastructure, such as big data, cloud computing, blockchain, and cybersecurity; and intelligent decision-making, such as machine learning, and artificial intelligence. Enabling technologies can make a contribution to the sustainability of supply chains by supporting data interchange, integrated planning, and automatic control mechanisms (van Nunen, Zuidwijk, and Moonen 2005).

16.4.1 Supplier Selection

Generally, a firm spends about half of its total revenue on purchasing goods and services. Thus, purchasing is considered one of the key determinants of its profitability and makes a company's success depends on its interactions with suppliers (Rezaei, Fahim, and Tavasszy 2014; Büyüközkan and Göçer 2017; Lima-Junior and Carpinetti 2016a; Beil 2010). The common consensus in the literature is that supplier selection is an essential and complicated duty within the purchasing process (Rezaei, Fahim, and Tavasszy 2014). The most significant mission of the purchasing function is selecting a supplier that is prone to technological developments, with low cost, high quality, and timely delivery qualifications (Tidwell and Sutterfield 2012).

Originally, two versions of supplier selection were common: single and multiple. In the single version, just one supplier satisfies the requirements of all customers; therefore, the customer chooses the best supplier only.

More than one supplier is selected in the version of multiple suppliers, which is more common. Thus, companies must choose several top suppliers and decide how much to order from them in order to generate controlled competitive conditions (Kannan et al. 2013).

16.4.1.1 Smart Supplier Selection

Recently, the development and application of advanced intelligent technologies have transformed traditional supply chains into smart supply chains by ensuring that all components in a supply chain are detectable, identifiable, interpretable, predictable, controllable, and optimizable. From smart purchasing to smart distribution, smart supply chain management leverages intelligent technologies to improve flexibility, transparency, responsiveness, integration, and collaboration performance in all its activities (Chen et al. 2020). The first stage of this system is smart supplier selection. Accordingly, organizations try to choose smart suppliers to improve their technological development. Intelligent technology tools can be audited and run as evaluation criteria for the smart supplier selection process.

Smart supply chain management with supplier selection has been a broad and current interest that has attracted the attention of many global industries worldwide. Yet very little research has been done on this topic as it is still an emerging concept. In particular, it is observed that supplier selection problems are not only evaluated in terms of smartness but are generally studied together with the concept of sustainability in literature.

Ghadimi et al. (2019) suggested an approach using a multi-agent system to address intelligent sustainable supplier selection procedures for Industry 4.0-supply chains. They approved technical capability for smartness while considering the three dimensions of the triple bottom line (TBL) for sustainability to evaluate suppliers. Chen et al. (2020) proposed an integrated methodology, rough-fuzzy DEMATEL-TOPSIS, for choosing sustainable suppliers in a smart supply chain. Hasan et al. (2020) used FTOPSIS to rank resilient suppliers in a Logistics 4.0 environment. When evaluating suppliers, they considered smartness criteria, such as digitalization, traceability, e-engineering, automation disruption, and cybersecurity risk management. Fallahpour et al. (2021) developed a new integrated model using FBWM (fuzzy best-worst method) with a two-stage fuzzy inference system for supplier selection management, taking into account sustainability and Industry 4.0 criteria.

16.4.1.2 Sustainable Supplier Selection

More and more researchers and practitioners pay close regard to sustainable supply chain management because of the growing mindfulness of environmental and social issues (Yu et al. 2019). Sustainable supply chain management includes many applications, such as sustainable supplier evaluation and selection, sustainable product design, sustainable production, and sustainable transportation (Li, Fang, and Song 2019).

Among these, appropriate sustainable supplier selection is a crucial component to the achievement of an organization since suppliers are first in the flow of the supply chain and will have important effects on its environmental, economic, and social performance in the later stages of the supply chain (Yu et al. 2019; Li, Fang, and Song 2019; Chen et al. 2020). The sustainable supplier selection problem could be described as the classical supplier selection problem that considers TBL criteria to choose and track supplier performance (Yu et al. 2019). Therefore, sustainable supply chain management practices could be described as basic criteria and easily operated for sustainable supplier selection (Li, Fang, and Song 2019; Chen et al. 2020).

Researchers and practitioners have focused much attention on sustainable supplier selection for a long time (Carter Craig and Liane Easton 2011; Yu et al. 2019). Chiouy, Chou, and Yeh (2011) and Büyüközkan and Çifçi (2011) studied sustainable supplier selection using FAHP. Azadnia et al. (2012) used fuzzy AHP and TOPSIS for clustering and selecting sustainable suppliers of an automotive manufacturing firm in Iran. Gold and Awasthi (2015) used fuzzy AHP for the selection of sustainable global suppliers. They determined 25 criteria under 5 different categories: economic, environmental, social, quality of the relationship, and global risks. Fallahpour et al. (2017) determined the most critical 13 criteria with 46 sub-criteria in each of the aspects of TBL for sustainable supplier selection via a survey, fuzzy preference programming, and FTOPSIS for identifying the best supplier. Zhou and Xu (2018) proposed DEMATEL-ANP-fuzzy VIKOR integrated approach depending on hybrid information aggregation and determined 6 aspects (operational agreement, corporate reputation, product advantage, green impact, service capability, and social responsibility) and 24 sub-criteria considering the trade-offs between economic, environmental, and societal objectives for sustainable supplier selection. Extended TOPSIS was used by Li, Fang, and Song (2019), with rough sets, and by Yu et al. (2019) under an interval-valued Pythagorean fuzzy environment for sustainable supplier selection. Kannan et al. (2020) combined interval VIKOR and fuzzy BWM to evaluate and prioritize sustainable suppliers in circular supply chains. They classified the evaluation criteria into three categories as social, economic, and cyclical factors, and evaluated six potential suppliers for the wire-cable industry. Tayyab and Sarkar (2021) developed a multiperiod multi-objective textile supply chain management model to achieve both supplier evaluation in terms of sustainability and order allocation. They applied an interactive fuzzy approach to control uncertainty. Liu, Gao, and Fujita (2021) proposed a new extension of the MULTIMOORA method with intuitionistic linguistic rough numbers for sustainable supplier selection.

16.5 A CASE STUDY APPLICATION

A supplier selection framework is designed to decide the qualified suppliers from which an automobile manufacturer will purchase materials that will be used in its production process. The company desires to work with several suppliers with innovative technologies and sustainable norms. Suppliers will be evaluated on two main factors separately, smart and sustainable maturity levels, which are significant for the company, and will be chosen with respect to the assumptions of smart-sustainable balance defined by the company. The concept of smartness includes new technology tools that come with the Industry 4.0 age. In order to analyze the smartness level of suppliers, their strategies, culture, customers, products, operations, and technology performances should be examined. The concept of sustainability is a holistic approach that includes economic, environmental, and social dimensions.

This paper suggests a two-stage decision-making framework for evaluating suppliers, given several smart tools and sustainable indicators. Firstly, to get the relative weights for smart-sustainable criteria and scores of suppliers, BWM is applied. After that, a multi-objective linear programming (MOLP) model is designed, and then the formulation of the model is developed using fuzzy linear programming. Secondly, suppliers' weights (scores) are integrated into the MOLP model to define the optimal order quantity to be purchased from each supplier. The suppliers' smart and sustainable weights are run as coefficients of their respective objective functions to improve the smart or sustainable or both criteria values for the organization; thereby, the sum of the smart/sustainable supplying value is maximized, and order quantities among selected suppliers are allocated.

Whole cost, capacity, demand, CO_2 emission, quality, lead time, budget, and percentage information were assumed constant and already known. It is also supposed that one type of product could only be purchased from each supplier, and there are no provisions for stock and stock-out and quantity reduction.

16.5.1 Mathematical Model

Indices:

i: Set of suppliers $(i = 1, 2, \ldots, I)$
j: Set of objective functions $(j = 1, 2, \ldots, J)$
k: Set of criteria $(k = 1, 2, \ldots, K)$

Parameters:

$\boldsymbol{B}$ **:** Total budget allocated for supplying
$\boldsymbol{D}$ **:** Total demand for the product
$\boldsymbol{O}$ **:** Total carbon emission limit for supply
$\boldsymbol{N}$ **:** Maximum acceptable percent (ratio) of the defective products
$\boldsymbol{R}$ **:** Maximum acceptable percent (ratio) of the late-delivered products
$\boldsymbol{C_i}$ **:** The capacity of supplier *i*
$\boldsymbol{P_i}$ **:** Unit supply cost of a product from supplier *i*
$\boldsymbol{K_i}$ **:** The percent (ratio) of the defective products delivered by supplier *i*
$\boldsymbol{L_i}$**:** The percent (ratio) of the late-delivered products by supplier *i*
$\boldsymbol{G_i}$**:** The carbon emission for a product supplied by supplier *i*
$\boldsymbol{Wa_i}$ **:** The smartness weight (smart priority value) of supplier *i*
$\boldsymbol{Wb_i}$ **:** The sustainability weight (sustainable priority value) of supplier *i*

Decision variable:

$\boldsymbol{X_i}$ **:** The product amount ordered from supplier *i*

Objective functions:

$$Max\,Z_1 = \sum\nolimits_i^I Wa_i\, X_i \tag{16.31}$$

$$Max\,Z_2 = \sum\nolimits_i^I Wa_i\, X_i \tag{16.32}$$

Constraints:

$$\sum\nolimits_i^I X_i = D \tag{16.33}$$

$$X_i \le C_i \qquad \forall i \tag{16.34}$$

$$\sum\nolimits_i^I K_i\, X_i \le ND \tag{16.35}$$

$$\sum\nolimits_i^I L_i\, X_i \le RD \tag{16.36}$$

$$\sum\nolimits_i^I G_i\, X_i \le O \tag{16.37}$$

$$\sum\nolimits_i^I P_i\, X_i \le B \tag{16.38}$$

$$X_i \ge 0\, and\, integer \quad \forall i \tag{16.39}$$

Objective functions: Equations 16.31 and 16.32 maximize the supply's total smartness and sustainability value, respectively.

Constraints: Equation 16.33 is the demand constraint to satisfy the total demand. Equation 16.34 is the capacity constraint to prevent the number of ordered products from each supplier from exceeding its capacity. Equation 16.35 is the quality control constraint, where the total defective products can't exceed the maximum acceptable limit of defective products. Equation 16.36 is the lead time constraint, where the total late-delivered products can't exceed the maximum acceptable limit of late-delivered products. Equation 16.37 is the carbon footprint constraint, where the amount of carbon emissions released by each supplier can't exceed the maximum total carbon emission limit. Equation 16.38 is the budget constraint, where the total supply cost of products can't exceed the allocated budget. Equation 16.39 is the non-negativity-integrity constraint.

16.5.1.1 Application of Fuzzy Linear Programming

A fuzzy MOLP model is suggested for smart and sustainable supplier selection. In order to model and solve the MOLP, fuzzy set theory is used due to the vagueness of the smart and sustainable value of supply, which is considered fuzzy numbers. After fuzzification, the model could be presented as follows:

$$\sum\nolimits_i^I W\,a_i\, X_i \precsim \tilde{Z}_1 \tag{16.40}$$

$$\sum\nolimits_i^I W\,b_i\, X_i \precsim \tilde{Z}_2 \tag{16.41}$$

and all other deterministic constraints

Where ~ indicates fuzzy numbers.

16.5.2 Decision Model

The automotive company managers responsible for production, finance, and marketing want to identify the most suitable smart and sustainable suppliers for them. After preliminary screening, the directors of the company identified five potential suppliers for further evaluation and evaluated them separately according to nine smart and nine sustainable criteria. Figure 16.2 show the structure of the decision model. The smart tools and sustainable indicators defined by the organization are offered in Table 16.1.

16.5.2.1 Application of the Best Worst Method (BWM)

BWM, introduced by Rezaei (2015), determines the best and worst criteria before making pairwise comparisons between criteria and only makes comparisons between these criteria and other criteria.

The best criterion is the most important one, while the worst is the least important one in smart and sustainable supplier selection based on decision-maker(s) opinion. As a result of consultations with experts, the best criterion was determined as IoT (C1), and the worst criterion was determined as simulation (C9) for smart supplier selection; the best criterion was determined as 3R (C13), and the worst criterion was

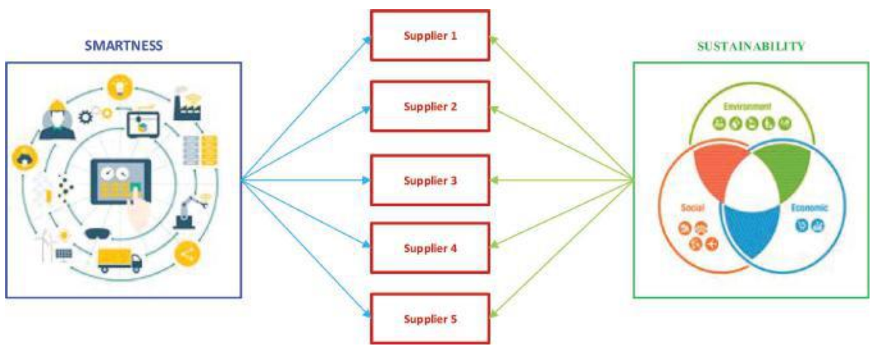

FIGURE 16.2 The structure of the decision model.

TABLE 16.1
Smart and Sustainable Supplier Selection Criteria

No	Smart Criteria Name	Code	Sustainable Criteria Name	Code
1	Machine learning	C1	Cost	C10
2	Artificial intelligence	C2	Quality	C11
3	IoT	C3	On-time delivery	C12
4	Robotics and autonomous systems	C4	3R (reduce, reuse, recycle)	C13
5	Blockchain technology	C5	Standard and certification	C14
6	3D printing	C6	CO_2 emissions	C15
7	Augment reality	C7	Occupational health and safety	C16
8	Cloud computing	C8	Corporate social responsibility	C17
9	Simulation	C9	Employee welfare	C18

determined as corporate social responsibility (C17) for sustainable supplier selection. Company administrators (decision-makers) provide the pairwise comparison vectors for smart and sustainable criteria, as shown in Tables 16.2 and 16.3, respectively. The smart and sustainable criteria weights are obtained separately by the BWM using pairwise comparison vectors.

The following linear optimization model is proposed to find the optimal weights in the BWM approach (Rezaei 2016):

$$min\,\xi^L \tag{16.42}$$

$$\left|W_B - a_{Bk}W_k\right| \le \xi^L, \qquad for\,all\,k, k = 1,2,\ldots,K \tag{16.43}$$

$$\left|W_k - a_{kW}W_W\right| \le \xi^L, \qquad for\,all\,k, k = 1,2,\ldots,K \tag{16.44}$$

$$\sum\nolimits_k W_k = 1 \tag{16.45}$$

$$W_k \ge 0, \quad for\,all\,k, k = 1,2,\ldots,K \tag{16.46}$$

After solving the model (equations 16.42–16.46), the optimal weights (W_1*, W_2*, . . ., W_K*) and ξ^{L*} are obtained. Here, ξ^{L*} could be considered as an indicator of the comparison consistency. ξ^{L*} close to zero indicates high consistency.

TABLE 16.2
Pairwise Comparison Vectors for Best and Worst of Smart Criteria

Best to Other (BO)	C1	C2	C3	C4	C5	C6	C7	C8	C9
Best objective functions: C1	3	6	1	5	4	8	7	2	9
Other to Worst (OW)			**Worst Objective Functions: C9**						
C1						4			
C2						2			
C3						9			
C4						2			
C5						3			
C6						1			
C7						2			
C8						5			
C9						1			

When the decision variables are written according to equations 16.42–16.46, the final version of the model is as follows:

$$min\,\xi^L$$

$$\left|w_3 - a_{3k}w_j\right| \le \xi^L, \qquad for\,all\,k, k = 1,2,\ldots,9$$

$$\left|w_K - a_{k9}w_9\right| \le \xi^L, \quad for\,all\,k, k = 1,2,\ldots,9$$

$$\sum\nolimits_1^9 w_k = 1$$

$$w_k \ge 0, \quad for\,all\,k, k = 1,2,\ldots,9$$

The preceding model with variables that are smart weight values and target is consistency value (ξ^L) was solved with the Gams software, and the weights minimizing consistency (ξ^L) were calculated as follows:

$$w_1 = 0.121,\ w_2 = 0.060,\ w_3 = 0.341,\ w_4 = 0.073,\ w_5 = 0.091,\ w_6 = 0.045,$$
$$w_7 = 0.052,\ w_8 = 0.181,\ w_9 = 0.036, \text{ and } \xi^L = 0.021.$$

The comparisons show a very high consistency, as the value of the consistency indicator (ξ^L) is close to zero.

TABLE 16.3
Pairwise Comparison Vectors for Best and Worst Sustainable Criteria

Best to Other (BO)	C10	C11	C12	C13	C14	C15	C16	C17	C18
Best objective functions: C13	3	2	4	1	5	7	6	9	8
Other to Worst (OW)			**Worst Objective Functions: C17**						
C10						3			
C11						4			
C12						3			
C13						9			
C14						2			
C15						2			
C16						2			
C17						1			
C18						1			

When the decision variables are written according to equations 16.42–16.46, the final version of the model is as follows:

$$min\, \xi^L$$
$$\left|w_{13} - a_{13k} w_k\right| \le \xi^L, \qquad for\, all\, k, k = 10, 11, \ldots, 18$$
$$\left|w_K - a_{k17} w_{17}\right| \le \xi^L, \qquad for\, all\, k, k = 10, 11, \ldots, 18$$
$$\sum\nolimits_{10}^{18} w_k = 1$$
$$w_k \ge 0, \quad for\, all\, k, k = 10, 11, \ldots, 18,$$

The preceding model with variables that are sustainable weight values and target is consistency value (ξ^L) was solved with the Gams software, and the weights minimizing consistency (ξ^L) were calculated as follows:

$$w_{10} = 0.123,\ w_{11} = 0.166,\ w_{12} = 0.092,\ w_{13} = 0.348,\ w_{14} = 0.074,$$
$$w_{15} = 0.053, w_{16} = 0.061,\ w_{17} = 0.036,\ w_{18} = 0.046, \text{ and } \xi^L = 0.020.$$

The comparisons show a very high consistency, as the value of the consistency indicator (ξ^L) is close to zero.

The following steps have been implemented to establish the supplier selection framework. First, the supplier performances on the smart tools and sustainable indicators are severally determined by decision-makers of the case company with the data for suppliers. A nine-point Likert scale (1: very low to 9: very high) is used for qualitative criteria, which are smart ones and some sustainable ones, such as corporate social responsibility; objective measures ($, ratio, etc.) are used for other sustainable criteria, such as cost. The decision matrices are shown in Tables 16.4 and 16.5, respectively.

TABLE 16.4
Decision Matrix for the Smart Performance of Suppliers

Unit	Likert Scale								
Suppliers \ Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	7	9	3	8	2	8	5	9	4
2	7	7	5	8	4	5	3	8	3
3	6	9	7	8	6	7	4	8	5
4	8	7	2	6	3	4	2	9	6
5	5	8	4	7	5	6	4	7	7

TABLE 16.5
Decision Matrix for the Sustainable Performance of Suppliers

Unit	$/unit	Ratio (%)	Ratio (%)	Likert	Likert	kg/unit	Likert	Likert	Likert
Suppliers \ Criteria	C10	C11	C12	C13	C14	C15	C16	C17	C18
1	890	80	90	5	9	1.53	6	8	9
2	950	80	83	4	7	2	7	7	5
3	900	75	86	6	4	1.87	4	9	6
4	870	82	80	5	8	1.85	5	4	8
5	920	90	72	4	6	1.62	8	6	7

The decision matrix of the alternatives is normalized using the following formula (Rezaei et al. 2016):

$$X_{ik} = \begin{cases} \dfrac{X_{ik}}{\max\{X_{ik}\}}, if\ x\ is\ positive(such\ as\ quality), \\ 1 - \dfrac{X_{ik}}{\max\{X_{ik}\}}, if\ x\ is\ negative(such\ as\ price). \end{cases} \tag{16.47}$$

Then the supplier scores are normalized using equation 16.47. The normalized scores for smart and sustainable performances are presented in Tables 16.6 and 16.7, respectively.

TABLE 16.6
Normalized Decision Matrix for Smart Tools

Suppliers \ Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	0.88	1.00	0.43	1.00	0.33	1.00	1.00	1.00	0.57
2	0.88	0.78	0.71	1.00	0.67	0.63	0.60	0.89	0.43
3	0.75	1.00	1.00	1.00	1.00	0.88	0.80	0.89	0.71
4	1.00	0.78	0.29	0.75	0.50	0.50	0.40	1.00	0.86
5	0.63	0.89	0.57	0.88	0.83	0.75	0.80	0.78	1.00
Weights of smart criteria	0.121	0.06	0.341	0.073	0.091	0.045	0.052	0.181	0.036

TABLE 16.7
Normalized Decision Matrix for Sustainable Indicators

Dimensions	**Economic**			**Environment**			**Social**		
Suppliers \ Criteria	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**	**C18**
1	0.06	0.89	1.00	0.83	1.00	0.24	0.75	0.89	1.00
2	0.00	0.89	0.92	0.67	0.78	0.00	0.88	0.78	0.56
3	0.05	0.83	0.96	1.00	0.44	0.06	0.50	1.00	0.67
4	0.08	0.91	0.89	0.83	0.89	0.08	0.63	0.44	0.89
5	0.03	1.00	0.80	0.67	0.67	0.19	1.00	0.67	0.78
Weights of sustainable criteria	0.123	0.166	0.092	0.348	0.074	0.053	0.061	0.036	0.046

With criteria weights W_k and the normalized scores of the alternatives X_{ik}, the final total score per alternative V_i could be calculated using the following formula (Rezaei et al. 2016):

$$V_i = \sum_k W_k \ X_{ik} \tag{16.48}$$

Finally, weighted normalized scores (Tables 16.8 and 16.9) and then the overall scores of the suppliers are found using equation 16.48, and the result is summarized in Table 16.10.

TABLE 16.8
Weighted Normalized Decision Matrix for Smart Tools

Suppliers \ Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	0.106	0.060	0.146	0.073	0.030	0.045	0.052	0.181	0.021
2	0.106	0.047	0.244	0.073	0.061	0.028	0.031	0.161	0.015
3	0.091	0.060	0.341	0.073	0.091	0.039	0.042	0.161	0.026
4	0.121	0.047	0.097	0.055	0.046	0.023	0.021	0.181	0.031
5	0.076	0.053	0.195	0.064	0.076	0.034	0.042	0.141	0.036

TABLE 16.9
Weighted Normalized Decision Matrix for Sustainable Indicators

Dimensions	Economic			Environment			Social		
Suppliers \ Criteria	C10	C11	C12	C13	C14	C15	C16	C17	C18
1	0.008	0.148	0.092	0.290	0.074	0.012	0.046	0.032	0.046
2	0.000	0.148	0.085	0.232	0.058	0.000	0.053	0.028	0.026
3	0.006	0.138	0.088	0.348	0.033	0.003	0.031	0.036	0.031
4	0.010	0.151	0.082	0.290	0.066	0.004	0.038	0.016	0.041
5	0.004	0.166	0.074	0.232	0.049	0.010	0.061	0.024	0.036

TABLE 16.10
Outranking of Alternative Suppliers

Supplier	Smartness			Sustainability		
	Scores	Normal Weights (Wa_i)	Ranks	Scores	Normal Weights (Wb_i)	Ranks
1	0.714	*0.191*	4	0.748	*0.217*	1
2	0.765	*0.205*	2	0.629	*0.183*	5
3	0.923	*0.247*	1	0.714	*0.207*	2
4	0.621	*0.166*	5	0.698	*0.203*	3
5	0.716	*0.191*	3	0.656	*0.190*	4

TABLE 16.11
Quantitative Information of Suppliers

Suppliers	P_i ($/unit)	C_i (kg)	G_i (kg/unit)	K_i (%)	L_i (%)
1	890	6500	1.53	0.20	0.10
2	950	9500	2.00	0.20	0.17
3	900	7000	1.87	0.25	0.14
4	870	10250	1.85	0.18	0.20
5	920	8500	1.62	0.10	0.28

The smart ranking of the suppliers in order is S3, S2, S5, S1, and S4; the sustainable ranking of the suppliers in order is S1, S3, S4, S5, and S2. After this stage, to achieve optimal order allocation, suppliers' smart and sustainable weights based on BWM results, given in Table 16.10, are utilized as coefficients for the fuzzy goals of the model.

16.5.3 Model Solution and Result Analysis

16.5.3.1 Application of the MOLP Model

The quantitative information on suppliers is presented in Table 16.11. Furthermore, total demand (*D*), budget (*B*), and carbon emission limit (*O*) values are taken at 18,500 units, $20,000,000, and 35,000 kg, respectively. The maximum acceptable ratios of the defective products (*N*) and late-delivered products (*R*) values are taken as 0.20 and 0.17, respectively. The multi-objective linear formulation of the problem is represented as follows:

$$Z_1 = 0.191x_1 + 0.205x_2 + 0.247x_3 + 0.166x_4 + 0.191x_5$$
$$Z_2 = 0.217x_1 + 0.183x_2 + 0.207x_3 + 0.203x_4 + 0.190x_5$$

Subject to

$$x_1 + x_2 + x_3 + x_4 + x_5 = 18500$$
$$x_1 \le 6500$$
$$x_2 \le 9500$$
$$x_3 \le 7000$$
$$x_4 \le 10250$$
$$x_5 \le 8500$$
$$0.20x_1 + 0.20x_2 + 0.25x_3 + 0.18x_4 + 0.10x_5 \le 0.10 * 18500$$
$$0.10x_1 + 0.17x_2 + 0.14x_3 + 0.20x_4 + 0.28x_5 \le 0.08 * 18500$$
$$1.5x_1 + 2x_2 + 1.87x_3 + 1.85x_4 + 1.62x_5 \le 35000$$
$$890x_1 + 950x_2 + 900x_3 + 870x_4 + 920x_5 \le 20000000$$
$$x_1, x_2, x_3, x_4, x_5 \ge 0$$

x_1, x_2, x_3, x_4, x_5 are integers.

TABLE 16.12
The Payoffs Matrix

Objective Functions	Z_1	Z_2	x_1	x_2	x_3	x_4	x_5
Z_1 (max)	**4,002.50**	3,663	2,500	5,500	7,000	0	3,500
Z_2 (max)	3,511.17	**3,860.21**	6,500	0	3,428	8,572	0

Each objective is solved individually to obtain a payoffs table for the max-min approach based on simultaneously maximizing the minimum satisfaction levels of each objective. Table 16.12 shows the values that each objective gets when optimized alone and the values that the other objectives take under those conditions.

16.5.3.2 Reformulation of the MOLP into a Fuzzy Linear Programming Model

In the Zimmermann approach, the identical weight is assigned all factors. The exact formula of the model is as follows, based upon the max-min method, with the membership functions obtained from Table 16.13 and the addition of the λ satisfaction level variable to the model.

$$\text{Maximize } \lambda$$

Subject to

$$\lambda \le \frac{\left(0.191x_1 + 0.205x_2 + 0.247x_3 + 0.166x_4 + 0.191x_5\right) - 3511.17}{4002.50 - 3511.17}$$

$$\lambda \le \frac{0.217x_1 + 0.183x_2 + 0.207x_3 + 0.203x_4 + 0.190x_5) - 3663}{3860.21 - 3663}$$

$$x_1 + x_2 + x_3 + x_4 + x_5 = 18500$$

$$x_1 \le 6500$$

$$x_2 \le 9500$$

$$x_3 \le 7000$$

$$x_4 \le 10250$$

$$x_5 \le 8500$$

TABLE 16.13
The Dataset for Membership Functions

Objective Functions	Lower Bounds ($\mu = 0$)	Upper Bounds ($\mu = 1$)
Z_1	3,511.17	4,002.50
Z_2	3,663	3,860.21

$$0.20x_1 + 0.20x_2 + 0.25x_3 + 0.18x_4 + 0.10x_5 \leq 0.10 * 18500$$
$$0.10x_1 + 0.17x_2 + 0.14x_3 + 0.20x_4 + 0.28x_5 \leq 0.08 * 18500$$
$$1.5x_1 + 2x_2 + 1.87x_3 + 1.85x_4 + 1.62x_5 \leq 35000$$
$$890x_1 + 950x_2 + 900x_3 + 870x_4 + 920x_5 \leq 20000000$$
$$x_1, x_2, x_3, x_4, x_5 \geq 0$$

x_1, x_2, x_3, x_4, x_5 are integers.

$$0 \leq \lambda \leq 1$$

The single-objective mixed-integer linear programming model given earlier was solved in the GAMS-CPLEX 24.0.1 package program, and the common satisfaction level was found to be $\lambda = 0.80$. Optimal objective functions are $Z_1 = 3904.17, Z_2 = 3820.75$, membership function values are $\mu_1 = 0.80, \mu_2 = 0.80$, and the quantities of products procured from suppliers are $x_1 = 6500, x_2 = 564, x_3 = 7000, x_4 = 1169, x_5 = 3267$.

In the Zimmermann approach, both dimensions are considered to be of equal importance and are optimized by defining a single λ satisfaction level. However, the decision-maker here can adjust the weight of smartness and sustainability (maturity coefficient) according to his own view and/or target. For example, if the firm sees the smartness performance as lacking and decides to focus more on this aspect, it will choose a larger coefficient for the first objective function that maximizes the smartness value of the supply. Therefore, the weighted additive model was used to reflect the relative importance of the goals/objectives. The objective function is formulated by multiplying each fuzzy goal's membership functions with an appropriate weight (W_j) and then summing them together. Where W_j is the relative weight of the jth fuzzy goal. It is the duty of decision-makers to accurately evaluate the relative importance of the goals (Tiwari, Dharmar, and Rao 1987).

Eleven different weight pairs were decided by considering various supplier profiles in terms of smart and sustainability maturity levels, considering the possible expectations of the relevant company. All scenarios were solved, and the results in Table 16.14 were obtained. On the basis of the weighted additive technique, the crisp formulation of the problem (for scenario 9) is represented as follows.

$$\text{Maximize } 0,\ 8 * \lambda_1 +\ 0,\ 2 * \lambda_2$$

Subject to

$$\lambda_1 \leq \frac{(0.191x_1 + 0.205x_2 + 0.247x_3 + 0.166x_4 + 0.191x_5) - 3511.17}{4002.50 - 3511.17}$$
$$\lambda_2 \leq \frac{0.217x_1 + 0.183x_2 + 0.207x_3 + 0.203x_4 + 0.190x_5) - 3663}{3860.21 - 3663}$$
$$0 \leq \lambda_1,\ \lambda_2 \leq 1,$$

and all other constraints.

TABLE 16.14
The Optimal Solutions for Each Weight Pairs

Number of Scenario	W_1	W_2	Z_1	Z_2	λ_1	λ_2	x_1	x_2	x_3	x_4	x_5
1	0	1	3,511.27	3,860.20	0	1	6,500	0	3,429	8,570	1
2	0.1	0.9	3,511.27	3,860.20	0	1	6,500	0	3,429	8,570	1
3	0.2	0.8	3,878.63	3,833.88	0.75	0.87	6,500	0	7,000	1,875	3,125
4	0.3	0.7	3,878.63	3,833.88	0.75	0.87	6,500	0	7,000	1,875	3,125
5	0.4	0.6	3,878.63	3,833.88	0.75	0.87	6,500	0	7,000	1,875	3,125
6	0.5	0.5	3,878.63	3,833.88	0.75	0.87	6,500	0	7,000	1,875	3,125
7	0.6	0.4	3,946.50	3,799	0.89	0.69	6,500	1,500	7,000	0	3,500
8	0.7	0.3	3,946.50	3,799	0.89	0.69	6,500	1,500	7,000	0	3,500
9	0.8	0.2	3,946.50	3,799	0.89	0.69	6,500	1,500	7,000	0	3,500
10	0.9	0.1	4,002.50	3,663	1	0	2,500	5,500	7,000	0	3,500
11	1	0	4,002.50	3,663	1	0	2,500	5,500	7,000	0	3,500

The results of scenarios 1 and 2, where sustainability priority is very high, are the same. The company worked with suppliers 1 with full capacity, 3, and 4, in that they are the best three sustainable suppliers. In scenarios 4 and 5, the company worked with suppliers 1, 2, and 7. The results of scenarios 10 and 11, where smartness priority is very high, are the same. The company worked with suppliers 3 with full capacity in that it is the best smart supplier, and then 2, 5, and 1, respectively.

In other scenarios in which the importance degree of both paradigms is effective, full-capacity products are supplied from suppliers 1 and 3, while the quantities supplied from other suppliers change. While supplier 1 is the best in terms of sustainability, supplier 3 is ranked first in terms of smartness and second in terms of sustainability.

For this reason, it is recommended that the company, which cares about smart and sustainability maturity performance, prefer to work with supplier 3 first, no matter which scenario it implements.

16.6 CONCLUSIONS

The decision-making problem, which we face in almost every aspect of our lives, has been studied for years and is a developing issue. Several methods and techniques have been developed to improve the decision-making process.

Fuzzy decision-making involves decision-making in complex and uncertain environments where information can be evaluated with fuzzy sets and systems in case of indefinite, incomplete, and uncertain data. With the inclusion of fuzzy theory in decision-making, the emerging new research area has aroused many researchers' interests and led to the production of many articles on different topics. This discipline has strong potential, and expectations for the future continue to grow (Blanco-Mesa, Merigó, and Gil-Lafuente 2017).

In this chapter, the subject of the supplier selection problem using the fuzzy decision-making approach, judging by the impact of smart and sustainable operations, was studied. Nine smart and nine sustainable criteria were determined to evaluate five alternative suppliers and consider them as two distinct groups. The two-objective model developed for the solution of the problem tries to maximize the smartness and sustainability values of the supply separately while meeting the problem-specific constraints. The coefficients for the objective functions were obtained by evaluating the smart and sustainable maturity levels of the potential suppliers, and the aim was to purchase more from suitable suppliers according to the relative importance of the objectives. Then the developed multi-objective model was advanced fuzzy linear programming by benefitting from fuzzy decision-making to get the optimum solution to the problem. Afterward, different smart and sustainability weight pairs were determined considering the expectations of the decision-makers, and the results obtained from all scenarios were analyzed by applying the weighted additive method.

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17 Cloud Technology

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CONTENTS

17.1 INTRODUCTION

Hardware systems have become cheaper, widely available, and easily accessible due to the advancements in computer processors, storage system capabilities, and the revolution caused by Internet technology. This trend has brought about a new type of computing system, cloud computing, on-demand availability of computer system resources (e.g., CPU, storage, and network) that can be leased by users through the Internet (Neto 2011). Cloud computing offers a flexible, on-demand, and dynamically scalable computing infrastructure for many business applications or personal use while disrupting many incumbent technologies. Undoubtedly, cloud computing is one of the major technologies transforming the information technology process in the Industry 4.0 era (Furht & Escalante 2010).

Cloud computing technologies constitute the foundation of the networked society, where billions of devices are connected to each other. These connected devices offer a wide range of services anytime and anywhere. Cloud computing systems support many technologies, such as cellular phones, wearable technologies, connected vehicles, and future networked society (Rimal & Lumb 2017). Cloud computing is one

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of the disruptive technologies growing at an exponential rate in the era of digital transformation. The cloud computing concept is associated with the upcoming evolution of distributed computing systems. Cloud computing aims to take advantage of distributed resources to do large-scale data analysis, deal with major computation problems, and generate higher output (Rimal et al. 2010).

Cloud computing has been reshaping information technology (IT) processes and the IT marketplace. Cloud computing technology allows users to access services offered by cloud computing service providers over the Internet. The services offered by providers include computational software, storage spaces, and application-development platforms. The users can access these services via various devices, such as personal computers, laptops, smartphones, and personal digital assistants. Cloud computing technology offers low-cost, highly available, and easily scalable services (Furht 2010). Many organizations outsource some or all their IT operations from a third-party cloud service provider. Since the computing structure and related technologies offered by a third-party service provider are shared among many customers, the cost of utilizing these technologies is in favor of customers. However, outsourcing organizations lose the autonomy and flexibility to manage the outsourced IT infrastructure (Nick et al. 2010).

Cloud service providers offer various software, computing, and storage through the Internet. Many individual cloud users demand storage, gaming, and video clouds. As cloud service providers are increasing day by day, cloud service users are concerned with the reliability of these services. Therefore, cloud service selection becomes an important decision for many users (Ma et al. 2020).

17.2 DEFINITION OF CLOUD COMPUTING AND ITS CHARACTERISTICS

Rimal et al. (2011) define “cloud computing” as “a model of service delivery and access where dynamically scalable and virtualized resources are provided as a service over the Internet.”

Cloud computing is a new paradigm in which data and computation are stored and done in a structure called the cloud. The term “cloud” refers to a collection of data centers owned and maintained by a third party (Jin et al. 2010a). Cloud computing systems lay the foundation for outsourcing computing power, data storage, and services from third parties. Therefore, cloud computing brings about a paradigm shift in ITs and business (Rimal & Lumb 2017).

The National Institute of Standards and Technology (NIST) defines “cloud computing” as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” (Mell & Grance 2011). The paradigm shift in computing technology during the last half-century is illustrated in Figure 17.1. These six computing paradigms include mainframe computing, PC computing, network computing, Internet computing, grid computing, and cloud computing.

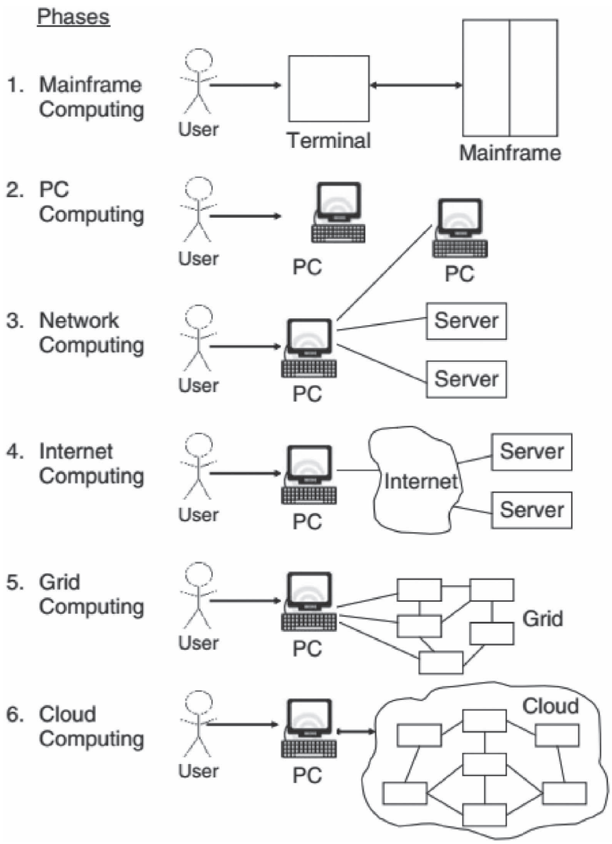

FIGURE 17.1 Six computing paradigms. (Furht 2010)

The six distinctive phases of cloud computing throughout its brief history are explained in Table 17.1.

A mainframe is a physical machine that offers finite computing power, while a cloud refers to all computing technology resources on the Internet and offers infinite power and storage capacity. A user with a simple PC gains significant computing power and caching support in a cloud computing paradigm. Due to providing efficient and limitless computing power, cloud computing has been reshaping the IT sector and IT marketplace (Voas & Zhang 2009).

Jain and Kumar (2014) state that cloud computing technology not only includes the applications offered as services over the Internet but also contains the hardware and systems software that provide those services. The idea behind cloud computing is to manage and allocate computing resources connected to a network and create a resource pool where users can get computing services. The entire network that provides these resources is called the cloud. Cloud computing is Internet-based

TABLE 17.1
The Phases during the Computing Paradigm Shift

Phase	Description
Mainframe computing	Powerful mainframes were shared by users who use terminals.
PC computing	Personal computers (PCs) became powerful enough to meet many users' expectations.
Network computing	Multiple computers were able to connect via local networks in order to share limited resources and increase computing power.
Internet computing	Local networks are connected to other local networks and create a global network such as the Internet. This structure allows users to connect to the Internet and benefit from remote applications and resources.
Grid computing	The electronic grid promoted shared computing power and storage resources through a distributed computing system.
Cloud computing	All available and shared resources on the Internet can be utilized by the network users in a scalable and simple way.

(Adapted from Voas & Zhang 2009)

computing where the shared resources, software applications, and information are distributed to the users on the network based on their needs.

17.2.1 Cloud Architecture and Taxonomy of Cloud Computing

Rimal et al. (2010) define cloud architecture as "the design of software applications that use Internet accessible and on-demand service." Cloud architectures constitute the foundation of an infrastructure that allows one to utilize the resources when necessary and perform the required job, then release and dispose of unnecessary resources after the task is fulfilled. Cloud architectures offer effective service solutions for the problems of large-scale data processing. The users can access the cloud system anywhere with an Internet connection, and the system can meet all the computing needs of users. According to Moghaddam et al. (2015), the architecture of cloud computing environments is divided into five major layers. These are the physical infrastructure, virtual infrastructure, platform, application, and network. Figure 17.2 illustrates cloud computing layers and models, which we will discuss in Chapter 17.3.

Rimal et al. (2010) classify the taxonomy of cloud computing into seven categories. This classification includes architecture, virtualization management, core services, security, data governance, and management services. Several sub-taxonomies are defined under each taxonomy category. The cloud computing taxonomy describes certain rules about how to understand cloud components and how to do things right. Figure 17.3 illustrates the taxonomy of cloud computing proposed by Rimal et al. (2010).

Crandell (2008) offers a cloud computing taxonomy that classifies product offerings into three categories. These are applications in the cloud, platforms in the cloud, and infrastructure in the cloud.

Hoefer and Karagiannis (2010) introduce a novel tree-structure-based taxonomy to compare current and future cloud computing systems easily. The proposed

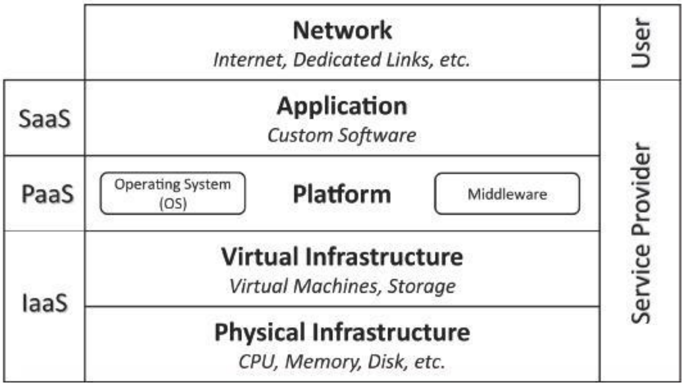

FIGURE 17.2 Cloud computing models and layers. (Adapted from Moghaddam et al. 2015)

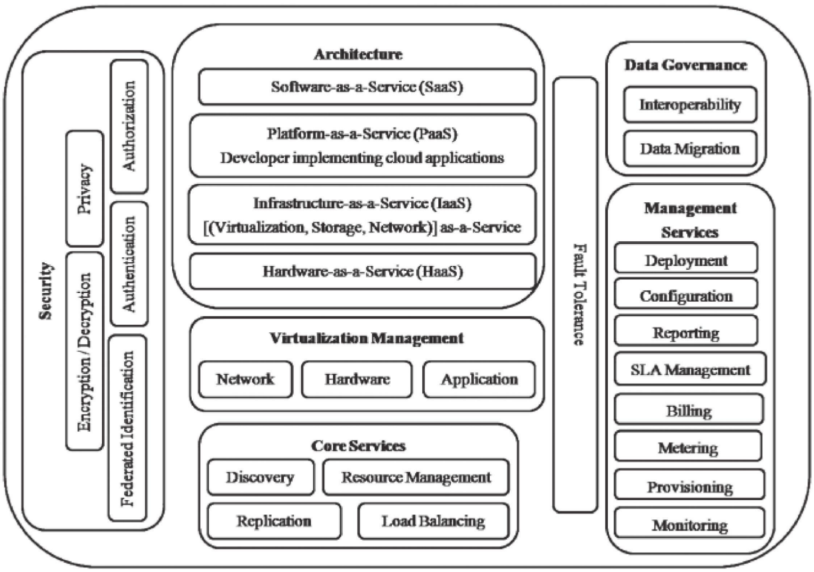

FIGURE 17.3 A taxonomy of cloud computing. (Rimal et al. 2010)

taxonomy levels are the main service category, license type, intended user group, payment system, formal agreements, security measures, and standardization efforts. Oliveira et al. (2010) classify the cloud computing paradigm into eight categories: architectural characteristics, business model, technology infrastructure, privacy, standards, pricing, orientation, and access.

Various taxonomic groups should be considered within the cloud system classification. Taxonomy helps figure out the technical strengths, weaknesses, and challenges in the existing cloud systems. These systems can be classified based on virtualization, scalability, interoperability, quality of service, failover mechanism, and cloud delivery models (Rimal et al. 2010).

17.2.2 Essential Characteristics of Cloud Computing

Moghaddam et al. (2015) extend the common definitions of cloud computing and define the cloud computing concept as follows:

> a technology that uses the concepts of virtualization, processing power, storage, connectivity, and sharing to provide a pool of resources, store and share them between various devices via a broad network (i.e., Internet) to offer on-demand services to end-users in compliance with the concepts of isolation, security, distribution, and elasticity.

This definition includes basic cloud computing specifications that are discussed in Table 17.2.

TABLE 17.2
Specifications of Cloud Computing

Specification	Explanation
Virtualization	A cloud has the ability to virtualize servers, storage spaces, and hardware and software resources, then offer them as various services.
Processing power	A cloud system supports processing power to allow users to effectively access the pool of resources with the lowest cost and shortest time.
Storage	A cloud system offers storage, which is a computational resource that can host numerous resources, such as applications and data.
Connectivity	A cloud can provide two types of connectivity. The first is the connectivity between each layer of resources in a cloud, and the second is the connection between users of a cloud service.
Sharing	Since virtualization causes isolation in a cloud, there is no actual sharing of resources in a cloud-based service.
Pool of resources	One of the main objectives of a cloud system is to establish a pool of resources, such as storage, infrastructure, data, application, and platform.
On-demand services	Users on a cloud system can use and release resources anytime, according to their needs.
Elasticity	Resource allocation to cloud users must be done dynamically. The resource pool should support elasticity in order to provide flexible resource allocation.
Isolation	The infrastructure service provider of a cloud system should establish the isolation procedures since services must be performed by using isolated network infrastructure and unique physical machines.
Distribution	Cloud computing systems are globally distributed environments. Cloud-based applications need to be disintegrated into specific components to have the ability to distribute among resources.

(Adapted from Moghaddam et al. 2015)

Mell and Grance (2011) specify the essential characteristics of a cloud system as on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. On-demand self-service refers to using the computing services on a cloud unilaterally without the need for any human interaction. Broad network access emphasizes the technological capabilities available over the cloud network and accessible via client platforms, such as mobile phones, tablets, and laptops. Resource pooling is the collection of computing resources provided by a cloud service provider. These physical and virtual resources are assigned and utilized by multiple cloud customers based on their demands. Some of these resources are storage, processing, memory, and network bandwidth. Rapid elasticity is the ability of a cloud system to flexibly allocate any amount of capabilities to users at any given time based on users' needs. Measured service refers to the ability to control and optimize resource use appropriate to services such as storage, processing, bandwidth, and active user accounts.

While Jain and Kumar (2014) define the characteristics of a cloud system within five categories, which are elasticity and scalability, virtualization, large-scale infrastructure, ubiquitous, and utility-based pricing, Stieninger and Nedbal (2014) cluster them into four distinct categories: financial characteristics, organizational characteristics, resource-based characteristics, and ecologic characteristics.

17.3 FUNCTIONAL ASPECTS OF CLOUD COMPUTING

Cloud computing can be considered as a set of services. Rimal et al. (2010) categorize the cloud service models into four groups: software-as-a-service (SaaS), platform-as-a-service (PaaS), hardware-as-a-service (HaaS), and infrastructure-as-a-service (IaaS). And Rimal and Lumb (2017) classify the deployment models into three categories: public cloud, private cloud, and hybrid cloud. Moghaddam et al. (2015) define three cloud computing service models (i.e., infrastructure-as-a-service, platform-as-a-service, and software-as-a-service) based on the five major cloud computing layers shown in Figure 17.2.

17.3.1 Cloud Service Models

17.3.1.1 Software-as-a-Service (SaaS)

Software-as-a-service is a multitenant platform that uses common resources and a single instance of both the object code of an application and the underlying database to support multiple customers simultaneously (Rimal et al. 2010). SaaS is often referred to as the application service provider model, and it is considered a new trend in application software delivery (Rimal & Lumb 2017). Cloud service providers offer applications through cloud infrastructure as Internet-based on-demand services. The end users can use these services without installing them (Gaire et al. 2020). Salesforce Customer Relationships Management (CRM) system, NetSuite and Google Office Productivity application (Rimal et al. 2011), and Google apps, such as Google Mail and Google Docs, are examples of SaaS (Gaire et al. 2020).

17.3.1.2 Platform-as-a-Service (PaaS)

PaaS provides developers with a platform comprising all the systems and environments, including the end-to-end lifecycle of developing, testing, deploying, and hosting sophisticated web applications (Rimal et al. 2011). PaaS provides a convenient method to design business applications and miscellaneous services over the Internet. Google App Engine and Microsoft Azure are examples of PaaS (Rimal & Lumb 2017). Cloud-based platforms can be categorized into three groups: integrated-oriented, development-oriented, and infra-oriented (Rimal et al. 2011). The classification of cloud-based platforms is given in Table 17.3.

PaaS introduces many advantages over conventional application development. PaaS offers hundreds of readily available services, leads to remarkable time reduction in application development, increases economies of scale, and reduces complexity by allowing the use of multiple applications on the same platform (Rimal et al. 2011).

17.3.1.3 Infrastructure-as-a-Service (IaaS)

IaaS is the delivery of computing resources, such as processing, storage, and networks, over the Internet (Rimal & Lumb 2017). IaaS comprises a group of virtualized infrastructural components (e.g., processing units, networks, storage) and allows the end users to build and execute their own operating systems, software, and applications (Gaire et al. 2020). This service offers many advantages to enterprises and end users, such as higher flexibility and usage-based payment options. The users of this service do not need to invest in purchasing, managing, and maintaining IT systems. Besides, the usage-based payment option allows users to pay as they grow. Customers can purchase and use the latest technology without any investment in the IT systems hardware. The key requirements of IaaS are on-demand, self-sustaining, multitenant service, and customer segregation. IaaS is sometimes called hardware-as-a-service (HaaS) (Rimal et al. 2011). Amazon EC2, Azure IaaS, Google Compute Engine (Gaire et al. 2020), GoGrid, Flexiscale, Layered Technologies, AppNexus, and Joyent (Rimal & Lumb 2017) are examples of IaaS.

TABLE 17.3
Classification of Cloud-Based Platforms

Type of Platform	Definition	Example
Integrated-oriented	The platform to develop e-business and apps that provide a wide range of interaction between platforms, languages in use, or users.	Facebook F8, Salesforce App Exchange
Development-oriented	The platform provides an environment to develop, test, and deploy applications.	Google App Engine, Bunzee connect, SF force.com
Infra-oriented	The platform provides scalable infrastructure and storage.	Amazon EC2, Simple Storage, Simple DB

(Adapted from Rimal et al. 2011)

17.3.2 Cloud Deployment Models

Four major types of cloud deployment models are investigated in this part: public clouds, private clouds, community clouds, and hybrid clouds.

17.3.2.1 Public Cloud

In this type of cloud deployment model, computing resources are dynamically presented over the Internet via web applications or web services (Gaire et al. 2020). Public cloud service is offered to the general public for open use, and the cloud infrastructure might be owned and operated by an enterprise, academic institution, or government organization (Mell & Grance 2011). Public clouds offer a shared hosting environment and provide an on-demand pay-per-use service accessible to multiple customers (Moghaddam et al. 2015). The public cloud characterizes a cloud computing system in a traditional sense where a third-party provider dynamically provisions resources over the Internet. Zimory, Azure, GigaSpaces, Rackspace, and Flexiscale are some examples of public cloud services (Rimal et al. 2010).

17.3.2.2 Private Cloud

The cloud service is designed for exclusive use by a single enterprise consisting of multiple users, such as different units in a company. The cloud infrastructure might be owned and operated by the organization or a third-party service provider (Mell & Grance 2011). A private cloud allows sharing of services and infrastructure in a single-tenant environment. Private clouds are not as cost-efficient as public cloud systems; however, they are still cheaper than investing in a data center. Private clouds provide customers with a high level of control over the cloud resources, just as public clouds (Rimal et al. 2011). When customers outsource computing resources via the cloud, confidential data is shared on public cloud servers. This situation leads to increasing concerns about data security and unauthorized access threats. Private clouds offer solutions by enabling cloud computing specifications in internal data centers of enterprises and providing easier management of upgrades, maintenance, and security. Besides, the system can balance the workload while resource usage is at high levels (Moghaddam et al. 2015). Private clouds ensure data management and processes without the restrictions that public clouds are subject to, such as network bandwidth limitations, security vulnerabilities, and legal requirements. Amazon VPC, Eucalyptus, OpenStack, VMWare, and Intalio are some examples of private cloud services (Rimal & Lumb 2017).

17.3.2.3 Community Cloud

Community clouds are designed for exclusive use by a particular community, such as financial institutions and health service providers (Onwubiko 2010). These specific communities of customers share similar interests and requirements, such as mission, security, policy, and compliance considerations. The cloud infrastructure might be owned and operated by one or more organizations in the community or a third-party service provider (Mell & Grance 2011). Grid computing and volunteer computing paradigms constitute the foundation of the community cloud. Community clouds allow multiple users with similar interests to share their infrastructure, leading to performance improvement and cost-sharing (Jin et al. 2010b). A form of community cloud is an agency cloud provisioned to use by the military, agency, or defense institutions. Agency clouds are operated by the agencies and are not open to public use (Onwubiko 2010).

17.3.2.4 Hybrid Cloud

A hybrid cloud infrastructure comprises two or more types of clouds (e.g., private, community or public). Hybrid clouds lead enterprises to strengthen their core competencies and gain a competitive edge by outsourcing secondary business activities from a public cloud while managing core business activities via a private cloud (Gaire et al. 2020). Hybrid clouds share resources between public and private clouds to provide improved performance for customers' specific needs (Ranjan et al. 2010). Hence, the complexity of determining how to distribute applications across both public and private clouds is inevitable (Furht 2010).

Public and private clouds represent two distinct sides of the cloud computing paradigm in terms of ownership and shared resource efficiency, and each type of cloud is used by enterprises depending on the service needs and targeted market segments. A newly emerging hybrid cloud models merge the characteristics of public and private clouds. In this type of cloud service, an enterprise provides cloud service by itself to manage some business activities while outsourcing an external cloud service for other business processes. For instance, an organization stores its customers' data in its own servers and procures a public cloud to use computing power for data processing (Lin & Devine 2010). A hybrid cloud comprises several internal and external service providers. The integration of a hybrid cloud with conventional infrastructure offers various benefits, such as cost reduction, scalable on-demand infrastructure, and cloud security (Rimal et al. 2011). Figure 17.4 depicts the comparison of three cloud types: public, private, and hybrid clouds.

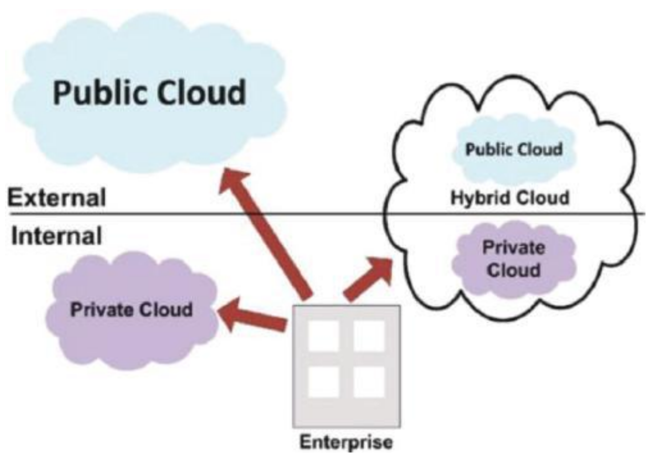

FIGURE 17.4 Cloud types: public, private, and hybrid clouds. (Jin et al. 2010b)

17.4 KEY ENABLING TECHNOLOGIES OF CLOUD COMPUTING

Jin et al. (2010a) define “cloud computing” as “data centers plus a layer of system software services designed to support the creation and scalable deployment of application services.” Hardware in a data center comprises a vast number of computing nodes and their subsystems (i.e., networking and storage), power distribution, and cooling systems. These data centers’ service is being utilized by technology giants such as Google, Amazon, Yahoo, and Microsoft.

Many technologies underlie the cloud computing paradigm. Furht (2010) states that the key enabling technologies of cloud computing include virtualization, web service and service-oriented architecture, service flows and workflows, and Web 2.0 and mashup. These technologies are explained in Table 17.4.

TABLE 17.4
Key Enabling Technologies of Cloud Computing

Key Technology	Definition
Virtualization	A cloud computing system can virtualize and share limited computing resources among multiple applications to increase server utilization and use fewer servers. Virtualization technologies cover virtual machine (VM) techniques and virtual networks. VMware and Xen are examples of virtual machine techniques, and VPN is an example of a virtual network (Furht 2010). Jin et al. (2010a) define virtualization as “the idea of partitioning or dividing the resources of a single server into multiple segregated VMs.” One of the first VM was used by IBM in 1960 to balance investment in high-priced mainframe computers.
Web service and service-oriented architecture	Developers need a set of web service technologies to build a real, user-friendly, and content-rich group of applications to support the cloud computing infrastructure effectively. Cloud services are presented as simple and user-friendly web services (Jin et al. 2010a). Web Services and Service-Oriented Architecture (SOA) constitute the foundation of cloud computing technology. Cloud computing systems are usually designed as web services that comply with industry standards such as Web Service Description Language (WSDL), Simple Object Access Protocol (SOAP), Universal Description, Discovery and Integration (UDDI). SOA contains a group of cloud services that work on many distributed platforms, and they are responsible for controlling the web services inside clouds (Furht 2010).
Service flows and workflows	Service flows or workflows refer to an integrated view of service-based activities. A sequence of structured activities and computations derived from information-assisted problem-solving is called IT-assisted workflow (Vouk 2008). A cloud system can systematically control services from various sources and different types to construct a service flow or workflow for users (Wang et al. 2008).
Web 2.0 and mashup	Wang et al. (2008) describe “Web 2.0” as “the trend in the use of World Wide Web technology and web design to enhance creativity, information sharing, and, most notably, collaboration among users.” The emergence of the Web 2.0 concept has improved web-based communities and hosted services. Mashup is a web application that can integrate data from multiple sources into a single integrated storage tool. An example of mashup is SmugMug, an image hosting/sharing and online video platform where users can upload an unlimited number of photos and videos.

Cloud computing can be interpreted as the integration of two major trends in information technology: IT efficiency and business agility. IT efficiency represents the ability of modern computers to create more efficient systems through highly scalable hardware and software resources. Business agility refers to the use of IT as a competitive advantage through rapid deployment, parallel batch processing, use of compute-intensive business analytics, and mobile interactive applications that provide real-time responses to user needs (Marston et al. 2011).

17.5 CLOUD COMPUTING IN BUSINESS

The Fourth Industrial Revolution (Industry 4.0) has begun with advancements in Information and Communications Technology (ICT). The Internet of Things (IoT) and smart automation of cyber-physical systems (CPS) with decentralized control establish the foundations of Industry 4.0. Conventional manufacturing and automation systems have been transformed into self-organizing cyber-physical production systems. Industry 4.0 has been built upon many transformative technologies, such as advanced robots, additive manufacturing, augmented reality, the IoT, cloud computing, and big data analytics. These key pillars of the Fourth Industrial Revolution continue to remodel production and support the advancements in the digitalization of manufacturing processes (Demir et al. 2020).

Being one of the key enabling technologies of Industry 4.0, cloud computing emerges as a new computing paradigm that aims to offer reliable, customized, and guaranteed quality computing service to the end users (Wang et al. 2008). Easy accessibility to broadband Internet and the ubiquity of smart devices have boosted the use of cloud computing among businesses. Cloud computing has many benefits for businesses. First of all, it saves time and reduces costs by increasing productivity, strengthening collaboration, and supporting innovation. Cloud computing systems bring about many benefits to end users and enterprises. Some of them are as follows (Martins 2020):

1. Cloud users can access information anywhere they have an Internet connection and a compatible device. Cloud computing systems store data on the Internet rather than on users' personal computers or a business-owned server. Since the information is available through a central web-based server, anyone with proper credentials can access it anywhere with an Internet connection.
2. Cloud system ensures consistency among users by automatically syncing the cloud-hosted data between all devices. Hence, mistakes are avoided when multiple employees work on the same digital file.
3. Businesses usually purchase expensive software, mostly installed on computers in the employees' offices. Cloud computing allows users to access the software remotely anywhere as if they were in the office.
4. Unexpected and unrecoverable data loss is a serious problem for businesses. There might be many reasons for data loss, such as natural disasters, power surges, and hardware failures. Storing important data in the cloud offers effective solutions for data safety in case of a contingency since the cloud keeps stored data intact regardless of the outside effects.

5. Cloud computing offers a cost-efficient business model since it does not necessitate enterprises to purchase and maintain their own servers and equipment. A cloud computing provider stores data and provides software and computing service without interruption at a cheaper cost than investing in a business-owned data center.

17.6 CASE STUDY: SOME OF THE MOST POPULAR CLOUD SERVICE PROVIDERS

This section will discuss some of the most popular cloud service providers:

1. **Amazon Web Services (AWS)**
   Amazon Web Services (AWS) is a cloud computing platform that offers infrastructure-as-a-service (IaaS) and platform-as-a-service (PaaS) solutions. AWS services offer scalable business solutions, such as computing, storage, databases, and analytics (What is AWS 2022). AWS offers a wide range of cloud-based products, including computing systems, storage spaces, databases, analytics, networking, mobile applications, developer tools, management tools, IoT, security, and enterprise applications (Cloud Products 2022). These services allow organizations to make faster decisions, reduce IT costs, and improve scalability in performance. Many enterprises and startups rely on AWS to effectively operate their business functions, such as web and mobile applications, game development, data processing and warehousing, storage, and archive (Getting Started with Amazon Web Services 2022).
2. **Microsoft Azure**
   The Microsoft Azure cloud platform offers more than 200 products and cloud services to solve business challenges. The areas that Microsoft Azure offers solutions include, but are not limited to, healthcare, government, manufacturing, financial services, and retail (What is Azure 2022). Some of the most popular Azure products are virtual machines, Azure Virtual Desktop, Azure SQL, Azure Cosmos DB, Azure Kubernetes Service, Azure Cognitive Services, App Service, Azure PlayFab, Azure Functions, Azure Quantum, Azure Arc (Cloud Computing Services 2022).
3. **Google Cloud**
   Google Cloud consists of a set of physical assets, such as computers and hard disk drives, and virtual resources, such as virtual machines (VMs), contained in Google's data centers around the globe (Google Cloud overview 2022). Some featured Google Cloud products are Compute Engine, Google Kubernetes Engine, Operations, Cloud Storage, BigQuery, Cloud Run, cloud SDK, Cloud CDN, Anthos, Cloud SQL, and Dataflow. Google Cloud helps businesses reduce their cost, increase operational agility, and acquire new market opportunities. Google Cloud offers services for the business areas such as retail, media and entertainment, supply chain and logistics, consumer packaged goods, telecommunications, government, financial services, gaming, education, healthcare, life sciences, and manufacturing (Why Google Cloud 2022).

TABLE 17.5
IBM Cloud Infrastructure Center Details

Efficient infrastructure management and provisioning	Delivers fundamental computation, networking, and storage resources to consumers on demand, providing the ability to scale and shrink resources based on need.
Fast deployments via image provisioning	Quickly deploy a virtual machine environment by launching it from the image library, filled with captured images from virtual machines.
Industry-standard user experience	Provides industry-standard user experience to define, deploy, and manage the lifecycle of virtual infrastructure for all types of containerized and non-containerized workloads, to automate via a self-service portal and integrate across the enterprise.
Self-service portal for end users	End users can easily provision predefined virtual machine instances required to do their work via the self-service portal on the Cloud Infrastructure Center.

(Adapted from IBM Cloud Infrastructure Center 2022)

4. **Alibaba Cloud**
   Alibaba Cloud, founded in 2009, offers cloud services to thousands of enterprises, developers, and government organizations in more than 200 countries and regions. Alibaba Cloud provides reliable and secure cloud computing and data processing capabilities for the successful business operations of its customers. The company became the official cloud services partner of the Olympics in 2017. The services offered by Alibaba Cloud provide good performance, high availability, and a competitive list price, and the products are similar to those that the major public cloud companies release. Alibaba Cloud offers flexible, user-friendly, and cost-effective product options that help customers save additional costs (About Alibaba Cloud: The Pulse of Digitalization 2022).
5. **IBM Cloud**
   The IBM Cloud Infrastructure Center offers IaaS that delivers an industry-standard user experience for the IaaS management of containerized and non-containerized workloads. The IBM Cloud Infrastructure Center provides scalable cloud management solutions across businesses (IBM Cloud Infrastructure Center 2022). Table 17.5 shows IBM Cloud Infrastructure Center details.

17.7 CONCLUSION

Cloud computing is the on-demand delivery of computer system resources over the Internet. It offers powerful, flexible, user-friendly industry solutions that impact the whole business world, from small- and medium-sized enterprises (SMEs) to large enterprises. Cloud systems offer a huge amount of computing power and storage space at a reasonably low cost. Hence, organizations of all sizes and needs can afford and take advantage of it.

Cloud systems offer a customized, flexible, and cost-efficient way of doing business to thousands of enterprises that operate in various sectors, such as automotive, education, finance, healthcare, insurance, and hospitality. As the business world rapidly enters a new era due to the impacts of disruptive technologies on manufacturing and service systems, companies are competing to gain a competitive edge by focusing on their core businesses and outsourcing game-changing services by collaborating with third-party service providers. More businesses are moving to the cloud service since web-based cloud services offer more scalable and trustworthy IT infrastructure that improves business performance, reduces cost, and supports business growth.

Businesses used to spend a considerable amount of time and financial resources on IT systems in the recent past. Building servers, purchasing and maintaining expensive hardware, and hiring technical staff impose huge expenses on enterprises. Cloud computing technology offers fast and cost-effective ways of creating and designing IT systems and applications without the need for servers, hardware, or technical staff. More and more companies have become so reliant on the cloud because of its transformative features, such as data accessibility (anywhere and anytime), easy scalability, data security, minimized implementation cost, and efficient backup and data recovery. Cloud computing is one of the main drivers of Industry 4.0, and it has already become of utmost importance and value for implementing and maintaining the progress of the Fourth Industrial Revolution.

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18 Blockchain Technology

Sercan Demir

CONTENTS

18.1 INTRODUCTION

Blockchain technology has attracted significant attention in academia and industry in recent years. Even though blockchain technology is still in its early days, it disrupts incumbent technologies by offering innovative applications. The rapid progress of blockchain technology shows no signs of slowing down, and the technology penetrates our everyday lives. Beck et al. (2017) define blockchain as “a distributed ledger technology in the form of a distributed transactional database, secured by cryptography, and governed by a consensus mechanism.” Blockchain is a shared, immutable digital ledger that enables storing transactions and tracking assets in a network (Gupta 2017). Blockchain is a distributed database of records or a public ledger shared among participants of a system. A blockchain system holds all the transactions made, and each of these transactions is verified by the consensus of the system participants (Crosby et al. 2016). The blockchain system keeps digital records and is sustained and managed by a consensus mechanism. These digital records are distributed, immutable, and shared by independent individuals or entities. While each individual is able to add digital records to the blockchain system, the update of these data can only be done by a consensus of the majority of the system’s participants (Avital et al. 2016).

Currency transactions between two individuals are centralized and usually done with the involvement and control of a third-party organization. Blockchain technology aims to generate a decentralized medium where individuals can interact without the need for the involvement of a third party (Yli-Huumo et al. 2016). Currently, we need third parties to construct and maintain records. For instance, banks are required to keep financial records, hospitals are required to keep health records, and

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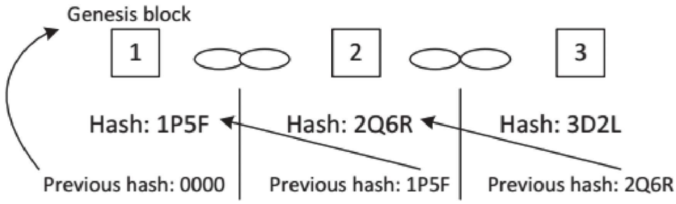

FIGURE 18.1 Structure of a blockchain. (Rathee 2020)

universities must keep education records. In the near future, enterprises or people will not require to work with third parties to keep their digital records due to the emergence of blockchain-based information systems applications. Blockchain-based digital systems will provide unbiased and incorruptible platforms and help prevent fraud with their features (Avital et al. 2016).

A blockchain consists of two elements: transactions and blocks. Transactions are the actions created by the system's participants. These transactions are constructed and maintained in blocks by the consensus of participants and kept in a proper sequence to avoid being tampered with. This database can be continuously extended; however, the history of the data cannot be changed (Banafa 2017). All independent participants of a system can access the set of blocks in a blockchain. Each block holds the stored data, a hash assigned to that data, and the previous block's hash. A specific hash number is assigned to each block, and this attribute forms the identity of that block. Each block stores its own and the previous block's hash value, and the system generates a specific hash value every time a new block is added to the system (Rathee 2020). Figure 18.1 illustrates the structure of a blockchain.

A blockchain is built on a data structure to contain an expanding log of digital transactions, data records, executables, and chronological order. These data structures form time-stamped blocks that are linked to the previous block. These cryptographically linked blocks create the blockchain structure (Andoni et al. 2019). According to Rathee (2020), a blockchain has three principles. It is an open, distributed, and synchronized ledger.

Blockchain offers opportunities for improving business performance through its inherited features, such as decentralization, traceability, and immutability. Table 18.1 depicts the key characteristics of blockchain technology.

Chen et al. (2018) state that blockchain offers reliable, trustworthy, secure, and efficient applications because of its technical features. Blockchain is an open and decentralized digital network that differs from closed and centralized ledgers. For instance, decentralized ledgers are controlled by tens of thousands of nodes, and the failure of a single node does not disrupt the operations of the entire network; however, centralized ledgers are maintained by a few nodes, and the failure of a single node affects the whole network. The ability to prevent a single point of failure ensures high reliability for blockchain-based decentralized networks. The decentralized nature of blockchain spreads out and ensures trust among the nodes throughout the digital network. The tamper-proofed nodes of the network cannot be interfered with. The

TABLE 18.1
Key Characteristics of Blockchain

Characteristics of Blockchain Technology	Explanation
Consensus	All system participants must agree on a transaction's validity to make it valid.[5]
Immutability	Once a transaction is done and recorded, it can never be changed.[1]
Decentralization	The data verification, storage, and transfer processes are executed on a distributed system structure.[3]
Traceability	All transactions are organized in chronological order, and blocks are linked to the previous block by the cryptographic hash function.[3]
Provenance	System participants get to know the origin of the assets and their ownership information.[5]
Anonymity	The inherent anonymity feature of BCT enables hiding participants' identities and keeping them private.[4]
Security	BCT establishes security aspects in a network by eliminating the problem of a single point of failure.[4]
Availability/ robustness	The availability and robustness of the data are guaranteed since the records on the blockchain are replicated in many nodes.[2]
Increased capacity	Thousands of computers working together make it possible to increase the capacity of a network.[1]

(Adapted from [1]Atlam et al. 2018, [2]Agbo et al. 2019, [3]Chen et al. 2018, [4]Dorri et al. 2016, [5]Gupta 2020)

one-way hash functions on each blockchain node make each process almost impossible to reverse, and the input cannot be determined from the output. The output does not carry any information from the input, establishing secure networks. One of the essential merits of blockchain technology is eliminating intermediaries within the processes. The transactions become faster and more efficient when the system's participants can directly communicate without any help from a third party. Hence, blockchain applications improve the overall system efficiency.

Blockchain can be categorized as permissioned blockchain and permissionless blockchain in terms of accessibility to the system. A permissioned blockchain refers to a type of blockchain with restrictions in its membership and control procedures. In this type of blockchain, each participant's roles, such as the ability to access, add information, or approve the admission of new members, are defined in the system's configuration (Liu et al. 2019). A permissioned blockchain requires approval from the network administrator; however, a permissionless blockchain does not require any special permission to participate in the system. Any other node in permissionless blockchains does not control new user registration and identity anonymity features. In contrast, a single node (private chain) or a group of nodes (consortium chain) controls the accessibility of the system in a permissioned blockchain (Chang et al. 2019). Hybrid blockchains fall within the intersection area of permissionless and permissioned blockchains. Hybrid blockchains possess the advantages of both permissionless and permissioned blockchains and can be used effectively to meet the

TABLE 18.2
Comparison of Different Types of Blockchains

Parameters	Permissionless	Private	Consortium	Hybrid
Network	Decentralized	Centralized	Centralized	Hybrid
TPS	Low	High	High	High
Visibility and participation	Open	Restricted	Restricted	Varies
System governance	Hard	Easy	Medium	Varies
Security	Varies	High	High	High
Examples	Bitcoin, Ethereum, EOS	MultiChain	Hyberledger Fabric	XinFin

(Cai et al. 2018)

increasing demand for complex systems (Cai et al. 2018). Table 18.2 indicates the comparison of different types of blockchains.

Morkunas et al. (2019) state that two types of blockchains exist concerning the type of accessibility to a network: public (open) and private (closed). Anyone can interact with another participant in a public blockchain system. A pseudonym or entirely anonymous identity is used in transactions between the two parties. All participants of a system can view all the transactions in public blockchains. Only preapproved individuals or groups of individuals can access the system and interact with other participants in a private blockchain system. Users know the identities of all the participants before the execution of transactions in this type of blockchain. A consortium blockchain is a variety of private blockchains in which only a pre-validated group of participants can access and change the records of transactions.

18.2 HISTORY OF BLOCKCHAIN TECHNOLOGY AND ITS DEVELOPMENT

Stuart Haber and W. Scott Stornetta introduced the foundation of blockchain technology in 1991. The two researchers intended to devise a system in which document time-stamps could not be changed. The idea of this system was to allow digital information to be recorded and distributed but not edited (Conway 2020). It is easy to tamper with digital systems. Research on maintaining and protecting the validity and integrity of digital information has been conducted since the mid-1990s. A solid, secure, and reliable mechanism was needed to fully reveal the potential of the Internet in business operations (Benton & Radziwill 2017). However, this idea materialized for the first time with the introduction of Bitcoin in 2009. Satoshi Nakamoto created Bitcoin, a digital cryptocurrency, in 2009 that is considered the first proper application of blockchain technology (Rathee 2020). The history of blockchain is illustrated in Figure 18.2.

Blockchain technology was introduced in 2008 for the first time; however, research on the digital ledger concept was started by Stuart Haber and W. Scott Stornetta in 1991. The researchers intended to build a system that does not allow

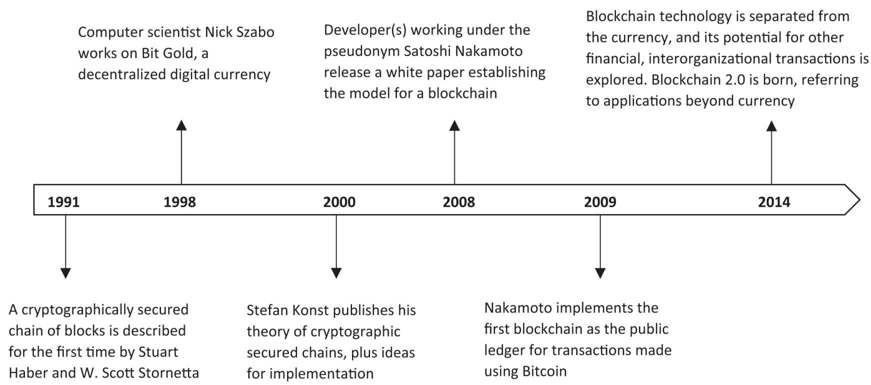

FIGURE 18.2 History and development phases of blockchain technology.

anyone to interfere or change document time-stamps. In 1998, a computer scientist and cryptographer, Nick Szabo, outlined a mechanism for a decentralized digital currency called Bit Gold. This currency was never put into practice; however, it had been a pioneer for Bitcoin. In 2000, Stefan Konst's theory helped us understand the cryptographic methods that prevent unauthorized persons from manipulating system data. Developer(s) working under the pseudonym Satoshi Nakamoto conceptualized the first blockchain in 2008. The design was based on the Hashcash cryptographic algorithm, and the blocks could be time-stamped without requiring them to be signed by third parties. In 2014, blockchain 2.0 emerged with potential applications, such as bonds and smart contracts (Soni 2020).

18.3 PROMINENT APPLICATIONS OF BLOCKCHAIN TECHNOLOGY

Advances in digital platforms and services, such as distributed ledger systems and digital transactions, result from rapid development in blockchain and distributed database technologies. Blockchain comprises a sequential distributed database that stores and shares the transaction history in a public ledger (Lindman et al. 2017). The set of databases, transactions, encryption, consensuses, and distributed system technologies form the infrastructure of blockchain technology. A distributed data structure is generated, maintained, and shared with the participants of the blockchain system. Each participant in a blockchain network can securely access and view the digital ledger of data without any permission from a centralized authority (Liao & Wang 2018). Blockchain technology can be applied in various industrial and technical fields. The inherent decentralized structure is the main strength of blockchain technology. A blockchain stores every transaction; each participant can view these records; however, they cannot change and delete these data. Hence, blockchain technology offers transparent, immutable, and secure digital systems (Golosova & Romanovs 2018). Figure 18.3 depicts the prominent areas in which blockchain can be applied.

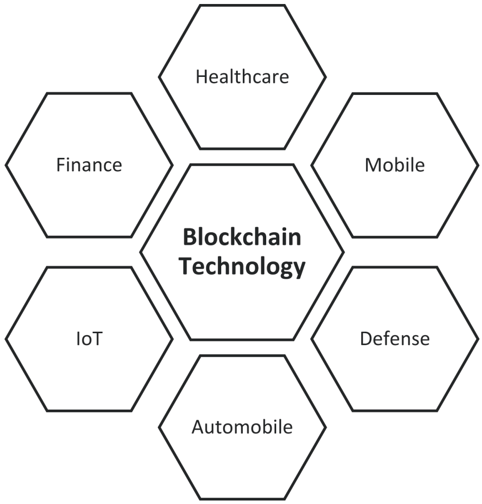

FIGURE 18.3 Application areas of blockchain technology. (Joshi et al. 2018)

The application areas of blockchain are rapidly growing and not limited to the areas shown in Figure 18.3. Blockchain technology has led to the emergence of many cryptocurrency systems, such as Bitcoin and Ethereum. That is why the concept is usually tied up to cryptocurrencies. Nonetheless, blockchain technology offers many solutions for various applications in many sectors (Yaga et al. 2019). The first blockchain applications and business models were introduced in finance; however, new blockchain-based business models are continually being implemented in many sectors, such as transportation, healthcare, and entertainment (Beck et al. 2017). We will review some of the prominent applications of blockchain technology in the following subsections.

18.3.1 Blockchain Applications in Finance

The birth of digital currency has affected conventional banking and financial services (Zheng et al. 2018). Bitcoin, the decentralized digital currency, was the first application of blockchain technology. Afterward, various digital currencies, such as Altercoin, Peercoin, Ethereum, and Binarycoin, embraced blockchain-based infrastructure, even though their consensus algorithms differ in verifying and validating blocks (Joshi et al. 2018). Traditional payment mechanisms use centralized ledgers to record all transactions maintained in account balances. Once a transaction is made from one party to another, intermediary checks validate the transaction and adjust account balances accordingly. Transactions in a blockchain system are sent to all nodes in the network, become part of the system, and are stored in every participant's computer. The blockchain-based digital platform within Bitcoin allows faster and cheaper transactions while removing the need for a trusted third party (Ammous 2016).

Verification of the entire transaction history is the idea behind Bitcoin, and this verification is done by using cryptographic computations. The verification method is named proof-of-work (PoW) (Lindman et al. 2017). Two fundamental cryptography technologies underlie the basis of Bitcoin: public-private key cryptography and cryptographic validation (Böhme et al. 2015). Bitcoin employs a public-key cryptography system to protect its currency and provide secure transactions. The participants in a blockchain system can make transactions with each other without any need for permission from a central authority. The validation of any transaction works under the rules of cryptographic proof-of-work. When a participant approves a transaction process, the Bitcoin transfer is done between two cryptographic addresses. Each transaction is announced to the whole network and recorded on each participant's computer (Muftic et al. 2016). Bitcoin transfer from a sender to a receiver is explained in Figure 18.4.

The transfer process illustrated in Figure 18.4 follows these steps (Castro 2018):

1. The sender creates a transaction.
2. The sender's Bitcoin wallet validates the transaction.
3. The transaction is sent to the memory pool (the transaction stays in the memory pool until the miner is ready to get it).
4. Miners get the transaction from the memory pool and start mining the block using a consensus algorithm.
5. After the block is fully mined, it is added to the network.
6. The chain validates the new block, and every peer in the network will get the blockchain with the new block added.
7. Finally, the receiver gets the Bitcoin.

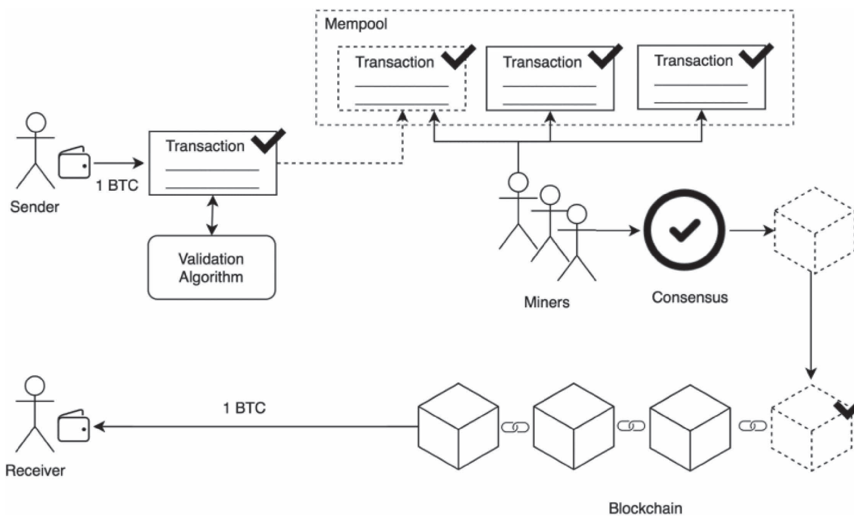

FIGURE 18.4 The Bitcoin lifecycle.

(Castro 2018)

18.3.2 Blockchain Applications in Smart Contracts

The term "smart contract" was coined by computer scientist Nick Szabo in 1994. The researcher designed a computer program with an if-then structure interacting with the real world (Foroglou & Tsilidou 2015). Szabo defines a smart contract as "a computerized transaction protocol that executes the terms of a contract" (Szabo 1994). His intention was to extend the range of capabilities of electronic transaction methods, such as POS (point of sale), to the digital world. A decade before the emergence of Bitcoin, Szabo invented the digital currency Bit Gold in 1998 (Frankenfield 2021).

The Ethereum Project is one of the first blockchain systems with smart contract functionality. Ethereum offers an independent platform where participants can create virtual contracts for any purpose (Foroglou & Tsilidou 2015). The smart contracts are tamper-proof, self-executing, and enforceable due to the nature of their configuration. These features are formulated into the contractual arrangements between participants during the design of a smart contract. The system can be risk-free and cost-conscious since the need for human involvement in the process is reduced (Mattila 2016).

Smart contracts must be deterministic, isolated, and terminable. Being deterministic refers to producing the same results every time the system executes the contract. Any system participant can upload smart contracts. A defect like a virus or a bug in a contract might impact the entire blockchain system. Smart contracts must be isolated to avoid unexpected and risky system errors and adverse effects. Smart contracts must complete each run within a specified time period, defined under the termination feature (Harris 2019).

Sillaber and Waltl (2017) investigate the lifecycle of a smart contract under four stages:

1. Creation of the smart contract
2. Freezing of the smart contract
3. Execution of the smart contract
4. Finalization of the smart contract

The creation stage consists of two steps: iterative contract negotiation and an implementation phase.

The participants agree on the content and objectives of the smart contract in the creation phase. After the agreement is done, it is turned into code. The codified version of the contract is submitted to the distributed ledger after the participants agree on it. This phase is called publication, and the contract is ready to be executed once the majority of the participants confirm it. Any modification in the smart contract will not be allowed once the blockchain accepts it. Hence, if any change is necessary, it is required to create a new contract. All participants in the system must use a digital wallet that is connected to the ledger platform. During the freeze stage, any transaction sent to a participant's wallet is frozen, and the prerequisites for contract execution are checked by the participant nodes, who take the role of a board of administration. Contracts on the digital ledger are read and validated by the participants. After the inputs are collected from participants, the inference engine

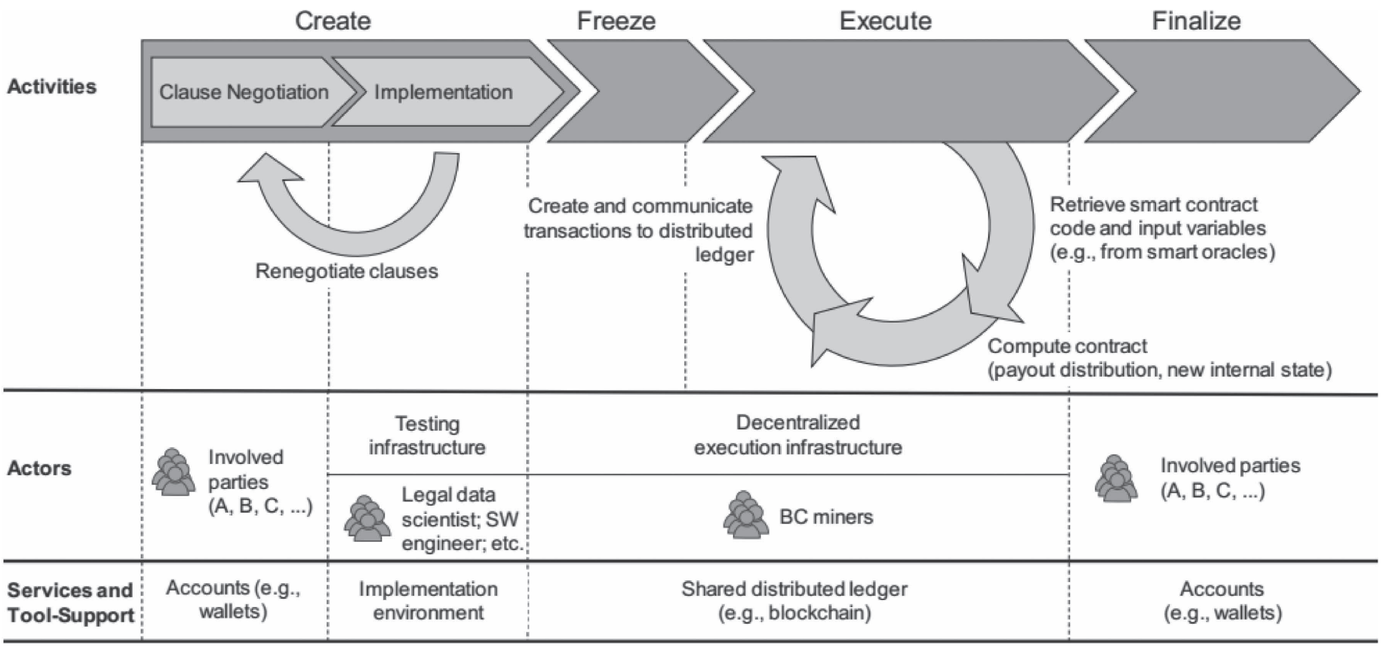

FIGURE 18.5 Lifecycle of a smart contract. (Sillaber & Waltl 2017)

of the system (e.g., compiler, interpreter) executes the code at the execution stage. The final transactions and new state information are recorded and confirmed based on the consensus protocol in the digital ledger after the execution of the contract is completed. This stage is called the finalization stage of the smart contract. The committed digital assets frozen at the freeze stage are released and transferred, and the contract is fulfilled after the confirmation of all transactions (Sillaber & Waltl 2017).

18.3.3 Blockchain Applications in Supply Chain Data Management

Today, many buyers cannot determine the origins of the materials or products they want to purchase, and companies have difficulty tracking their complex supplier networks. Blockchain technology offers data management solutions with its immutability feature. The system allows individuals to access detailed supply chain records of products, such as the product's origin, payment history throughout its supply process, and storage conditions during transportation. This system improves product safety and allows consumers a chance to select better products and suppliers (Mattila 2016). According to Kumar and Mallick (2018), blockchain technology offers many application opportunities in various sectors, such as agriculture, business, distribution, energy, food, finance, healthcare, and manufacturing. Further, the authors state that blockchain systems offer many advantages for large-scale IoT systems. Some of these advantages are tamper-proof data, high reliability, records of historical actions, distributed file sharing, and built-in trust.

The key characteristics of blockchain technology offer promising business solutions for sustainability issues in complex supply chain networks. Blockchain-based applications support data collection, storage, and management while ensuring openness, transparency, neutrality, reliability, and security for all parties in a supply chain network (Saberi et al. 2019). Agriculture is another sector in which blockchain technology has gained significant attention. Blockchain applications in the agriculture sector can significantly improve the food supply chain and satisfy the needs of the ecosystem. Blockchain application benefits include increasing transparency of food safety, IoT-based food quality control, provenance traceability, improvement of contract exchanges, and transaction efficiency (Lin et al. 2020).

18.3.4 Blockchain Applications in the Healthcare Industry

Blockchain can be implemented in many areas of the healthcare industry. Some of these areas are public health management, the pharmaceutical sector, medical research, and consumer-oriented healthcare (Mettler 2016). According to Agbo et al. (2019), the research on blockchain technology in the healthcare industry is relatively new; however, blockchain applications will widely influence the healthcare industry in the near future. The authors investigate the current research endeavors in blockchain technology in healthcare, such as managing electronic medical records, drugs, and pharmaceutical supply chain management, biomedical research and education, remote patient monitoring, and health data analytics. Gordon and Catalini (2018) analyze the challenges experienced during the transition from institution-driven interoperability to patient-driven interoperability and the applicability of blockchain

TABLE 18.3
Blockchain Benefits to Healthcare Applications

Decentralization	As a result of the decentralization feature of blockchain, the same health records can be reached by the stakeholders in the health data management system.
Improved data security and privacy	Security of the health data is ensured due to the immutability property of blockchain. Besides, the identity and privacy of the patients are protected in a blockchain system.
Health data ownership	Cryptographic structures and smart contracts help protect patients' data and prevent them from being misused by unauthorized parties.
Availability/ robustness	The records on a blockchain system are held on multiple nodes. This feature of blockchain ensures the availability of health data, and the entire system becomes robust and resilient against data losses, data corruption, and cyberattacks.
Transparency and trust	The open and transparent nature of blockchain creates trustworthiness for healthcare applications; hence, the system participants will be more eager to get involved in these applications.
Data verifiability	The verification of the stored records on blockchain nodes can be done without accessing the plaintext of these records.

(Adapted from Agbo et al. 2019)

technology to patient-driven interoperability. The authors assert that digital access rules, data aggregation, data liquidity, patient identity, and data immutability are among the blockchain features that enable patient-driven interoperability. Table 18.3 specifies the benefits of blockchain to healthcare applications.

Table 18.4 illustrates studies about current and potential blockchain applications in various industries and domains in the literature.

18.4 FUTURE OF BLOCKCHAIN TECHNOLOGY

Blockchain has become one of the most popular emerging technologies in recent years, and many organizations consider it one of their strategic priorities. Blockchain technology is one of the disruptive technologies in the Industry 4.0 era, and it offers many opportunities for various industries. Bitcoin and other cryptocurrencies are the first applications of blockchain technology; however, this technology has the implementation potential for various business fields and industries.

Blockchain technology has a promising potential to introduce innovative business solutions and improve the efficiency of many business areas, such as digital art management, supply chains, and healthcare (Hughes et al. 2019). The advancement in digital technology can discard incumbent organizations, such as banks. Blockchain technology creates opportunities for individuals and organizations to make transactions and share information without the need for an intermediary (Nguyen 2016). Biomedicine science and the healthcare sector are two potential areas in which blockchain could provide exponential value. Blockchain can set up personalized, reliable, and secure healthcare applications and distribute real-time clinical data safely and rapidly (Siyal et al. 2019). Smart contracts are another outstanding application that

TABLE 18.4
Blockchain Technology Literature Review

Digital Currency	Digital Wallet	Smart Contracts	Smart Property	Voting Systems	SC Data Management	Intellectual Property Rights	Identity Management	IoT/ Mobile	Cybersecurity	Healthcare	DAO	Agriculture	Study
X		X	X	X		X							Foroglou & Tsilidou (2015)
X	X	X		X	X		X	X			X		Mattila (2016)
		X	X								X		Avital et al. (2016)
	X									X			Mettler (2016)
		X					X	X					Crosby et al. (2016)
X	X	X		X				X		X			Beck et al. (2017)
					X	X	X			X			Peck (2017)
X		X											Ishmaev (2017)
		X			X			X	X	X			Ahram et al. (2017)
										X			Angraal et al. (2017)
										X			Gordon and Catalini (2018)
									X				Bell et al. (2018)
X		X			X				X		X	X	Kumar and Mallick (2018)
								X	X	X			Joshi et al. (2018)
X		X											Macrinici et al. (2018)
		X	X				X			X			Agbo et al. (2019)
X		X			X								Saberi et al. (2019)
X	X	X			X	X		X		X	X		Gatteschi et al. (2018)
					X				X			X	Lin et al. (2020)
										X			Omar et al. (2021)

blockchain has put forward, with a disruptive potential to create a novel way of doing business. Self-executing smart contracts allow rapid transactions and reduce transaction costs between participants (Mattila 2016).

Blockchain is one of the top emerging technologies with an exceptionally broad set of potential applications. An ever-increasing need for securing digital transactions and controlling big data across the Internet will be more obvious as the Internet changes the way of doing business and digitalization becomes an essential part of business operations. Blockchain is a unique technology that addresses many

TABLE 18.5
Some of the Most Prominent Distributed Applications (dApps) for Blockchain Technology

Application	Function
Chainlink	Chainlink is a secure middleware that promotes an open standard for secure, decentralized data input or oracle system. Chainlink offers any smart contract secure access to data feeds, APIs, and payments.
Brave	Brave is a web browser with almost 9 million active users, and it creates a new measure of value in the advertising world where consumer attention is used to set value more than unverifiable views or clicks on a webpage. The software allows consumers to have full control of the situation by blocking online advertisements and website trackers.
EOS Dynasty	EOS Dynasty, which has nearly 12,000 unique daily users, claims to be the first role-playing, player-versus-player (PvP) game based on blockchain.
MakerDAO	A decentralized credit service that runs on the Ethereum blockchain platform, MakerDAO supports Dai, a stable coin whose value is pegged to the U.S. dollar.
Chainyard	Chainyard is a permissioned blockchain-based network, and it is designed to improve supplier validation, onboarding, and lifecycle information management.
TRACEDonate	TRACEDonate is an identity management platform designed to allow for transparent and traceable cross-border remittances and giving.
Circulor	Circulor provides service for supply chain traceability for the electric vehicle and electronics industries. It provides traceability to demonstrate the ethical and sustainable sourcing of raw materials used in the production of the latter.
Cipher	Cipher is middleware that supports a portfolio of four blockchain dApps for government agencies and regulators in different regions. It includes a reconciliation and settlement network, tokenization of loyalty points, a procurement payment network, and a document exchange, verification, and compliance network for banks and their customers.
KYC-Chain	KYC-Chain verifies customer identities and streamlines the onboarding process to meet know-your-customer (KYC) regulations. It can verify individuals as well as corporate and institutional business clients for criminal or prohibited activities in real time through a partner sanction and watchlists database that spans more than 240 countries.
DLT.sg	DLT.sg (Distributed Ledger Technologies, Singapore) includes a series of enterprise-grade blockchain dApp modules focused on supply chain and counterfeit recognition technologies. DLT.sg is built for collaborative e-commerce in large supply chain organizations. It enables trade finance, tracks end-to-end product flow, and delivers a model for unlocking inventory and freeing up cash.

(Adapted from Mearian 2019)

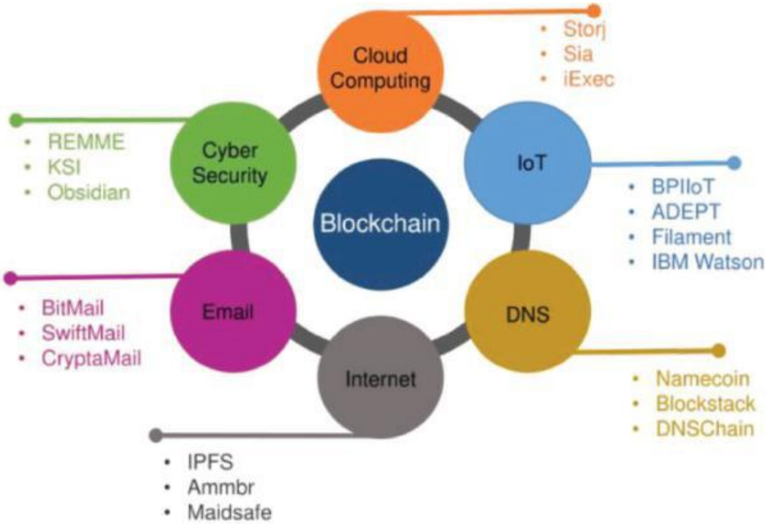

FIGURE A Blockchain-based network applications and their solutions. (Ali et al. 2019)

challenges businesses face, and it has great potential to transform conventional ways of doing business in various sectors. As the power of blockchain and its innovative way of doing business is understood, it will gain ground in different sectors.

18.5 CASE STUDY: A REVIEW OF BLOCKCHAIN-BASED APPLICATIONS

This section will discuss blockchain-based applications and their real-life uses. The most prominent applications of blockchain are as follows (Dutta 2021):

1. Money transfer and payment processing
2. Supply chain monitoring
3. Retail programs based on loyalty rewards
4. Digital IDs
5. Sharing of data
6. Protection of royalty and copyright
7. Digital voting
8. Transfer of real estate, land, and auto title
9. Food safety
10. Unchangeable data backup

Figure A shows some blockchain-based network applications and their platforms.

18.6 CONCLUSION

A blockchain is a digital ledger of duplicated transactions distributed across the whole network of computer systems on the blockchain. Blockchain is the core technology behind cryptocurrencies; however, it has vast application areas, and it offers promising potential beyond digital currencies. Blockchain offers decentralized, traceable, anonymous, and secure methods for performing transactions. This technology can be applied to many fields, such as healthcare, finance, automobile, and the IoT.

A blockchain system possesses the following characteristics:

- It is digitally distributed across a number of computers.
- It uses many users in the network to reach a consensus.
- It uses cryptography and digital signatures to prove identity.
- Its historical records cannot be changed (very difficult).
- It consists of time-stamped blocks.
- It is programmable.

Blockchain offers promising application areas, such as money transfer, real estate transactions, voting, logistics and supply chain operations tracking, smart contracts, and sharing medical records. Cybersecurity is one of the most prominent areas with considerable potential for growth with the help of blockchain technology. Data tampering is one of the biggest concerns for many businesses in the digital era. Blockchain can help companies prevent their data from being tampered with and unauthorized access.

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19 AI, Robotics, and Autonomous Systems

Yusuf Kuvvetli and Adem Erik

CONTENTS

19.1 INTRODUCTION

With the defeat of Kasparov by Deep Blue (Campbell, Hoane and Hsu 2002), which is a famous artificial intelligence program, the world of algorithms that transcended the boundaries of the human brain, or artificial intelligence, as it was known, became a part of daily life. Looking at the roots of artificial intelligence, it can be traced back to ancient Greek mythology, and in terms of the computer world, the Turing experiment introduced by Alan Turing can be presented as the first example of the concept of artificial intelligence. However, it is possible to say that the progress of artificial intelligence with different algorithms continues with increasing interest in the journey that started. When the crucial developments in artificial intelligence are examined, it is possible to reach the following milestones during improvements:

- McCulloch and Pitts neural model, which is inspired by the human brain (McClulloch and Pitts 1943)
- Turing machine, which is a computational mathematical system that simulates rules (Turing 1937)
- Artificial neural networks mimic biological neural networks to model complex non-linear systems (Jain, Mao and Mohiuddin 1996)
- Discovery of agent-based systems, which provide modeling software or robotic agents and their interactions (Wooldridge 2000)
- Deep Blue is a famous chess machine (Campbell, Hoane and Hsu 2002)
- Robotic systems include various operations handled by autonomous systems

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- Deep learning algorithms, which is the extension of classical artificial neural network idea

With all these advances, artificial intelligence and autonomous systems have become a phenomenon that has become widespread with the tools we use in our daily lives. From the production perspective, welding with industrial robots, and so on, jobs have been replaced by robot and software systems with much more complex skills, artificial intelligence applications, and autonomous vehicles. This situation has revealed the necessity of re-evaluating the supply chains with a similar perspective, and it has become possible to examine artificial intelligence and other concepts in supply chains with different applications. Classical artificial intelligence includes many sub-components, such as machine learning, artificial neural networks, expert systems, heuristic algorithms, fuzzy logic, and intelligent agents.

19.2 AI, ROBOTICS, AND AUTONOMOUS SYSTEMS IN SUPPLY CHAINS

Supply chains are a complex management structure that includes many members, including suppliers, manufacturers, distributors, wholesalers, customers, and logistic service providers. A typical supply chain structure is depicted in Figure 19.1. When all members of the supply chain are evaluated, the functions that may occur are summarized as follows:

- Supply chain design
- Purchasing management

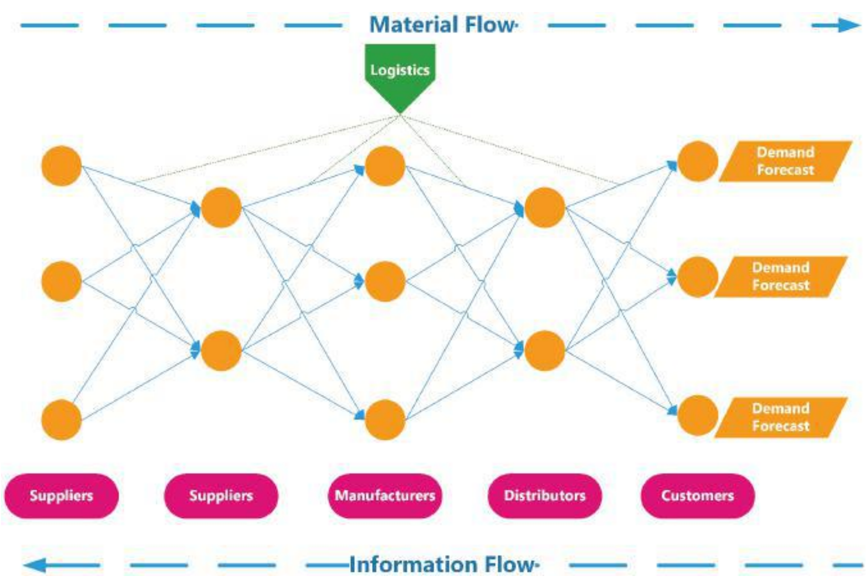

FIGURE 19.1 Supply chain structure.

- Demand planning
- Planning
- Inventory management
- Logistics services
- Information sharing

A supply chain diagram showing the supply chain members used in the study, which are suppliers with different tiers, manufacturers, distributors, and customers. Information flow starts from customers to suppliers and conversely with the material flow. The logistic operations are also depicted. Demand forecast points are also shown in the figure.

Different studies have focused on the topic related to supply chain design and artificial intelligence techniques. Generally, the planning capability of artificial intelligence is focused on these design problems. For instance, the supply chain design problem that considers the multiproduct supply chain is solved via ant colony optimization, one known meta-heuristics (Moncayo-Martínez and Zhang 2011). Throughout the supply chain, each member generates a large amount of data, and this data generated requires big data analytics. It is recommended to use artificial intelligence methods in big data analysis (Toorajipour, Sohrabpour, Nazarpour, Oghazi and Fischl 2021). Artificial intelligence includes many different techniques. However, not every technique can provide an equally effective solution to problems in the supply chain. In the study of Toorajipour, Sohrabpour, Nazarpour, Oghazi, and Fischl (2021), the most widely used artificial intelligence techniques in the supply chain were found to be artificial neural networks, fuzzy logic, and agent-based systems/multi-agent systems. Although artificial neural networks are used in many subjects, they are frequently used especially to find complex patterns that people cannot find. However, fuzzy logic can express ambiguous expressions with natural language and can be used effectively as a modeling tool in many intelligent systems. Agent-based systems (ABS)/multi-agent systems (MAS), which is another widely used method, can be used for planning, design, complex behavior analysis, and so on, in the supply chain. It produces effective solutions for many problems by understanding the environment and acting autonomously and proactively. Therefore, ABS/MAS is seen as a widely used artificial intelligence technique in the supply chain. The use of AI techniques in supply chains makes processes autonomous and proactive. It also helps in customizing products and services.

Due to the large and complex nature of supply chains, possible disruptions affect all members at once. The disruption of outsourcing with the emergence of Covid-19 has created a global debate about increasing in-house production in supply chains (Pournader, Ghaderi, Hassanzadegan and Fahimnia 2021). One of the main agendas of this discussion is that the end-to-end supply chain is difficult to map and replicate because of supply chain complexity and the interconnectedness of supply chain members. AI is promising for solving this issue by increasing the agility and understandability of supply chains (Pournader, Ghaderi, Hassanzadegan and Fahimnia 2021). Artificial intelligence applications have been used in tactical and operational areas rather than strategic decisions in the supply chain. Min (2010) stated in the study that artificial intelligence techniques could make more important contributions to supply chains and listed the possible applications as follows:

- Multi-agent systems can address strategic issues, such as supply chain integration and risk management.
- Multi-agent systems can provide price optimization in auctions with instant pricing using smart agents.
- Game theory can be used to create strategic supply chain partners by working with multi-agent systems.
- Profiles of identified supply chain partners can be developed with the help of information discovery technologies.
- Decisions on issues, such as logistics outsourcing and contract manufacturing, can be improved with the help of rule-based expert systems.
- Expert systems can be used to make improvements in airline finance management.
- By combining the artificial intelligence features in the genetic algorithm with the ant colony, hybrid meta-heuristics can be developed for combinatorial transportation network design.
- It can be used to reduce logistics costs by integrating genetic algorithms and artificial neural networks with fuzzy logic.
- Rule-based expert systems can be added to supply chain knowledge management.
- Rough set theory and machine learning techniques can be used to evaluate supplier and third-party logistics companies.

Robotic process automation is one of the recent aspects related to artificial intelligence. Robotic process automation that maps the current processes with software robots provides a solution to daily subjects (Van der Aalst, Bichler and Heinzl 2018). Purchasing management includes some daily processes such as price research, supplier contract management, etc. Thereby, purchasing management can make applications with robotic process automation, as shown in some studies such as (Viale and Zouari 2020). Thanks to the advancing voice and chatbot technology, virtual assistants are being developed to provide next-generation customer service, and these virtual assistants can be very effective as they reach a certain level of complex dialogues with customers (Ribeiro, Lima, Eckhardt and Paiva 2021). RPA is a technology that paves the way for automatic organization and business processes. For the automated organization to function properly, information must be presented correctly and processes must be fully identified, classified, estimated, and optimized (Ribeiro, Lima, Eckhardt and Paiva 2021). For all these processes, artificial intelligence algorithms and techniques can be used as a complement. Per Ribeiro, Lima, Eckhardt, and Paiva (2021), RPA features were defined for proprietary tools, such as UiPath, Kofax, Automation Anywhere, WinAutomation, and open-source tools, such as AssistEdge and Automagica, and integration with ERPs was achieved. It is concluded that most of these proprietary tools discussed have implemented the algorithms of recognition, optimization, classification, and information extraction from RPA documents associated with artificial intelligence objectives. Experts work with RPA tools instead of artificial intelligence tools, and these experts manually guide the RPA tools within the framework of the previously determined rules. This situation prevents the widespread use of RPA tools in business process management (Agostinelli, Marrella and Mecella 2020). With the integration of artificial intelligence techniques into RPA tools, it is expected that customer service in the front office will improve and the work in the back office will decrease. Thus, it is foreseen that there will be positive contributions to the company workforce in the long run (Agostinelli, Marrella and Mecella 2020). With Industry 4.0, the effects of digitalization can be felt directly or indirectly in all areas of life. Arguing that RPA tools can be used quite effectively on some issues, Reddy, Undavalli Harichandana, and Rajesh (2019) listed a few of these applications as follows:

- RPA tools can be used to run a process without error and without inappropriate data collection, fraudulent interventions, and deviations from predetermined processes. Thus, a safer process is carried out without any loss of data and violation of personal rights in sensitive matters.
- RPA can be used to develop tools that offer new self-service solutions that mimic human behavior for the spread of self-service.
- RPA software can be used to collect and organize inconsistent data between different systems. Thus, errors in the use of data by artificial intelligence in big data analytics are prevented.
- The use of RPA tools can create new business opportunities for producers with various legal and political barriers to offshoring.

Forecasting forms an essential intersection of supply chains and artificial intelligence methods. It has become possible to make effective decisions, such as planning and inventory management, with accurate demand planning and forecasting. For this reason, demand planning is at a very critical point. In this context, artificial intelligence has great potential to create an accurate and effective demand forecasting system. Artificial neural networks have been used frequently in the literature in this context, for example (Al-Saba and El-Amin 1999). Energy consumption is a very important issue in smart home systems, which are very popular with today's technology. Forecasting energy consumption demand is, therefore, important. Rocha et al. (2021) developed a new methodology for estimating the energy demand of smart home systems using the elitist nondominant sequence genetic algorithm II, support vector regression, and k-means clustering techniques. Accordingly, in the NGSA-II method, electricity prices that change over time, equipment usage priority, operating cycles, and battery bank are considered. The prediction of the generation distributed the day before with support vector regression was considered, and finally, user comfort levels were determined by k-means clustering (Rocha et al. 2021).

Artificial intelligence elements in planning and inventory management include scheduling problems with different characteristics, inventory control methods, and inventory management concepts. Production scheduling aims to optimize the work for different purposes by deciding the start-end times and make-span value. This problem can be given for a multi-objective structure as an example of a study showing different meta-heuristics (Loukil, Teghem and Tuyttens 2005). In inventory management, it can be seen that RFID and robotic technologies are frequently used in warehouse management. Robotic systems have been proposed in different studies in systems such as material counting and material transfer for situations with complex materials (Lee 2018). In the supply chain, transportation is one of the non-value-added processes, but it creates a significant cost due to different transportation routes and non-optimized transportation routes. In order to avoid these costs, autonomous vehicles are used in supply networks. There are several challenges associated with the use of smart autonomous vehicles in the real world. To eliminate these difficulties, it is necessary to use conceptual and simulation modeling at the beginning. Thus, supply chain operations can be discovered where optimal performance can be achieved (Tsolakis, Bechtsis and Srai 2018). Apart from material transfer and counting, robotic systems are also widely used in production. It can be said that robotic systems, which are used in many different sectors, have different difficulties in practice. The food industry, which is closely related to human health, is also an important area that needs attention when integrating robotic systems. Duong et al. (2020) examined the analysis of the integration of robotic and autonomous systems in the food industry under the headings of food quality, food safety, food waste, supply chain efficiency, and supply chain analysis. The same study examined the adoption of robotic systems in food supply chains by considering the role of robotics and autonomous systems, data availability, cybersecurity, skill capacity, and financial costs. As a result of the examinations, it has been concluded that robotic and autonomous systems can keep food at a level that can be taken by protecting the food supply chain from the risks of labor shortages caused by possible disruptions and uncertain political policies.

Similar to planning and design problems, logistics services involve the planning capabilities of artificial intelligence techniques. The vehicle routing problem is one of the known problems in this area and is solved with different heuristic methods, such as invasive weed optimization (Yıldırım and Kuvvetli 2021). Resource planning of remanufacturing systems can be quite difficult in terms of problem size and uncertainties. It is not an effective method to try many solutions found through studies in a complex structure. Therefore, to establish the relationship between rough set theory, which is a machine learning method, and the feasibility of the plan, Song, Guan, Zhao, and Ho (2005) applied an iterative reinforcement process to ensure confidence. In this study, a basis was established to develop a simulation-based optimization method.

Finally, some software systems, such as enterprise resource planning systems and electronic data interchange systems, allow the potential for supply chain information-sharing structures. These structures can be extended with agent-based systems or robotic process automation systems with different studies.

19.3 SUSTAINABLE AI, ROBOTICS, AND AUTONOMOUS SYSTEMS

Sustainable supply chains are one of the issues that gain importance with the integration of classical supply chains with reverse logistics applications and evaluation in different sustainable dimensions. Reverse logistics deals with the management of returned products, called end-of-life products, that have completed their lifecycle and includes some recovery operations to transform them into items that can be valued with services. In this way, the economic, environmental, and social benefits of sustainability can be achieved. The reverse logistic operations can be summarized as follows:

- Collection
- Repair
- Refurbishing
- Remanufacturing
- Cannibalization
- Recycling
- Disposal

Different artificial intelligence techniques can be associated with reverse logistics operations. For example, it is of great importance that the returned products are classified and priced according to their quality during the collection process. In this context, a pricing study can be evaluated by combining methods, such as fuzzy logic and artificial neural networks, considering the status of returned products (Kuvvetli 2017).

When a general evaluation is made, the planning and management of returns is more difficult than new products. This is due to the high level of uncertainty in returning products. For example, the fact that the collected parts are transformed at different rates in order to perform remanufacturing processes causes remanufacturing processes to be made according to incoming products. Therefore, approaches such as machine learning appear as usable methods (Song, Guan, Zhao and Ho 2005). In addition to reverse logistics applications, passenger transportation in cities is also becoming smart. Connected and automatic vehicles used in smart transportation systems provide passengers with safer and more enjoyable routes. In addition, environmentally autonomous vehicles contribute to sustainable development with reasonable fuel consumption and lower carbon dioxide emissions (Chehri and Mouftah 2019). By providing smart transportation, a smart city transformation is envisaged by using many different artificial intelligence technologies in terms of social, environmental, and economic sustainability. For this, Yigitcanlar, Mehmood, and Corchado (2021) propose a framework that they define as green artificial intelligence in their study. The proposed framework supports the ability to make efficient, sustainable, and fair decisions (Yigitcanlar, Mehmood and Corchado 2021).

There are different opinions among scientists about the use of artificial intelligence technologies. While some scientists argue that technology should be used at the highest levels, some other scientists argue that artificial intelligence carries existential risks for humanity due to its non-transparent decision-making process (Khamis, Li, Prestes and Haidegger 2019). Intelligent systems may deteriorate to a large extent due to the deradicalization of the environment by natural or human-induced effects. Intelligent systems based on process technology are not considered sustainable because high energy consumption is ignored or secondary. Therefore, these intelligent systems need to be reformulated with neuromorphic hardware systems combined with model-based computing principles (Kozma 2021). Supporting rapidly developing artificial intelligence technologies with regulatory understanding and oversight will prevent gaps in transparency, security, and ethical standards. New technologies have very critical effects on the environment as well as the way of life in society. Therefore, in order to achieve sustainable development, the potential of artificial intelligence should be used correctly. This situation requires the establishment of adequate policy and legislative frameworks for artificial intelligence technologies (Vinuesa et al. 2020).

There are many pieces of research based on artificial intelligence methods related to climate change and its environmental effects, which have been on the main agenda of the whole world in recent years. In general, two driving forces cause the research of artificial intelligence, which has gained importance in sectors that are of fundamental importance for sustainability, such as agriculture, forestry, and the extraction of marine resources. The first is to pave the way for new approaches to uncertainty, efficiency, productivity, and decision-making through various AI methods, IoT systems, satellite technologies, increasing computing capacity, and new developments in the robotics industries; and the second is to help society better manage limited natural resources with accelerating climate change and their demands for understanding environmental impacts (Galaz et al. 2021). In the study of Galaz et al. (2021), it was stated that ensuring sustainability will require hybrid and highly adaptable methods due to the risks arising as a result of human, nature, and machine interaction.

Some development plans are determined to ensure sustainability. The methods that can be applied to these development plans and the expected effects accordingly are given in Table 19.1 (Khamis, Li, Prestes and Haidegger 2019).

TABLE 19.1
Technological Approaches for Sustainable Development Plan

Sustainable Development Plan	Methods	Expected Effects
Having the absence of poverty (access to basic services)	Artificial intelligence Big data analytics	Mapping poverty Increasing revenues Creating new business models
Providing food security and enhanced nutrition	Data analytics techniques Artificial intelligence Satellite image analytics	Assessing soil/plant/animal health Predicting crop/animal diseases Planning pesticide applications and livestock management
Ensuring healthy lives Promoting well-being for all people	Data analytics Artificial intelligence	Determining the correct medication, dose, and delivery time for the patient
Providing an inclusive, equitable, and quality education Promoting lifelong learning opportunities for all	Artificial intelligence Machine learning	Having online courses and tools Having challenge-based learning Having global classrooms and intelligent information systems
Ensuring gender equality Seeking to empower all women and girls	Descriptive analytics tools Tactile and immersive reality	Having the ability to monitor gender bias Ensuring balanced recruitment Having skill development Providing vocational training for women

Sustainable Development Plan	Methods	Expected Effects
Having access to drinking water at the local level in developing countries Managing freshwater ecosystems and sanitation facilities	Artificial intelligence	Mapping resources Optimizing infrastructure creation Making capacity calculations Having wastewater filtration and management
Protecting the oceans, seas, and marine resources	Submarine robots Smart stationery Mobile sensors Pattern recognition	Exploring the sea and ocean Monitoring marine resources Monitoring illegal fishing activities Monitoring marine life migration
Protecting the long-term use of terrestrial ecosystems	Artificial intelligence Predictive analytics	Monitoring species health Monitoring land use changes Monitoring food safety and nutrition Monitoring noise levels Monitoring weather-related stresses Monitoring disease vectors and epidemics
Having law enforcement ensure the safety of citizens Managing natural/man-made disasters	Artificial intelligence Smart governance	Ensuring efficiency, transparency, and participation Having personalized and responsive smart services Having smart technologies for internal security, surveillance, reconnaissance, and mine clearance

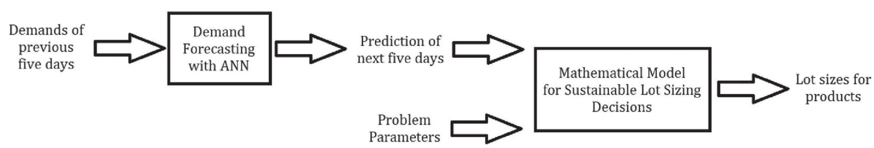

FIGURE 19.2 The methodology of the case study.

19.4 CASE STUDY

As a case study problem, the smart sustainable capacitated lot-sizing problem is addressed. In this context, the problem examined has been evaluated in different products as classical, smart, and sustainable systems. While the first problem is a variant of the capacitated lot-sizing problem that frequently occurs in supply chains, in the second problem, how sustainability criteria can be added to the problem was evaluated. In the third part, one of the artificial intelligence methods has been added to the suggested problems. Figure 19.2 shows the planned flow for the case study section.

19.4.1 Demand Forecasting Approach

Artificial neural networks are quite useful tools for forecasting, as can be found in different studies, such as that of Kuvvetli, Dağsuyu, and Oturakci (2015). In the

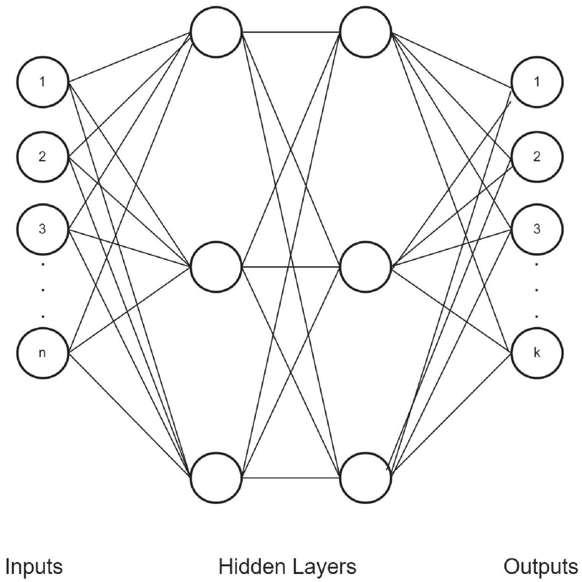

FIGURE 19.3 Architecture of the ANN model.

artificial neural network method for the demand forecasting model, the actual demands of previous n periods are used as inputs, and the next k periods are forecasted. The artificial neural network model of the study is given in Figure 19.3.

Artificial neural network models need to be trained in order to find the best weight values between the connections of layers and neurons. Therefore, it is important to find the most suitable training algorithm for the dataset. The learning algorithm not only decreases the performance of the prediction but also increases the generalization capability of the model. In the case model, the Levenberg-Marquardt learning algorithm (Hagan and Menhaj 1999) is adapted to the model.

In the application of the learning algorithm to the ANN, the dataset is divided into three subsets, which are training, validation, and test sets. The training dataset is used for obtaining the best model weights during the application of the learning algorithm to the ANN. The validation dataset is used for overfitting the model, and the test dataset is used for testing the performance of the model.

19.4.2 Capacitated Lot-Sizing Model

Capacitated lot-sizing model decides the production and inventory levels $\left(y_{pt}\right)$ of different products during the planning horizon, considering capacity and setup conditions. In this model, there are P products and T periods, which are indexed as p and t, which are products and periods. The h_p and s_p denotes the inventory holding costs and setup costs for a product. Demands of product p at period t are depicted as d_{pt}, and I_p is the beginning inventory level of product p. b_p and g_p denote the processing and setup times for product p, while the capacity level of period t is denoted by q_t

. The decision variables are production amounts $\left(x_{pt}\right)$, inventory levels $\left(y_{pt}\right)$, and binary setup conditions $\left(v_{pt}\right)$.

The capacitated lot-sizing model is formulated in the literature as follows (Quadt and Kuhn 2008):

Model A

$$\min z_1 = \sum_{t=1}^{T}\sum_{p=1}^{P} h_p * y_{pt} + \sum_{t=1}^{T}\sum_{p=1}^{P} s_p * v_{pt} \tag{19.1}$$

$$y_{pt-1} + x_{pt} - d_{pt} = y_{pt} \qquad p \in \{1,\ldots,P\},\ t \in \{1,\ldots,T\} \tag{19.2}$$

$$\sum_{p=1}^{P} \left(b_p * x_{pt}\right) + \left(g_p * v_{pt}\right) \leq q_t \qquad t \in \{1,\ldots,T\} \tag{19.3}$$

$$x_{pt} \leq M * v_{pt} \qquad p \in \{1,\ldots,P\},\ t \in \{1,\ldots,T\} \tag{19.4}$$

$$I_p = y_{p0} \qquad p \in \{1,\ldots,P\},\ t \in \{1,\ldots,T\} \tag{19.5}$$

The objective function (equation 19.1) aims to minimize the total costs that are related with inventory holding and setup costs. The constraint in equation 19.2 ensures the inventory balance between periods. The constraint in equation 19.3 forces to produce products less than the capacity. The constraint in equation 19.4 ensures producing products if the setup is applied. The constraint in equation 19.5 is the beginning inventory levels. Finally, the x_{pt} and y_{pt} are the positive variables, and v_{pt} is the binary variable.

19.4.3 Sustainable Capacitated Lot-Sizing Model

The capacitated lot-sizing model only considers the economic dimensions. The model can be extended to a sustainable model considering environmental conditions. The carbon emissions from the production amount $\left(c_p\right)$ and the carbon emission amounts of the scraps due to the setups $\left(r_p\right)$ are added to the model given in Chapter 19.4.2.

Model B

$$\min z_2 = \sum_{t=1}^{T}\sum_{p=1}^{P} c_p * x_{pt} + \sum_{t=1}^{T}\sum_{p=1}^{P} r_p * v_{pt} \tag{19.6}$$

A new objective function (z_2) is introduced to the model for minimizing the total environmental effects, as given in equation 19.6. Constraints in equations 19.2–19.5 should also be included in the second model.

A goal programming approach can be proposed in order to consider both of the objectives, z_1 and z_2. The newly added equations for the goal programming model are given as follows:

Model C

$$\min \mathrm{z} = \frac{o_1^+}{z_1^*} + \frac{o_2^+}{z_2^*} \tag{19.7}$$

$$\sum_{t=1}^{T}\sum_{p=1}^{P} h_p * y_{pt} + \sum_{t=1}^{T}\sum_{p=1}^{P} s_p * v_{pt} - z_1^* = o_1^+ - o_1^- \tag{19.8}$$

$$\sum_{t=1}^{T}\sum_{p=1}^{P} c_p * x_{pt} + \sum_{t=1}^{T}\sum_{p=1}^{P} r_p * v_{pt} - z_2^* = o_2^+ - o_2^- \tag{19.9}$$

$$o_1^+ * o_1^- = 0 \tag{19.10}$$

$$o_2^+ * o_2^- = 0 \tag{19.11}$$

The objective function (equation 19.7) aims to minimize the deviation from the optimal values of the objectives z_1 and z_2. The constraints in equations 19.7 and 19.8 are the equations for calculating the deviations from optimal values. Finally, the constraints in equations 19.10 and 19.11 are the valid ranges for the variables.

19.4.4 Results

In this case model, 90 days of demand values for four products are used as inputs of the forecasting model. The *n* and k values are selected as five and five. The number of hidden layers and the number of hidden neurons are evaluated and set as 1 and 14. The dataset is divided randomly into 3 datasets, which are 65%, 15%, and 20%, respectively. The performance of the ANN is depicted in Figure 19.4. According to the results, the $R2$ values for the training, validation, test, and overall datasets are calculated as 0.948, 0.934, 0.958, and 0.949, respectively.

A scatter diagram with four subplots, which are the training, validation, test, and overall datasets, with $R2$ values of 0.948, 0.934, 0.958, and 0.949, respectively. Most of the data points are assigned to the training set, and the most fitted one is also the training set.

The predicted demand values are supplied to models A, B, and C in order to find the optimal lot sizes for each period. The GAMS software is applied to solve all mathematical models. According to the results, model A is solved with a total cost of 5,653.42, model B is solved with total emissions of 96,233.71, and model C is solved with a total percent of deviations of 0.0034. The deviation from the second objective value equals 329.

The production quantity for each product and periods for all models are given in Table 19.2.

Basically, the cost-oriented model and environment-oriented model differ from decisions. The environmental-concerned model focuses on more productions than

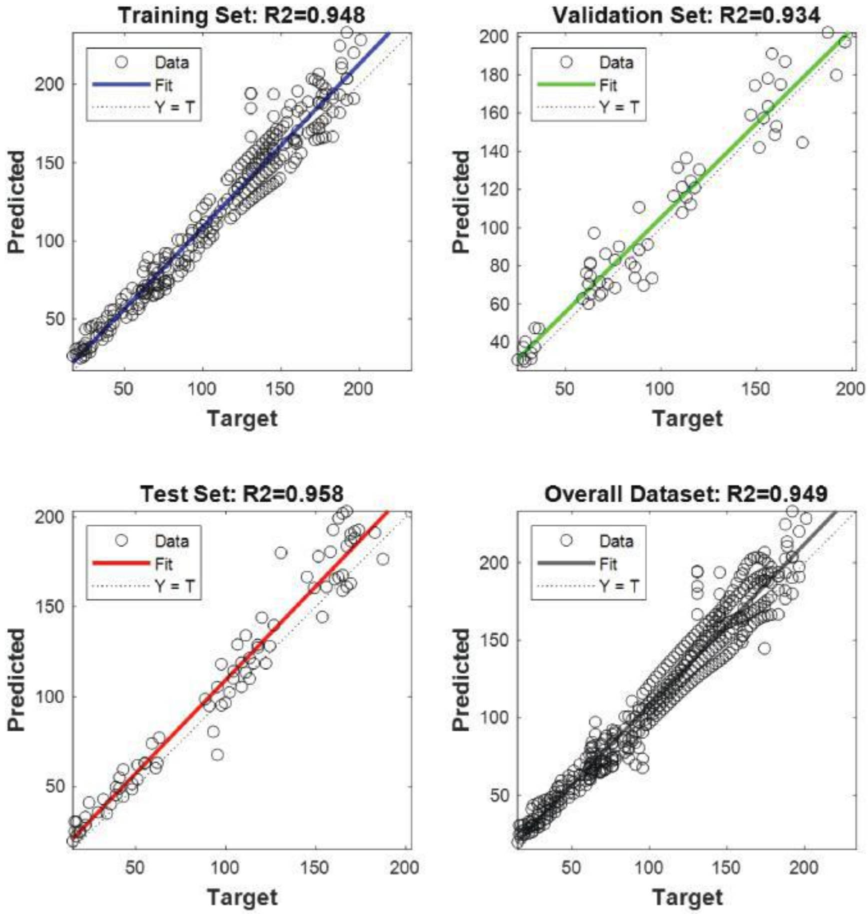

FIGURE 19.4 Results of the ANN model.

the cost model due to the tendency of inventory. All the models have the same total production quantities, which means the models focus on minimum production quantities.

Table 19.3 shows the inventory levels for all models.

Conversely, of the productions, model B tends to hold more inventories than the other models. According to this case study, a smart sustainable capacitated lot-sizing model is introduced. The environment-oriented model results differ from the cost-oriented one, which means that sustainability affects the results.

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TABLE 19.2
The Production Amount of the Models

Model A			Model B			Model C		
Product	**Period**	**Production Quantity**	**Product**	**Period**	**Production Quantity**	**Product**	**Period**	**Production Quantity**
1	2	98	1	2	642	1	2	98
1	3	153	2	3	498	1	3	153
1	4	204	3	2	215	1	4	204
1	5	188	3	4	434	1	5	188
2	3	156	4	2	349	2	3	156
2	4	145	4	3	358	2	4	145
2	5	197				2	5	197
3	2	43				3	2	43
3	3	172				3	3	172
3	4	220				3	4	220
3	5	213				3	5	213
4	2	78				4	2	78
4	3	191				4	3	191
4	4	210				4	4	210
4	5	228				4	5	228
Total		**2,495**	**Total**		**2,495**	**Total**		**2,495**

TABLE 19.3
The Inventory Levels of the Models

Model A			Model B			Model C		
Product	**Period**	**Inventory Level**	**Product**	**Period**	**Inventory Level**	**Product**	**Period**	**Inventory Level**
1	1	127	1	1	127	1	1	127
2	1	173	1	2	544	2	1	173
2	2	24	1	3	392	2	2	24
3	1	190	1	4	188	3	1	190
4	1	129	2	1	173	4	1	129
			2	2	24			
			2	3	342			
			2	4	197			
			3	1	190			
			3	2	172			
			3	4	213			
			4	1	129			
			4	2	272			
			4	3	439			
			4	4	228			
Total		**643**	**Total**		**3,631**	**Total**		**643**

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20 Human Resource Management

Işık Çiçek

CONTENTS

20.1 INTRODUCTION

Human resource management can be described as all the purposes and activities that ensure the efficient management of human resources in any organization and environment in a way that is useful to the organization, individual, and the environment related to the law (Sadullah, 2010). The responsibility for all activities related to people in companies belongs to the human resource management function. Human resource management is a set of functions and activities that allows to effectively manage people in a way that benefits the organization, the individual, and the environment, in compliance with ethical rules and laws (Benligiray, 2016: 38). Human resource management is a strategic and consistent approach to managing people, the

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organization's most valuable asset (Armstrong, 2006). From this definition, HR management is a feature designed to maximize the performance of employees in an organization to achieve their employer's strategic goals (Johnson, 2009; Benligiray, 2020)

The management of human resources generally consists of seven fundamental functions: planning, hiring of personnel (procurement, selection, and recruitment), evaluation, remuneration, training-development, protection, and industrial relations. The main tasks of the human resources department as a functional unit in the company are the selection and recruitment of personnel (recruitment), job analysis, human resource planning, training and development, performance evaluation, career management, job evaluation, pay, occupational health and safety, and industrial relations (Uyargil et al., 2000; Benligiray, 2020)

Job analysis: Job analysis is the collection of detailed information about jobs and working conditions. It is the process of collecting data and information about jobs through observation, interviews, questionnaires, and similar methods. Information obtained as a result of job analysis is used in many decisions regarding human resource management. After job analysis, job descriptions are created. The job description specifies the duties, responsibilities, working conditions, and ways of doing the job of the person who will work in that job. Job requirements are also prepared based on job descriptions and specify the minimum qualifications that should be found in the person who will work in that job (Uyargil et al., 2000). Personnel selection and placement: This includes activities to find, select, and recruit people with the appropriate qualifications (suitable for the job) required by the company. Human resource planning is a function of HRM, which aims to accurately identify human resource (workforce) needs. It is decided which places in the organization need to be filled and how this will be done. With HRM, the workforce (demand) needed by the organization to carry out the planned work and achieve its goals is determined in terms of number and quality and compared with the internal job offer. Training and development: It is a change process in which employees acquire the necessary knowledge, skills, and attitudes, and develop their own behavior in the desired direction. The training needs analysis consists of the training planning, training implementation, and training needs analysis phases. Career management is the process that lets workers know and develop their skills and interests more accurately and use them correctly in the organization or in other activities after leaving the organization (Uyargil et al., 2000). Performance evaluation and performance management studies determine the actual success of employees in a given period and their development potential for the future, and the performance improvement process (Uyargil et al., 2000). Job evaluation is a systematic method aimed at revealing the "process of systematically determining the relative values of jobs" or "differences in value between workplace jobs in an organization" (Uyargil et al., 2000). Wage Management: The process involves establishing, implementing, and controlling a wage management system (WMS) that meets the corporate goals and strategies. In this process, first, establish a unified management system by establishing a basic salary policy and structure, designing the salary system, and determining the responsibilities of the salary; second, study the implementation and control of the established wage management system (Uyargil et al., 2000; Benligiray, 2020). Occupational health and safety refers to the organizational practice carried out by protecting employees from workplace accidents and occupational disease patients in the work environment (Uyargil et al., 2000).

Human resource management and practice cannot be unaffected by the changes. This structural change causes people to change by influencing their value judgments, expectations, and beliefs. With the popularization of education in quantity and quality, the level of information usually enhances. Different cultures merge and influence each other. Satisfied with the past, without questioning authority. A new generation of employees who are more knowledgeable, are not content with less, are inquisitive when essential, have distinct intentions and requirements, and find it significant to allot time to themselves have come to take over the employees who are content with few in the past and approve power without question. Especially as generation Z starts to become employees in the sector, the mentioned characteristics of the workday will increase even more.

The organization is an open system. It is established through the combination of various resources to achieve specific goals, and through the interaction with the environment, both affect the environment and are affected by it. Open systems are also created by smaller subsystems that interact with each other and with the environment. From this perspective, human resource management is a subsystem of the organization. Human resource management will maintain constant interaction with its organization and environment. Human resource management will be affected by environmental factors and will also have an impact on it (Koçel, 2016; Uyargil et al., 2000)

20.2 ERA OF HUMAN RESOURCE MANAGEMENT

Considering the historical process, human resource management can be called pre-personnel management period, personnel management, human resource management, strategic human resource management, integrated human resource management, and talent management. Before the period of personnel management, the effects of the Industrial Revolution that began in England in the second half of the 18th century are seen. With the factorization, which is a result of the Industrial Revolution, a new business relationship and a working status based on this relationship has been born. Factories turned to excessive profit and capital accumulation in order to exist in the markets. This trend made it inevitable to reduce costs. The effects of the scientific management approach put forward by Frederick W. Taylor (1856–1915) also influenced the approach to the management of the workforce in this period. It was suggested that the workforce should specialize in the job, and the planning task was taken from the worker and became the duties of the managers. Considering that incentive wage systems will play a major role in increasing efficiency, they proposed some incentive wage systems (Benligiray, 2020). The big industry companies fired some employees and hired new ones to keep the sustainability of the work system at the same level of productivity because they operationalize the work by simple process steps. According to the Taylorist philosophy, it is assumed that employers want to take advantage of the employees and the employees are motivated by the money (Benligiray, 2020). Changes and developments in the economic, technological, social, cultural, and political environment cause the philosophical approach to emerge under neo-classical management (human relations) in the 1930s. Elton Mayo (1880–1974) and Fritz J. Roethlisberger (1898–1974) demonstrated the importance of psychological conditions on the increment in productivity with the experiments named Hawthorne Researches in the years 1924 and 1932. This study leads to the idea of human relations that centralize the awareness of the need to increase productivity (Benligiray, 2020). After the 1960s, seeking new methods, such as utilizing personnel selection tests to increase the job satisfaction for employees, enlarged as a way to increase productivity (Decenzo et al., 2017: 50). Adding the course of Human Resource Management to the Master Program MBA in the USA Harvard Business School in 1981 is a cornerstone for the development of human resource management in the Western world. At the beginning of 1980, the political developments in the West gave rise to a human management philosophy focused on the relationship between organizations and employees. The human resource management model was adopted as a result of the individual performance depending on the individual and holistic values focused on the understanding of entrepreneurship culture. Organizations prefer outsourcing non-core activities, such as security, personnel transportation, catering, cleaning of the workplace, and unskilled monotonous work to external providers. Besides, employees have the opportunity for more flexible work and part-time jobs (Rotich, 2015).

According to the strategic human resource approach developed starting in the 1990s, it was necessary to play new roles, for the functions of human resources have expanded. Human resource managers participated in the process of developing corporate strategy and politics. Wright and McMahan (1992) explained that human resource management has looked to become integrated into the strategic management ground by means of the appearing discipline addressed as strategic human resource management (SHRM). The individual human resource management applications that shape the barrels counterpart each other in creating united synergistic impacts that are more considerable than that of each separate best application for the strategic HRM approach (Anlesinya and Susomrith, 2020). HR managers should know about all business functions to develop a strategy (Dessler, 2008: 79). The globalization tendency started in the 1980s, the movement of products beyond the national borders, the increasing number of multinational companies and international business operations depending on global free trade efforts had an influence on human resource management. The competitive value of effective HR management in multinational and international companies is greater than in the national context. Most of the multinational companies in the 1950s and 1960s are American-origin. Toward the 2000s, the strategic management approach did not meet the needs of the organizations and employees. Time-based manpower, personal development of the employees, and competency-based wages are the initial forms of integrated human resource management applications in companies (Günbey, 2016). Starting from 2000, the idea that all human resource functions (job analysis, recruitment, training and development, salary and compensation, performance, career, etc.) are internally integrated to develop departmental strategies contributing to organizational mission and vision has been adopted. Besides, the importance of an integrated form of human resource as a functional unit with other business functions, such as production, marketing, finance, and accounting, is recognized (Mwangi and Kiambati, 2015).

Due to the rapid and unexpected changes in organizational environments, increased foreign competition, and technological complexity, the integration of human resource functions with other business functions became a necessity. A systems perspective is embodied in the human resource approach to management. A human resource information system is a significant tool of an integrated human resource management system (Pernick, 1981). In this period, the effects of technological breakthroughs directed the companies. The experiences of the Third and Fourth Industry Revolutions by the organizations caused the organizations to utilize some technological tools to gain a competitive advantage. E-HR, e-training, e-recruitment, telecommuting, virtual teams, and social media are some examples of reformed HR applications (Rotich, 2015). Holbeche (2001) pointed out that by means of the integration of HRM with the institutional strategy, rather than human resource strategy being an isolated variety of preferences, workers will be administered more productively, and corporate performance will enhance (Othman, 2009). The increasing importance of the knowledge economy influences the post-modern model of business administration. In this respect, the profile of the new human resource brings along systematic management approach (Salepçioğlu, 2015). Institutionalized businesses with substantial physical capital also suffered losses during the global economic crisis in 2009. In this period, it came to the fore to have talented employees and to direct them in line with the goals of the organization. Instead of hiring only certain qualified candidates and developing them within linear career models, the understanding of hiring high-quality candidates and benefiting from them in a different way gained importance. The concept of talent management was announced with the research of "War for Talent" conducted by McKinsey & Company at the beginning of the 2000s. It has become important to create a corporate culture and organizational structure that will attract outstanding talents.

20.3 HR POLICIES AND IMPLICATIONS IN SUSTAINABLE OPERATIONS

20.3.1 Sustainability of Human Resource Management

Sustainability is stated as a process that links economic and social perspectives while considering ecological equilibrium and environmental conservation. It was announced in the 1960s as a reply to the quickly expanding population and regarding hazards, like disproportionate utilization of natural resources, ecological pollution, starvation, or destruction of the Earth's surface (Von Weizsacker and Wijkman, 2018). Elkington (1997) stated the three terms (labeled as the triple bottom line) to which sustainable development is related: environmental integrity (planet), social equity (people), and economic prosperity (profit). Environmental integrity addresses the narrow reproducing capacity of an ecosystem; social equity covers the right of all stakeholders to reach resources and establish translucent links that stress the sharing of value creation; and economic wealth refers to the excellence of life succeeded by means of the generative scope of a system.

Sustainable development could be expressed regarding some levels of analysis, which are national, regional, and organizational. Organizational sustainability was announced by Dyllick and Hockerts (2002) as "meeting the requirements of a firm's stakeholders (such as shareholders, employees, clients, communities, etc.), without compromising its ability to satisfy the needs of future stakeholders as well." Sustainability is an organizational strategy and is closely associated with competitiveness (Samant and Sangle, 2016: 106). The organizational performance will now be more dependent on employees, depending on the achievement of sustainability-themed goals. This understanding points to a new perspective on human resource management (Anlesinya and Susomrith, 2020). This understanding can be named sustainable human resource management by defining the new roles of human resource management within the framework of corporate sustainability (Ehnert, 2009; Ehnert et al., 2016; Kramar, 2014). Sustainable human resource management could be described as follows:

> the adjustment of HRM strategies and applications that enable the success of financial, social, and ecological goals, with an effect of inside and outside of the corporation and over a long-term time horizon while administering for unforeseen secondary impacts and adverse response.
>
> (Ehnert et al., 2016: 90; Anlesinya and Susomrith, 2020)

Sustainable HRM types are green HRM, socially responsible HRM, and triple bottom line (TBL) HRM (Stahl et al., 2019). Aust et al. (2019) concur with these three and added a fourth, "Common Good HRM," which highlights the development of answers for great sustainability challenges. The common good HRM goes in any of the previous three, depending on whether the great challenges relate to social, ecological, or the TBL aspects (Anlesinya and Susomrith, 2020). Sustainable HRM terms are labeled as green HRM (Ren et al., 2018; Saeed et al., 2019) when environmental aims rise to prominence and as socially responsible HRM (López-Fernández et al., 2018) if HRM is matched with the idea of corporate social responsibility (CSR). CSR is engaged with the internal and external stakeholders of any organization (Carroll, 1998). Employees are the internal stakeholders and participate in decisions that affect their functioning in the firm. Triple bottom line HRM is interested in accomplishing environmental, social, and financial aims synchronously. It is, therefore, coherent with the common meaning of sustainable HRM and can also be described as general sustainable HRM. Common good HRM is the employee- and environment-based aspect that stresses solving grand global issues. It is displayed in modest working circumstances and—as with socially responsible HRM—workers' participation (Aust et al., 2019; Dyllick and Muff, 2016). HRM utilizes numerous variety of theories, such as stakeholder theory (Ferrary, 2009). The relationship between HRM and organizational performance in terms of sustainable development has been investigated in many studies (e.g., Au and Ahmed, 2014; Muduli et al., 2020; Saifulina and Carballo-Penela, 2017; Singh et al., 2013; Timur and Timur, 2016). Kramar (2014) pointed out that the studies about sustainable HRM become distinct regarding the priority given to specific internal and external outcomes (p. 7). Some literature reviews linking HRM with sustainable development have already been published. Macke and Genari (2019) connected sustainable HRM with sustainable leadership in their systematic review. Renwick et al. (2013) concentrated on green HRM in their systematic review. Kumar et al. (2020) researched sustainable and green HRM. Anlesinya and Susomrith (2020) analyzed the general concept embraced by studies aimed at sustainable, green, and socially responsible HRM. Zaugg et al. (2001) correlated sustainable HRM with HRM functions, like the long-term socially and economically efficient recruitment, development, and retainment of workers. Shen and Benson (2016), in describing socially responsible HRM, emphasized its fundamental functions: providing employees with admirable pay and working conditions, recruiting and retaining socially responsible employees, providing CSR training, and considering workers' social contributions in promotion and performance appraisal (Piwowar-Sulej, 2020)

20.3.1.1 Drivers and Barriers to Sustainable HRM Adoption

Internal elements, like the managers' and owners' ethical leadership, company scale, anticipated advantages, and external elements, like government legislation and policy, societal values, negative externality associated with customer demands, and regulatory pressure, are remarkable routers of sustainable HRM adoption and implementation (Au and Ahmed, 2014; Mak et al., 2014; Fernandez et al., 2017). Key challenges to sustainable HRM in organizations include the lack of a formal system, inadequate commitment to integrating HRM with sustainability applications, deficient commitment to green and sustainability training, failure to consolidate sustainable HRM in recruitment and selection criteria and performance appraisal criteria, and compensation and reward systems in the design of sustainable HRM practices (Baum, 2018; Stalcup et al., 2014; Anlesinya and Susomrith, 2020).

20.3.1.2 The Effects of Human Resource Management on Individual Outcomes and Sustainable Organizations

Studies investigating micro-level results aim to determine the impacts of sustainable HRM practices on employee behaviors and attitudes, like employee commitment to the employer brand (App and Büttgen, 2016), employees' organizational commitment (Kim et al., 2019; Shen and Zhu, 2011), employee trust in employer brand (App and Büttgen, 2016), employee trust in management (Celma et al., 2018), employee environmental performance, individual task performance and organizational citizenship behavior for the environment (Paillé et al., 2014; Dumont et al., 2017; Shen and Benson, 2016), employee green behavior (Subramanian et al., 2016; Kim et al., 2019), individual green performance potential, intention to quit (Shen et al., 2016; Vihari and Rao, 2018), and employee voice behavior (Vihari and Rao, 2018).

Freitas et al. (2012) pointed out that the human resource department plays a critical role by means of training, employee development, recruitment, and selection for maintaining sustainability and achievement of sustainable performance. A communication system that acts as a bridge between human resource management and sustainable values and practices is designed (Anlesinya and Susomrith, 2020)

Findings about the studies investigating the firm-level outcomes of sustainable HRM practices indicate that organizations can leverage sustainable HRM applications to succeed in competitive benefit and to enhance their financial performance, environmental performance, human capital value, and organizational attractiveness (Aragão and Jabbour, 2017; Masri and Jaaron, 2017; Teixeira et al., 2016; Wagner, 2013). Ogbeibu et al. (2020) displayed how green HRM enhances green team creativity (Anlesinya and Susomrith, 2020)

20.3.2 HRM and Supply Chain Management

Today's increasingly complex business environments—which are shaped by shorter product lifecycles, product proliferation, ongoing outsourcing, and the globalization of the supply base and markets—magnify the challenges of human resource management in supply chain settings. HRM practices can be used to stimulate supply chain members to enhance valuable inter-company relationships and to constitute knowledge-sharing routines. The result is a better coordinated, streamlined supply chain, and ultimately, a new competitive advantage (Rao and Raju, 2015). There are three guiding fundamentals: value, alignment, and sustainability. Adopt value as a leading fundamental to convey upper managerial performance with meaningful business effect. Explore tools to align principal processes bringing about the success of operational merit. Know frameworks to administer risks and opportunities for sustainable supply chain management on a global scale with the help of human capital (Rao and Raju, 2015)

20.3.2.1 The Role of Human Resources in Supply Chain

There are powerful associations between supply chain management and human resource (HR) management, and thus, it is hard to know accurate boundaries. These boundaries are moving to include an integration of supply chain and human resource operations. It is extremely hard to adjust coordinated human resource strategies that span functional units; many logistics professionals lack knowledge and experience in that specialized field. If logistics specials are to be persistently effective, they should have an integrative vision, human resource ability (skill for utilizing human resource politics because focused human resources must become fundamental for logistics specialists' portfolio), and the ability to manage customer relationships.

The core proponents for integrating human resource management with supply chains are technology, skill and education, demand of a supply chain talent, training and career development (Jurčević et al., 2019).

Practicing intra-organization HR planning and recruitment operations with supply chain partner companies yields these inter-organization merits: Standard recruitment process among the supply chain companies, sharing of the applicant-candidate pool, and estimation of labor demand and supply for the whole supply chain. The benefits of HR training practices are 1) diagnosis of training needs and objectives for supply chain stances, and 2) joint training and cross-organizational training of employees across the supply chain. One remarkable benefit of human resource performance appraisal systems in the supply chain is learning from supply-chain partner feedback on individual and group performance (Rao and Raju, 2015)

Human resources have played a solo role in aiding and quickening inter-organizational relationships (Jick, 1990). Because of outsourcing and the formation of inter-organizational partnerships, employees are employed by other organizations, trained and developed by client organizations, and are under the guidance of supervisors from partner institutions (Rubery et al., 2010). Multinational companies aid in the development of the human and social capital that increases supplier firms' competencies and provide them with more concentration on becoming more customer-oriented and flexible work applications (Wilkinson et al., 2005). Mutual training programs between suppliers and customers can enhance commitment and long-term consensus (Noel et al., 1990). Administrating human resources across organizational boundaries can lead to protecting the corporate's reputation and brand image with supplies that provide employees with working conditions for the sake of perceiving as decent or acceptable by customers. HRM can help to build a sustainable competitive advantage when competitors adopt similar supply chain management best practices (Gowen and Tallon, 2003). A sustainable competitive superiority displays four dimensions: value added, rareness, imitation cost barrier, and organizational structure for implementation (Barney and Wright, 1997). All four dimensions are stimulated by human resource management elements, like employee training programs (Canadian Logistics Skills Committee, 2005; Yu, 2017)

20.3.2.2 Supply Chain Partnership and HRM Transfer in a Dynamic Market

Integrating human resources with the supply chain is questionable in multi-employer networks where the human resource strategies differ among participating organizations and when they are executed by supervisors from different institutions who can be selected, trained, evaluated, and rewarded in distinct approaches (Marchington et al., 2011). Succeeding consistency in human resource practices and the related perceptions of fair procedure for the employees can be dubious in multi-employer networks where a variety of different human resource practices is utilized (Marchington et al., 2011).

Supply chain HRM knowledge transfer and integration turn more complex in a dynamic and uncertain environment. Demand uncertainty, supply uncertainty, and technological uncertainty could be the sources of environmental uncertainty (Davis, 1993, cited in Fynes et al., 2004: 179). To succeed with increased performance, the human resource management of one firm should adapt to its external macro business environment and its specific supply chain circumstances and align to its whole business strategies (Yu, 2017)

20.3.3 Needs and Shortage of the Workforce

In the last terms, the requirements for qualified manpower have grown substantially. This is the consequence of the expansion of economic actions, the geographical dispersion of manufacturing and consumption, the increasing number of firms in the international and global context, and the progressively complex demands in supply chains. Two reasons can be stated for the poor availability of manpower with the necessary skills. The first is that there is no sufficient manpower on the labor market with the required skills and qualifications. Second is the scarcity of skills in the current supply chain workforce. Speedy technological advancement in supply chains requires new competencies that the existing employees do not have (McKinnon et al., 2017). Due to the features of the operational tasks in the supply chain, many positions have very stressful jobs with hard work and night shifts. The logistics sector must provide some components that are critical for retention, other than salary. Some of the factors are level working hours, working environment, and job satisfaction (McKinnon et al., 2017; Kilibarda et al., 2019). Employees within this job field are ready to search for new job opportunities within and outside of the supply chain.

20.3.4 The Relationship Between Green Human Resource Management and Green Supply Chain Management

Environmental performance can remain among the aimed ends, and therefore, human resource management is a principal field of examination to research environmental management systems (e.g., Renwick et al., 2012). Human resource management has taken into account a key element in developing environmental performance (e.g., Milliman and Clair, 1996; Wehrmeyer, 1996; Longoni et al., 2018).

Several human resource management practices that aim to improve environmental performance (i.e., the so-called green HRM bundle) have effects on greening the organization (Combs et al., 2006; Longoni et al., 2018). GHRM concepts to support the greening of the organization and the offering of a synergistic effect are shown in Table 20.1.

TABLE 20.1
Green Human Resource Management Concepts

GHRM Bundle	Practices	Definition
A bundle of consistent and coherent GHRM practices that is considered to have synergetic and superior effects on the company's environmental performance (Jackson et al., 2014; Renwick et al., 2012; Combs et al., 2006)	Green hiring	Adoption of environmental criteria (i.e., environmental competencies and/or personal orientation) in hiring and selection processes (e.g., Renwick et al., 2012; Jabbour and Santos, 2008)
	Green training and involvement	Development of green-related competencies, which in turn enhances organizational capacity and performance, and reinforces the importance of the organization's commitment to environmental initiatives (e.g., Daily et al., 2012; Teixeria et al., 2012) and employee involvement in green processes, thus providing employees the opportunity to contribute to the environmental development debate within the company (e.g., Liebowitz, 2010)
	Green performance management and compensation	Monitoring and incentivizing employees for environmental management (e.g., Berrone and Gomez-Mejia, 2009)

Green HRM bundle is a consistent array of organizational practices that have systemic impacts on environmental performance by (i) selecting ideal candidates associated with the environmental targets (Jabbour and Santos, 2008), (ii) providing workers with green competencies and institutional opportunities to become part of greening actions by means of green training and involvement (Teixeira et al., 2012), and (iii) improving the motivation to support the greening of the organization by means of compensation and incentives attributed to environmental consequences (Jabbour and Santos, 2008; Ramus and Steger, 2000; Longoni et al., 2018)

20.4 HR POLICIES AND IMPLICATIONS IN SMART OPERATIONS

20.4.1 Manpower Qualifications in the Digital World

20.4.1.1 Digital Economy, Digital Era, Digital Transformation

We are now in the phase of the Fourth Industrial Revolution. The First Industrial Revolution was described as mechanical production by means of the discovery of the steam engine, causing mobility. The Second Industrial Revolution began with scientific improvements; mass production expanded with the utilization of electricity, and at this time, radio and telephones changed communication (Morrar et al., 2017). The Third Industrial Revolution was associated with the digital revolution through the presentation of semiconductors, personal and industrial computing, and the Internet, directing social change in a global context. The Fourth Industrial Revolution is more compound, being characterized by multiple technologies that affect rapid integration (Philbeck and Davis, 2019). With the appearance of new technologies in the Fourth Industrial Revolution, the focus shifted to multifaceted affinity (e.g., machine to machine, machine to human, process to process) (Lasi et al., 2014; Kaymaz et al., 2019).

The digital economy addresses an economy that is grounded in digital computing technologies (Geetha and Bhanu, 2018). Digital transformation as a new paradigm provides organizations with a competitive advantage (Jakson, 2019). Digital technologies are altering the rules of the game for lots of sectors regarding where and how to contest and what business model to select. Considering the experience of digital transformation, three factors can be highlighted: cognition (i.e., how managers perceive the world, shape their decisions, and share this framing with related main stakeholders), routines (i.e., the casual patterns of workers' behavior), and organizational forms (i.e., the formal structures and responsibilities). Industry 4.0 offers a higher level of service orientation and developed customer services (Al Bastaki et al., 2020; Upadhyay and Khandelwal, 2019).

As digital technologies, like cloud and edge computing, machine learning, advanced artificial intelligence (AI), and the Internet of Things (IoT), unfold, mobile data analytics, augmented reality, intelligent factories, robotics, nanotechnology, 3D printing, and traditional industries, such as telecoms, media, entertainment, and financial services, are being rearranged, and new sectors are appearing. Actors occasionally develop new digital business models; they are more prone to utilizing digital technologies to expand their current activities in an evolutionary style (Foss and Saebi, 2018; Volberda et al., 2018; Warner and Wager, 2019).

Moreover, the COVID-19 pandemic has led companies to quicken their digital transformation attempts and has made it harder for firms that have fallen behind to intercept. Depending on the COVID-19 crisis, digitally executed routines for internal and external processes are being rolled out faster than in the past.

In Europe, it was predicted that the percentage of workers choosing home working raised from 5.4% to 9% between 2009 and 2019 (Milasi et al., 2020). The eruption of the COVID-19 pandemic in 2020 has been a stimulant for transforming working applications and quickening the adoption of remote working. The rate of employees affected by the lockdown was predicted at 81% of the global workforce (ILO, 2020). In this vein, the digital transformation process experienced in previous terms enables this compulsory condition easier for the organization. Organizations have continuously reached greater flexibility for employees, with improved accessibility to remote technologies, including the ability to work from home (Veile et al., 2020; Rauch et al., 2019). Industry 4.0 and the digital age have remarkably affected both information technology (IT) job characteristics and IT labor demand (Siddo et al., 2019).

The requirements for the labor force regarding the future need for skills and abilities can be summarized as follows (Bayme vbm, 2016: 44; Autor, 2015; AUTO 4.0, 2019):

1. Trend: Firms without Industry 4.0. No changes in direct production but in indirect production (e.g., workplaces for the future implementation of Industry 4.0).
2. Trend: Firms with a low Industry 4.0 level. Inactivity or a negligible increase in the highly qualified skilled workforce.
3. Trend: Firms with high Industry 4.0 level. Expanding by 20 to 30% in the higher qualification levels and meaningful reduction of the low-qualified labor force (semi-skilled and unskilled) (Georg Spöttl and Windelband, 2021).

20.4.1.2 Competencies in the Digital World

The labor force in different positions of industrial jobs is faced with diverse replacement regarding the development of Industry 4.0 (Sapper et al., 2021). Regarding the desired characteristics for new employees, Industry 4.0 will require intellectual and cognitive skills as well as multidisciplinary and team working skills (Schwab, 2016; Siltori et al., 2021).

In 2006, the European Parliament and the Council defined digital competence as one out of eight fundamental competencies for lifelong learning (Ferrari, 2012; Oberlander et al., 2020). It described "digital competence" as "the confident and critical use of Information Society Technology for work, leisure and communication" (Søby, 2013:135; Oberlander et al., 2020).

Depending on the digital talent objectives, key competencies are described in Table 20.2.

Other classifications for the most crucial digital competencies are as follows: "(1) evaluating data, information, and digital content; (2) browsing, searching, and filtering data, information, and digital content; (3) interacting through digital technologies; (4) managing data, information, and digital content; and (5) collaborating through digital technologies" (Vuorikari et al., 2016: 8).

The qualitative survey resulted in skills such as "Cognitive, Emotional and Behavioural skills" and their subskills. "Cognitive skills" was found as the most

TABLE 20.2
Digital Talent Objectives and Key Competencies

Digital Talent Objectives	Key Competencies
Continuous learning and innovation	Learning, adaptability, creativity and innovation, strategic thinking
Insightful analytics	Applying expertise and technology, critical thinking
Network performance	Collaboration, building relationships, influence, communication (oral and written)
Execution excellence	Decision-making, planning and organizing, delivering results, innovative

(*Source*: SHL, 2019)

TABLE 20.3
Skills Required to Develop Human Capital 4.0

Complex problem-solving (CPS)	**Cognitive skills**
Critical thinking (CT)	
Creativity (CR)	
Cognitive flexibility (CF)	
IT skills (ITS)	
Analytical skills (AS)	
Ability to interact with smart system (AIS)	
Legislative awareness (LA)	
Awareness of data protection (ADP)	
Emotional intelligence (EI)	**Emotional skills**
Judgment and attentive decision-making (JAM)	
Positive attitude (PA)	
Negotiation (NG)	
Human skills (HS)	
Ability to work in a team (AWT)	
Sustainable mindset and compliance (SMC)	
Social intelligence (SI)	
Time management (TM)	**Behavioral skills**
Adaptive thinking (AT)	
Service orientation (SO)	
People management (PM)	
Coordinating with others (CO)	
Ambiguity tolerance (ATO)	

important skill, followed by "Emotional skills" and "Behavioural skills" (Singh et al., 2021). They are shown in Table 20.3.

According to the McKinsey Global Institute (2018), there are five skills required in the era of automation and artificial intelligence, which include the following: physical and manual (general equipment operation and navigation, inspecting, and monitoring), basic cognitive (basic data input and processing; basic literacy, numeracy, and communication), higher cognitive (creativity, complex information processing, and interpretation), social and emotional (entrepreneurship and initiative-taking, leadership and managing others), and technological (advanced IT skills and programming, basic digital skills) (Santoso et al., 2021).

20.4.2 HRM Functions and Policies in Light of Smart Operations

When considering studies for HRM in 2016, the themes are developing people and teams, developing competencies (knowledge and skills), and reinforcing human capital (personal, collective, and organizational development). For 2017, "vocational education and training," "human machine interaction," "employees," and "e-learning" were the motor themes. In 2018, the "skill," "engineering education," and "human performance" clusters appear as motor themes (Kipper et al., 2021).

Dhanpat et al. (2020) carried out a study about the intersection between HRM and Industry 4.0. The themes that emerged depending on the results are shown in Table 20.4.

TABLE 20.4
Themes in the Intersection Between HRM and Industry 4.0

Theme	Description	Sub-Theme
Industry 4.0 in organizations	Industry 4.0 and its influences on organizations	Embracing new technologies New ways of work Automation HR agility
Industry 4.0 and HR strategy	Digital transformation and its effects on the HR strategy	Digitalization of work Delivery of work Reskilling
Developing 4.0 competencies	The avenues through which HR professionals can develop the competencies required to navigate Industry 4.0	Understanding the environment Development programs Networking
HR 4.0 competencies	The competencies required by HR professionals needed to navigate through Industry 4.0	Change agent Strategic partner Creative innovator People enablement
HR's role in Industry 4.0	The type of work the HR professionals will embark on through initiatives of Industry 4.0	HR delivery Strategic shift Reskilling needed Talent management
Challenges of Industry 4.0	The complexities that HR professionals foresee with regard to Industry 4.0.	Uncertainty Adapting to change
Industry 4.0 opportunities	Opportunities ushered in by Industry 4.0	Innovation and improved systems Enhanced talent management Delivery of HR work

As for green HRM, practices can be explained in light of their functions. According to Renwick et al. (2013), three components of GHRM practices can be described. They are increasing green skills (recruitment and selection, training and development, job descriptions), motivating green workers (performance management/appraisal, pay and reward system), and providing green opportunities (employee involvement and empowerment, supportive climate/culture, unions' role, organizational learning) (e.g., Moraes et al., 2018; Tang et al., 2018). Definitions of green HRM practices are shown in Table 20.5 (Pham et al., 2020).

TABLE 20.5
Brief Descriptions of Green Human Resource Management Practices

Green Practice	Definition	Reference(s)
Recruitment/selection	The highlighting of environmental aspects in recruitment and selection processes (Longoni et al., 2018)	Ren et al. (2018)
Training and development	Policies to heighten employees' environmental awareness, to equip them with environmental skills, and to raise green ability and expertise for employees in the organization (Renwick et al , 2013)	Jabbour (2013)
Job description and analysis	The inclusion of environmental issues in employees' job descriptions, linked not only to their usual activities but also further environmental obligations in their work (Jabbour et al., 2010)	Renwick et al. (2013), Roscoe et al. (2019)
Performance management/ appraisal	Policies for monitoring and evaluating employees' performance in terms of attaining environmental goals (Govindarajulu and Daily, 2004)	Longoni et al. (2018)
Pay and reward system	A system of monetary and non-monetary rewards for those who contribute toward environmental management goals (Jabbour et al., 2010)	Masri and Jaaron (2017)
Employee involvement and empowerment	An HRM system aimed at providing opportunities for employees to participate in environmental management initiatives and activities (Renwick et al., 2013)	Tang et al. (2018)
Organizational culture	An organization's assumptions, values, symbols, and artifacts reflecting their desire or need to pursue environmentally sustainable goals (Harris and Crane, 2002)	Jabbour and Santos (2008), Masri and Jaaron (2017), Gupta (2018)
Role of unions in environmental management	Trade unions' encouragement of top management to create new environment-related jobs and extend their sphere of influence at work (Renwick et al., 2013)	Gholami et al. (2016)
Organizational learning	Managerial levels' development of environment-related knowledge acquisition, discussion, ideas, and information sharing (Jabbour et al., 2010)	Jabbour and Santos (2008)

(*Continued*)

TABLE 20.5 (Continued)

Green Practice	Definition	Reference(s)
Work-life balance	Work-life balance is defined as an employee's working-private life balance in relation to green values, attitudes, and behavior (Muster and Schrader, 2011)	Ren et al. (2018)
Green health and safety	Green health and safety also emphasizes employees' lives through health and safety procedures aligned with environmental management (Shah, 2019)	

Human resource policies constitute the organizational and individual complements of this ongoing technological innovation. Veile et al. (2020) highlighted the requirement for developing new employee competencies and for encouraging employee involvement by means of the creation of flat hierarchies and decentralized decision-making. Talent mapping can be an efficient way to analyze current and future talent requirements by fitting current and future organizational goals with resources (Murphy, 2007; Santoso et al., 2021). Strategies for talent management are talent retention, incentives and promotions, appreciation, recognition, and rewarding employees (Amiri and Shawali, 2021).

Ongoing learning is a significant requirement, and executives should upskill their workers for technology-based work (Popkova and Zmiyak, 2019). Empowering the labor force to succeed at high-quality levels in the digital age is one of the core challenges that organization encounter (Gunasekaran et al., 2019). One of the challenges of the factories on the horizon is the coordinated man-machine process that directs the concepts of mutual learning (intelligent men and machines) (Kipper et al., 2021).

20.5 CONCLUSION

In today's increasingly competitive conditions, the changing face of human resource management requires the discovery of new dynamics in the understanding of sustainable management. Humans, as a fundamental element in economic, social, and environmental sustainability, will be able to be directed in accordance with the purpose and the perspective of human resource management. As a result of Industry 4.0, the increasing importance of the human element in the design of smart systems will require the development of new human resource policies to define new workforce qualifications and to reveal the new competencies that will be needed.

20.6 CASE STUDY

An airline cargo transportation company, which is in the process of institutionalization, has purchased a new technology that it will integrate into the service production process. With the spread of Industry 4.0 applications in the sector it is involved in, it will be necessary to create a human resource inventory where new competencies will be needed. With the importance of core competence understanding, the perspective of benefiting from external resources has begun to dominate in business management. The digital transformation to be realized in the organizations depending on the technology to be newly integrated into the processes draws attention to which functions of human resource management should be outsourced. Along with digitalization, new organizational structuring will be required for human resource management. Digital transformation leads to the use of various technologies related to human resource management functions. The use of new information technologies for human resource management will come to the fore. In particular, recruitment strategies may vary depending on various technological applications.

The digital transformation that Industry 4.0 will bring about in business processes causes a high level of uncertainty in the organizational environment. This uncertainty also creates uncertainty about the changes that will occur in the internal environment of the organization. In order to adapt the existing organizational structure in the firms or institutions to this integrated system, functional units and hierarchical levels need to be reconstructed. New technology requires increased teamwork among members of workgroups. The current digital transformation will also introduce resistance to change.

Determine the structure by using the reengineering perspective in creating the new organizational structure of the human resource unit. Which management applications would you utilize with this structure? Explain the reasons. In this context, which variables will be decisive in the decision to outsource which human resource management functions? What information technologies would you recommend using for HRM? How do you create a technological platform for e-recruitment (social media analyzing, mobile recruitment, etc.)? What will be your strategies for increasing teamwork among employees and your suggestions for eliminating resistance to change? After this process, it becomes important to measure the performance of human resource management. What resources can you use?

1. Reengineering approach in creating the new organizational structure of the human resource unit: Determiner of structure: hierarchical level, number of sub-functional units, communication channels, control area, degree of centralization, physical spread, required personnel qualifications, division of labor-expertise, degree of formalization, degree of complexity, subcommittees and groups in the organization. In addition, it is important to know the specific and industry-specific criteria related to the scale of the enterprise: load weight, load volume, speed according to delivery times, pallet used, container properties, available ton kilometers (ATK), and revenue ton kilometers (RTK).

In redesigning the organizational structure of the human resource unit from a reengineering perspective, a fundamental review and restructuring of all business procedures and processes are taken into account. First of all, job analyses for the existing new structure will need to be carried out, and job descriptions will need to be recreated. As a result of job analysis, the semantic closeness and interdependence at work are graded to reveal the job structure for job families, functional sub-units, and departments.

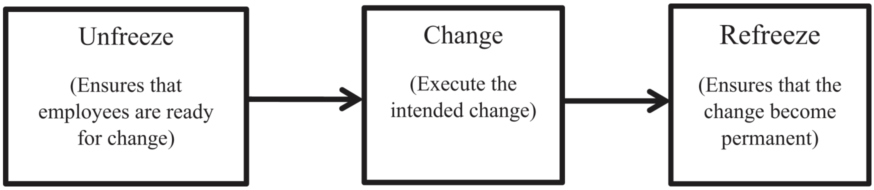

FIGURE 20.1 Kurt Lewin Change Model. (Oojorah, 2011)

Redesigning the processes instead of the classical structures, which are insufficient due to customer satisfaction and the necessity of responding quickly to customer requests, is a necessity from a reengineering point of view. Diagnosis of external (general, sectorial, and remote environment) and internal environmental components gains importance. In the context of sustainability and smart operations, the diagnosis of smart technologies that are used in the internal environment and that have not yet started to be used gains importance. Responsibilities for the problems that arise are shared by all functional sub-units in a cause-effect relationship. The understanding of arranging the processes in a way that allows providing services in a shorter time by reducing the costs again becomes dominant. All sub-units are coordinated in the understanding of value creation related to the human resource service offered. The focus is on building everything from scratch, and radical change is envisioned. Processes require radical changes rather than marginal improvements. Processes that do not add value to the created human resource service should be removed. Jobs of different quality can be combined under one group. Those who do the work are given more decision-making authority. Existing processes and the work within them are broken down, and the contribution of each work and process to the value creation function of the enterprise is examined, and the ones with low contribution are removed. It includes the stages of redesigning business processes in a way that will respond to the demand as quickly as possible.

Institutionalization: It is the system of harmonious and controlled activities that arise in the interaction of the enterprise with its external environment and the process of executing the rules, practices, and procedures that result from this system. In this context, the digital transformation that emerged with Industry 4.0 draws attention to the standardization of new processes and activities within the communities or the rules to be followed in the understanding of the reorganization of internal processes. Organizations with a high level of institutionalization will keep the operation of the business away from personal values and beliefs by influencing their environment with the mission, purpose, rules, and values that have taken place in the institution after adapting to environmental conditions. It is important for a business to have rules, standards, and procedures independently of people, to establish systems that follow the new environmental conditions that have emerged with digital transformation, and to create its organizational structure in accordance with the developments, to make its own communication and business methods a culture, and thus, to be different and distinguishable from other businesses. This can be explained by the process of impersonation. In the institutionalization process, the human resources department will play an active role in terms of preparation of the business constitution, professionalization, new organizational structure, delegation of authority and authorization, management approach and participation in management, decision-making style, and creation of an effective communication system.

2. Management applications to be used with this structure: Matrix organizational structure can be used in projects to be realized in order to reduce costs, increase technological literacy, and use new information technologies in human resource processes. The matrix organizational structure will be effective in the management of the project group to be determined by the IT unit and other relevant department members. In addition, functional benchmarking, which will be adapted to the institution by taking the most successful applications as an example, can be seen as a management application that can benefit. In today's world, where environmental uncertainty is increasing, multidirectional communication should be designed for intra-departmental and inter-departmental communication with a problem-solving-oriented approach instead of classical functional organization. In this context, the establishment of a team-based organizational structure will be beneficial. The digital transformation brought about by Industry 4.0 will require experiencing the effects of new variables related to the external environment and making the necessary changes in the internal environment accordingly (reactive strategy) and adopting a learning organization approach. Employee empowerment can be used as a management practice in order to adapt to the smart technologies to be used within the company and to increase the competencies of the employees in this context. Value chain analysis is a method that can be used to identify activities and core capabilities that will provide a competitive advantage for human resource functions. It is a method of separating human resource functions into strategically important functions and understanding the effects of these functions on cost and value. With the understanding of basic competence gaining importance, some human resource functions, such as recruitment and training, come to the fore from companies that have provided expertise in this field. Outsourcing can also be interpreted as strategic cooperation. The decision about which functions to outsource without jeopardizing the existence of human resource management in the organization can be made within the framework of resource dependence theory and transaction cost theory. It would be a good decision to outsource human resource functions, such as personnel selection and placement, training and development, all kinds of IT that exceed the technological infrastructure within the company, occupational health and safety, payrolls. In addition, a strategic cooperation approach can be adopted in the form of cooperation with the competitor, establishing a joint enterprise in which an unqualified workforce will be employed. Establishing a joint supplier company for the packaging materials to be used in air cargo transportation will be possible with feasibility. Again, the execution of joint social responsibility projects in

cooperation with the competitor may be a strategy to be followed in a win-win relationship.

3. Recommendations on eliminating resistance: In this company, the new organizational structure may cause a change in the hierarchical levels of some employees and may cause conflict between individuals. The change in functional subunits and hierarchical levels as a result of the change in the structure will bring conflict between different parties. It can offer the following suggestions to eliminate resistance to change.

   Participation: the participation of those who will be affected by the change in the planning and implementation of the change. Communication and training: Communicating with those who will be affected by the change. Analyzing the organizational communication process and removing the barriers in communication is an important step in eliminating the changing resistance. Hesitations about change are clarified in the periodic meetings held by the top management of the organization. Manipulation and cooptation: Manipulation means presenting an event to people by changing it in a way that will benefit the parties and making people perceive it differently by showing the event differently. Cooptation, however, means making those who are against a subject a part of the problems and solutions related to the subject.
4. Information technologies recommended for use in human resource management: Software, such as SAP and Global HRIS, are tools to be used in the management of business functions around the world. Besides, some of the commercial software for the human resource information system are as follows: Monday.com, Sapling, Connecteam, Eddy, Sage HRMS, PeopleStrene, HR Cloud, Built for teams, VAIRKKO, Workday, and NETSIS for executing HR functions (https://peoplemanagingpeople.com/tools/hrms-human-resources-management-system/).
5. Creation of the technological platform for e-recruitment: The accounts for Skype, Facebook, Instagram, Twitter, WhatsApp, YouTube, Dailymotion, LinkedIn, and Xing should be activated for the company. Candidates with new competencies should be interviewed via Google Meet, Skype, and Zoom. Webinars can be organized, especially for group interviews. Candidates' social media profiles can be examined before the interview. By examining social media, such as YouTube, Facebook, Instagram, Twitter, Snapchat, and blog pages, it is possible to get information about the candidate. Which potential candidates use which social media accounts will be useful for a characteristic evaluation. In this context, employing a social media expert and social media content analyst may be a strategy to be followed in e-recruitment. In addition to allowing candidates to upload CVs on the business website, vacancies to be recruited can be published on a job posting and job application pages, such as kariyer.net, secretcv.com, yenibiris.com. Adopting a proactive recruitment strategy to reach the target candidate would be a useful approach. Instead of waiting for candidates to apply to us, it is a proactive strategy to filter candidates according to various

search criteria by using web and mobile recruitment tools and to reach the candidate directly. Thus, an effective feedback system will be established.

6. Strategies to increase teamwork: Informal communication process to be established in a central type is an organizational variable that can be used in overcoming formal obstacles for the spread of teamwork. Giving more team-oriented awards than individual awards will also encourage people to work in teams. Creating a team with the right members; determining a common purpose, vision, and mission; developing strong communication within the team; developing a sense of belonging to the team; sharing authority and responsibility; and developing a belief that success will be achieved jointly will be effective in increasing teamwork at the desired level (Becerikli, 2013).
7. Measuring human resource unit performance: Evaluation of the personnel selection process (reduction in recruitment costs per candidate, increase in the acceptance rate of job offers by candidates), evaluation of the orientation process (trial period evaluation), evaluation of absenteeism and employee turnover rate, increase in the success in the process of backing up critical positions, reduction in training and development costs, increase in the ratio of processes that create added value in human resource functions to processes that create added value, increase in return on investment in training, change in the ratio of the number of employees in the human resources department to the total number of employees, change in employee requests compared to previous years, increase in the level of annual employee satisfaction research (Ünlü and Bayraktar, 2017).

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21 Social and Environmental Dimensions

Nurcan Deniz

CONTENTS

21.1 INTRODUCTION

According to the evolution of operations management (OM) from the 1800s, there is a shift from cost focus to quality (1980–1995) and customization (1995–2010) focus (Heizer and Render 2004). In the 1990s, there was also a focus on resource productivity. After reducing resources, green products and processes, CO_2 emissions and waste reduction, recycling, and reverse logistics or closed-loop supply chains came onto the scene (Walker et al. 2014). Empowered employees and environmentally sensitive production were two of the exciting new trends in operations management in

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the early 2000s (Heizer and Render 2004). Concurrently, Elkington (1998, as cited in Hong et al. 2021) proposed the triple bottom line (TBL), in which the planet, people, and profit (3Ps) are simultaneously taken into account. Planet, people, and profit were replaced with the environment, society (social), and economy, respectively, and became the three pillars of sustainability. Both practical and academic communities gave attention to sustainability (Hong et al. 2021), identified as a megatrend (Machado et al. 2017).

The first attempt was to include environmental issues in traditional economic-based models. This approach was called green. Manufacturing can be transformed from traditional to green by making products recyclable and using recycled materials, less harmful ingredients, lighter components, less energy, and less material. Processes called environmentally friendly meant efficient use of resources, reduction of waste by-products, emission controls, and recycling (Heizer and Render 2004). By including a social dimension to the green perspective, it became sustainable. Despite the majority of sustainability research focus on environmental issues, the focus on social issues has increased in the OM area since 2010 (Walker et al. 2014).

At first glance, integrating both environmental and social dimensions into OM activities can be seen as expensive, but it was shown that processes could be both socially responsible and environmentally friendly while profitable (Heizer and Render 2004). Hong et al. (2021) found that a balance can be ensured between profits and sustainability goals with regulators' policies and the green behaviors of consumers. Furthermore, sustainable OM (SOM) helps companies to become adaptive and agile (Kleindorfer et al. 2005).

The numbers show the importance of sustainability. The electrical waste of the world is 50 million tonnes a year. This quantity corresponds to more than all the commercial airliners ever made. The worrying side is that only 20% of electrical waste is recycled. According to the World Health Organization, 45% of children below 5 years of age die because of undernutrition, while one-third of the food supply chains are wasted every single day (Fantini 2021). Due to its importance, the 193 member states of the United Nations (UN) General Assembly adopted the 2030 Development Agenda in 2015. This agenda includes 17 Sustainable Development Goals (SDGs) to be achieved by 2030. These goals are presented on the UN website (https://sdgs.un.org/goals). The first three goals are no poverty, zero hunger, and good health and well-being.

Sachs et al. (2019, as cited in Gupta et al. 2020) suggested six main transformations in the UN SDG framework. The first transformation is the advancement in human capacity with improvement in both education and healthcare. Responsible consumption and production, decarbonization of energy, and access to nutritional food and clean water for all are the other transformations. The last two transformations are both related to technology: building smart cities and the digital revolution. Through all, the digital revolution is considered one of the significant forces in realizing the SDGs.

Digital transformation, known as Industry 4.0, was initially presented at the Hannover Fair in Germany (2011). Since the presentation of the concept, several new technologies have emerged. Industry 4.0–related technologies were listed as advanced robots, augmented reality, additive manufacturing, simulation, Internet of

Things (IoT), horizontal and vertical system integration, cybersecurity, cloud computing, and big data and analytics (Brunelli et al. 2017, as cited in Demir et al. 2021a). Artificial intelligence, cloud computing, blockchain, 5G, and big data are the new disruptive technologies, and they play highly important roles in achieving sustainability. Digital transformation also has an effect on innovative business models, such as sharing economy and social media (Hong et al. 2021). Big data analytics (BDA) is called a "game-changer" (Raut et al. 2021). "Sustainability" and "digital transformation" are the two important terms reshaping the OM field, and there is an intricate relationship between them. Gupta et al. (2020) coined the noun "digitainability", a merging of the terms "digitalization" and "sustainability".

The co-production and co-creation theory, contract theory, circular economy, and shared value are the grounding concepts behind SOM. The co-production and co-creation theory emphasizes multiparty interactions to improve values and performances. Meanwhile, contract theory highlights the significant values of contracts in SOM (Hong et al. 2021). Recently, companies started shared value initiatives. Reconceiving products and markets is one of the ways of shared value creation. In this way, the company can enhance its competitiveness, simultaneously advancing the economic and social conditions. The other ways are redefining productivity in the value chain and enabling local cluster development companies. Porter and Kramer (2019) highlight that social and environmental issues are required to overreach today's corporate social responsibility (CSR) approaches. Both social and environmental entrepreneurship are important in shared value models.

The rest of this chapter is organized as compatible with the sub-areas of OM under the part of "Sustainable Operations Management Issues." Lean and resilience concepts are discussed in another part. The other related issues and maturity of sustainable OM are the consequent parts. The operations management in smart cities is also considered according to the digital transformation and future directions, as shown in another part. The chapter concludes with a case study after the future directions part.

21.2 SUSTAINABLE OPERATIONS MANAGEMENT ISSUES

Service and product design, quality management, process and capacity design, location, layout design, human resources and job design, supply chain management, inventory, scheduling, and maintenance are the ten critical decision areas in OM (Heizer and Render 2004). All these aforementioned OM areas can be studied in a sustainable way. Meanwhile, in the pioneering study of Kleindorfer et al. (2005), three basic SOM areas were displayed. Green product and process development are some of them. The others are lean and green OM and remanufacturing and closed-loop supply chains (CLSC).

According to a review of SOM articles, CLSC is one of the main research areas in SOM. Environmental management and performance, low-carbon economy, innovation, and social responsibility are the other main research areas in SOM. Consumer returns, remanufacturing, and recycling activities are studied in CLSC based on the circular economy. Environmental resource allocation, pollution control, environmental management practices and standards, information-related instruments, supply chain activities, and market valuation of environmental efforts are studied in the environmental management and performance research area. The effects and design of carbon emission regulation are studied in the low-carbon economy research. The adoption of energy-efficient or clean production technologies and the analysis of renewable energy strategies are also studied in the low-carbon economy research. Innovation category–related studies consist of process improvement, the development and adoption of advanced technologies, creative designs of products or services, and sustainable business model innovations. Crowdsourcing in logistics service offerings, serviticizing, and sharing economy models are examples of sustainable business model innovations (Atasu et al. 2020). Walker et al. (2014) added risk management to the aforementioned SOM issues. The consecutive subsections are related to OM issues in the sustainability issues.

21.2.1 Sustainable Product Design

"Eco-design," "green product design," and "design for X" (DfX) are related terms to sustainable product design." Eco-design activities consist of designing products to reduce the consumption of not only materials but also energy. In addition to these activities, designing products for reuse, recycling, and recovery of materials and components are also considered in this context (Machado et al. 2017). In the DfX concept, *X* can be replaced with environment, safety, disassembly, and recycling (Kleindorfer et al. 2005). For example, in design for disassembly, products are designed to be easily disassembled.

Cradle-to-cradle (McDonough and Braungart 1998, 2000, as cited in Drake and Spinler 2013) is another important concept in sustainable product design. The Ecomagination project launched by General Electric (GE) in May 2005 is a beneficial example of sustainable product design. Immelt, the CEO of GE, denoted the objectives of this project are to meet the need for clean water, reduced emissions, and renewable energy. Energy-conserving household appliances are one of the products developed in Ecomagination. The others are a hybrid electric diesel locomotive and a fuel-efficient jet engine. According to the first Ecomagination Report published in May 2006, revenues from energy-efficient and environment-friendly products were $10.1 billion in 2005. Analysts highlight that Immelt's commitment to the project and efforts to change the mindset of the employees are two of the critical factors in the success of this project (George and Regani 2019).

The other beneficial example is the Sustainable Product Index developed by another pioneering company, Walmart, in 2009. To measure the sustainability of products and help customers, the index consists of three steps. In the first step, supplier assessment is made via a 15-questions survey. The questions are divided into four areas: 1. energy and climate, 2. material efficiency, 3. natural resources, and 4. people and community. The Lifecycle Analysis Database was generated with the Arizona State University and the University of Arkansas in the second step. Last but not least, in the third step, a simple tool for consumers was displayed (Crawford and Smith 2019). Not only the design of the products needs to be sustainable, but also the process and production technology need to be chosen in a sustainable way. For a sustainable future, cleaner technology adoption is required (Drake and Spinler 2013).

21.2.2 Sustainable Supply Chain Management

Green supply chain management (GSCM), reverse logistics, remanufacturing, and CLSC are important issues in sustainable supply chains. Especially disassembly plays a crucial role in sustainable supply chains, whether the decision is to repair, remanufacture, or recycle. According to the European Commission (2010, as cited in Drake and Spinler 2013), transportation is the second largest source of the world's carbon emissions. The adoption of cleaner vehicle technologies and the integration of transport planning and policy perspectives are important issues in sustainable transportation.

Assessing or improving environmental performance is the aim of GSCM. Meanwhile, reverse supply chains consist of reverse logistics, inspection and disposition, remanufacturing, and remarketing activities. As a consequence, a closed loop is formed by forward and reverse supply chains (Machado et al. 2017).

Sustainable supply chain activities start with sustainable purchasing, in which both environmental and social criteria are taken into consideration in addition to the economic criteria. Quality or cost are traditional performance objectives associated with the economic dimension. To address the environmental dimension, goals, such as reducing or eliminating waste and greenhouse gas emissions, promoting materials reuse, and using renewable energy sources, are needed. In addition, maintaining and improving human capital, eliminating child and forced labor, improving equality, and improving transparency are some of the goals related to the social dimension (Machado et al. 2017).

There are good cases in this context. Walmart saved $200 million in 2009 not only by reducing its packaging but also rerouting (Porter and Kramer 2019). The other example is the Smart Truck project developed by DHL Express used to optimize paths and reduce logistics distribution costs. Not only transportation time and fuel use were decreased, but also costs and pollutant emissions were decreased, and customer satisfaction was improved by path optimization. Apple's Give-Back program and the disassembly robot Daisy for extracting recyclable materials from iPhones are also stated in their sustainable supply chain activities (Hong et al. 2021). On the academic side, Goodarzian et al. (2021) developed a problem in the sustainable medical supply chain network during the COVID-19 pandemic to meet both social and environmental requirements.

21.2.3 Sustainable Human Resource Management

Employee competencies, the voice of employees, care of employees (preservation of employees and flexibility), employee–employer relations, and care of the environment are the important principles in the concept of sustainable human resource management (HRM). Employees are accepted as equal partners in employee–employer relations concerns. It was shown that work-related stress, work-family conflicts, and burnout could be reduced with sustainable HRM (Palm et al. 2020).

Palm et al. (2020) focused on the emotion of stress in the sustainable HRM context and found that stress in the working area is not only related to work. They also found that stress in the private area is not only related to private life. The initiative conducted by Johnson & Johnson to help employees stop smoking is a good example in the context of sustainable HRM. From 2002 to 2008, for every dollar spent on employee wellness, the company got a return of $2.71 (Porter and Kramer 2019).

The other important issue is team management in sustainable HRM. It is recommended to build environmental teams from different functional areas to address a wide range of environmental issues (Heizer and Render 2004). Also, team members can be non-human machines, according to the "new diversity" (De Cremer and Kasparov 2021).

According to digital transformation, employees are anxious about being replaced by smart machines. But it is stated that the correct question is, "How can human intelligence work with artificial intelligence (AI) to produce augmented intelligence?" The results of the partnership of Kasparov and a PC in a chess competition provided important results about how humans might work with AI. Kasparov denoted that he could focus more on strategic planning instead of calculations. The unexpected result was that the power of working with an AI depends on the interaction process. Kasparov formulized this situation as a weak human and machine, with a better process outperforming the strong computer alone. A weak human and machine with a better process also outperformed a strong human and machine with an inferior process (De Cremer and Kasparov 2021).

21.2.4 Sustainable Quality Management

Empirical, reference, reflective, and emergency are four quality management paradigms identified by van Kemenade and Hardjono (2021, as cited in Silva et al. 2021). Quality was perceived as conformance to requirements in the empirical paradigm, and the focus was on rules. Then models and guidelines (ISO 9000, EFQM Excellence, etc.) were provided instead of rules in the reference paradigm (Silva et al. 2021). The core elements of ISO 14000, an environmental management standard, are environmental management, labeling, lifecycle assessment (LCA), auditing, and performance evaluation (Heizer and Render 2004). The reflective paradigm assumed no universal reality and perceived quality in a subjective way. The fourth paradigm, called emergency, is still under development. It is based on the creation of networks to encourage a quality culture with an openness to change. It is expected that sustainability's integration into quality management systems (QMS) could be appropriate in which collaborative, participative, and situational leadership plays a crucial role (Silva et al. 2021).

21.2.5 Sustainable Location

Previously, as a result of inexpensive logistics, rapid information flows, and global markets, cheaper location was preferred. Along with the increase in energy and carbon emissions costs, this approach has started to change the sustainable location concept. Walmart and Nestlé are two pioneering companies that established smaller plants closer to markets and started to maximize the use of locally available materials. The formation of open and transparent markets is also a key aspect of local clusters (Porter and Kramer 2019).

21.2.6 Sustainable Facility Layout

Facility layout is one of the OM issues, and recently, it has started to be solved in the sustainability context. Durmusoglu (2018) evaluated activity relationship chart (ARC) alternatives based on three factors (environmental aspect, safety concerns, and manufacturing efficiency) instead of a traditional single factor. The origin of this study was taking into consideration safety indicators (damages, injuries, deaths, and claims) to minimize operations risks, contrary to existing layout models that only minimize the travel cost of resources. According to expert evaluations, the highest important factor was found as safety concerns. Environmental aspects and manufacturing efficiency follow, respectively.

21.2.7 Sustainable Scheduling

Traditional scheduling models neglect by-products threatening the environment, such as excessive carbon emissions, as they focus on profit-based performance indicators, such as cycle time. Sustainable manufacturing scheduling, sustainable transportation scheduling, and sustainable supply chain scheduling are the three main areas of sustainable scheduling. Recently, in some studies, energy consumption, especially, has started to be taken into account. Also, in scheduling vehicles, new types of vehicles, such as hybrid electric vehicles, have started to be considered to reduce emissions and control the carbon footprint of transportation (Zhang et al. 2016).

21.2.8 Sustainable Maintenance

Maintenance is one of the challenging issues as a result of the complexity of manufacturing processes and automation. There are limited studies related to sustainable maintenance. In one of these studies, Singh and Gupta (2020) developed a framework for a sustainable maintenance system. Fourteen factors have been identified for effective maintenance management in this study. Other contributions of this study were providing the major factors to provide a sustainable competitive advantage. These are top-management support and commitment, cost, continuous upgradation of the maintenance system, and strategic planning and implementation (Singh and Gupta 2020).

21.2.9 Sustainable Inventory Management

The aim of sustainable inventory management is to reduce the environmental and social impact. But it is also important not to affect profitability. Transporting is not the only source of carbon emission. Keeping the deteriorating items and warehousing also cause carbon emissions. Vehicle fuel consumption, fuel emission, and the distance traveled are the sources of transportation emissions. In addition, the total inventory and the warehouse energy consumption per unit item are the sources of warehouse emissions. Last but not least, the emission of deteriorating items is related to their disposal (Tiwari et al. 2018). Sustainable Economic Order Quantity (EOQ) Model (S-EOQ) is an example of sustainable inventory management. In this study, Battini et al. (2014) improved the traditional EOQ developed by Harris. In this model, the environmental impact of transportation and inventory is also incorporated.

21.2.10 Sustainable Process Management

Sustainable technology is very important to realize sustainable development objectives. United Nations Environmental Program (UNEP) classified sustainable technologies as CO_2/emission reduction, material/fuel substitution, energy/material efficiency, and recycling technologies. These technologies can be used in all stages of the process: preparation, production, and after-production. Cleaner technology types are changing the input materials and input energy. On the other side, equipment modification, better process control, and technology change are the cleaner technology types in the production stage. On-site recovery is one of the cleaner technology types that can be used in after-production. Production of useful by-products and end-of-pipe technology are also classified in the same context. Sustainable process technology adoption was mostly influenced by both environmental regulations and firm characteristics. Market pressure, technology capability, and cooperation are also some of the other important factors in sustainable process technology adoption (Fu et al. 2018). It is claimed that cloud manufacturing (CM) has the potential for sustainable manufacturing. CM can increase sustainability with collaborative design and improved process resilience. Greater automation, improved waste reduction, reuse, and recovery (waste valorization) are the other ways of CM to increase sustainability (Fisher et al. 2018).

21.3 LEAN AND RESILIENCE IN SUSTAINABLE OPERATIONS MANAGEMENT

Lean and green operations are some of the three SOM areas (Kleindorfer et al. 2005). Lean ensures social ground for sustainability from a systems perspective (Machado et al. 2017). Beyond the lean philosophy related to eliminating waste to improve value, LARG (lean, agile, resilient, and green) supply chains have started to be discussed. Agile means to respond to rapidly changing demands not only in variety but also in volume (Raut et al. 2021). According to Sheffi (2005, as cited in Mohammed et al. 2019), supply chain resilience is defined as the "inherent ability to maintain or recover its steady state behavior, thereby allowing it to continue normal operations after a disruptive event".

In supplier/vendor selection problems, resilience has started to be incorporated into the traditional models. As an example, Mohammed et al. (2019) added robustness, agility, and flexibility criteria in the resilience dimension with costs, product quality, implementation period, technology capability, successful previous related projects, performance history, and staff training and support criteria in the traditional dimension. According to the result of DEMATEL, the most important criterion is agility under the resilience dimension, where cost is the most important one under the traditional dimension. This supplier selection problem is called "trasilience" (Mohammed et al. 2019).

In another study, Raut et al. (2021) investigated the role of BDA as a mediator between sustainable supply chain business performance and key factors (lean, social, environmental, organizational, supply chain, financial practices, and total quality management) and showed that it helps to lower production lead time and transportation time, improve integration level, and achieve effective information exchange.

21.4 OTHER ISSUES IN SUSTAINABLE OPERATIONS MANAGEMENT

In addition to the issues previously cited, there are other issues related to SOM. Corporate social responsibility (CSR) and ethics, sustainable consumption and marketing, and behavioral issues are some of them.

21.4.1 Corporate Social Responsibility and Ethics

Recently, organizations have been interested in managing CSR in addition to sustainability as a part of their OM activities (Walker et al. 2014). European Commission (2001, as cited in Machado et al. 2017) defines "CSR" as "a concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with stakeholders on a voluntary basis". It is advised to recognize, value, and promote the capability of people for true corporate sustainability (Walker et al. 2014).

21.4.2 Sustainable Marketing and Consumption

Customers are vital in the communication of sustainable business practices (Machado et al. 2017). It is possible to combine the needs/desires of consumers and protect the public welfare/environment with sustainable marketing (Mataracı and Kurtulus 2020). According to the results of studies, sustainability can be promoted by improving consumers' green behaviors (Hong et al. 2021). Mataracı and Kurtulus (2020) showed that there are some factors that have significant impacts on behavior and intention toward buying. These are lifestyle, environmental consciousness, and involvement. They also showed that the greatest impacts on buying behavior are the behavioral dimension of environmental consciousness and purchasing intention.

At this point, sustainable consumption deals with understanding the impact of high-consumption lifestyles on the environment and on other people. Sustainable consumption is a multidisciplinary (psychology, sociology, business studies, cultural studies, and politics) field. The results of the studies that focus on the correlation between social difference and sustainable consumption show that income and gender are two important factors. It was found that high-earning people produce more carbon emissions. In addition, women express more pro-environmental sentiments than men (Middlemiss 2018).

21.4.3 Behavioral Issues in Sustainable Operations Management

It was proven that there are deviations from the rational man, unlike the classic economic models. Perceptual factors are some of the sources of this deviation.

Psychological and cognitive factors also cause variations from the rational man. Kahneman and Tversky showed that heuristic principles are guilty of causing cognitive biases that affect both individual and organizational decisions. Behavioral operations research (BOR) is a new field in which psychological aspects of decision-making are studied (Deniz 2020). It was stated that bias in AI increases mistrust across society (Allgood 2021).

According to the behavioral studies in SOM, setting a much lower price for remanufactured products was proposed. In the other study, it was concluded that an original equipment manufacturer (OEM) increases the perceived quality with the presence of a third-party remanufacturer but decreases when they remanufacture their own goods (Drake and Spinler 2013). Behavioral studies were also incorporated with analytic results in some recent CLSC research (Drake and Spinler 2013).

21.5 MATURITY OF SUSTAINABLE OPERATIONS MANAGEMENT

Maturity models can be used as change management and process improvement model. The five levels of maturity framework based on sustainable operations capabilities evolution are sustainable operations integration, network and stakeholder integration, sustainability management system, operations eco-efficiency, and compliance and conformity (Machado et al. 2017). Specific goals are design for sustainability (D4S), lifecycle assessment (LCA), sustainable supply chain management, sustainable production, integrated performance management system, and corporate social responsibility. Specific practices related to D4S are design for recycling, design for disassembly, design for remanufacturing, eco-design, and servitization. In addition, SSCM-related specific practices are GSCM, RL and CLSC, risk management, and sustainable purchasing. Sustainable production covers eco-efficiency, cleaner production, and lean and green operations. Specific practices related to integrated performance management systems are QMS/EMS/OH&SM, social accountability, and social systems. Last but not least, CSR covers stakeholder engagement, supplier development program, legal and regulatory regime, sustainable marketing, and sustainability business case practices (Machado et al. 2017).

21.5.1 Are Social and Environmental Criteria Important in Decisions?

Supplier selection is one of the well-known OM problems in the literature and is highly important in SCM. Multicriteria decision-making (MCDM) techniques are generally used in supplier selection struggling with conflicting criteria. In traditional supplier selection problems, decision-makers pay attention only to economic criteria. According to a meta-review result, quality, flexibility, price, technology capability, and cost are the common economic criteria (Rashidi et al. 2020).

Traditional supplier selection problems flourished into sustainable supplier selection problems by introducing new aspects. Primarily, the supplier selection problem evolved to the green supplier selection problem with additional criteria related to the environment. Zimmer et al. (2016) divide environmental criteria into main themes of environmental practices and environmental performance. The environmental practices theme consists of environmental commitment, environmental capabilities, and environmental management. On the other side, materials, energy, emissions, water, waste, and environmental product performance constitute the environmental performance theme. The most common criteria among them are environmental management system, eco-design, and resource consumption (Zimmer et al. 2016).

Subsequently, the sustainable supplier selection problem arose with the introduction of social criteria. The first sub-section in the social dimension is internal social practices. Social performance and external social practices are the other sub-sections. Internal social practices consist of social commitment, child/forced labor, and social management. Occupational health and safety, wages/working time, and training of employees are some of the sub-themes of social performance. The second sub-section, external social practices, consists of stakeholder involvement and corporate citizenship involvement of stakeholders, social management commitment, and staff training as the most common criteria among them (Zimmer et al. 2016). Rashidi et al. (2020) stated that "work safety & labor health" is the most applied criterion.

However, as stated by Zimmer et al. (2016), the integration of the social and environmental dimensions is not a simple task. Since the seminal paper of Dickson (1966, as cited in Zimmer et al. 2016), new supplier selection criteria have been included, but according to the literature review on sustainable supplier selection, it was shown that there is a focus on the environmental aspect, but the social aspect is neglected. Consistently, the meta-review analysis results show that the ratio of the applied criteria is 40% (economic), 36% (environmental), and 24% (social). Biased selections can be made according to this inequality among sustainability dimensions (Rashidi et al. 2020). The first reason for this is that the first modeling approach on social aspects in sustainable supplier selection was developed in 2007 (Huang and Keskar), and ten years after came the environmental criteria (Noci 1997, as cited in Zimmer et al. 2016). In addition, the quantification and measurement of the social criteria are more difficult than the environmental criteria (Zimmer et al. 2016). The results of another study showed that firms' ethical culture has a significant impact on social and environmental criteria weighting in supplier selection (Goebel et al. 2012).

However, the results of the studies on sustainable supplier selection show that the weights of environmental criteria are still higher than the environmental and social ones. A case study from the medical industry in which sustainability in the supplier selection process is a strategically important issue shows the dominance of the economic dimension. Priority was given to the economic criteria based on the experts' evaluation. These economic criteria are price, quality, on-time delivery, assortment width, innovativeness, organization and management, and reliability. In contrast, social criteria weights were determined higher than environmental ones in this case (Stevića et al. 2020).

21.6 SUSTAINABLE OPERATIONS MANAGEMENT IN SMART CITIES

The smart city plays an important role in achieving sustainability and is one of the applications of the smart environment. Smart homes, smart grids, smart transportation, and smart healthcare are the other applications of smart environments (Hashem 2016). Qi and Shen (2019) claimed that the smart city would improve from the tech-oriented to the decision-oriented step. Thanks to the advanced analytical frameworks, OM discipline can contribute to in-depth comprehension of smart cities. OM researchers can develop new models, algorithms, and insights for business models and urban systems. There are some OM research opportunities in smart cities. Interconnecting smart buildings and smart grids are some of them. Integrating smart mobility and smart grid, emerging service integrations, and people-centered and data-driven research OM disciplines have the advantage of joining statistics and computer science to improve data science in smart cities. Zero-emission buildings and smart grids are the main issues related to the OM discipline in smart cities (Qi and Shen 2019). There are mega-trends, such as climate change and scarcity, that will affect all Industry 4.0 players (Deniz 2021). Production and consumption move from global to local, manufacturing moves from competitive to collaborative, and business moves from a shareholder to a multiple-stakeholder perspective in the smart city idea (Graham 2016).

As a result of digital transformation, manufacturing systems have become more complex, automated, and sustainable (Demir et al. 2021a). Digitalization, autonomization, and transparency are the first three characterizing features of Industry 4.0 described by Pfohl et al. (2015, as cited in Demir et al. 2021b). The other described features are modularization, mobility, network collaboration, and socializing (Demir et al. 2021b). Thanks to the IoT, supply chains can be data-driven, flexible and agile, and operationally efficient (Paksoy 2021).

Information and Communications Technology (ICTs) integration with urban infrastructures in smart cities firstly improved not only the efficiency but also the effectiveness of public services, such as utilities and healthcare, that rely on urban infrastructures. The creation of new innovative services was enabled. Lastly, it encouraged the update of existing operations models by unlocking the economic value of city-based resources. Thanks to digitalization and smart technologies, such as IoT, products and services design and delivery in a more customer-oriented way can be possible. In this way, customers will become more involved in this process (Li et al. 2016).

As an example, to improve food and water security and eradicate poverty, big data can be used to model and test different scenarios. Consumers can also actively participate in sustainable actions (e.g., garbage classification, green consumption, waste reduction, and personal resource sharing) (Hong et al. 2021). Supplier chain performance can be dramatically changed with BDA through process design, customer integration, and supplier integration (Raut et al. 2021).

The foundations of a smart city logistics system are not only economic and operational but also resilient and environmental (Graham 2016). Gupta et al. (2020) proposed a Digitalization Sustainability Matrix (DSM). Technologies were divided into three categories in this matrix. Mobile Internet technology, blockchain, and IoT are classified under data-driven opportunities. Meanwhile, analytics-driven opportunities consist of big data, cloud computing, and AI. Lastly, virtual/augmented reality and adaptive manufacturing/3D printing are categorized as design-driven opportunities (Gupta et al. 2020).

Wood and Sanders (2020) investigated Google, Haier, Apple, Zappos, and Siemens over five years and concluded that having technology is not sufficient to gain a competitive advantage through AI. Additionally, organizational transformation is required. Machines and people are integrated to complement each other in the business model (Wood and Sanders 2020).

Rio de Janeiro (a city in Brazil) has a smart city initiative, and Rio Operations Center (COR) is one of the main innovative management initiatives and the backbone of the city. COR enhances integration between agencies and utilities, and also supports the local government's decision-making process by having real-time information. The local government has the chance to continuously monitor the city from COR and act more quickly in unforeseen events in traffic or environmental disasters. With the use of applications and social networks, social participation can be realized in the success of an operations center (Schreiner 2016).

In Finland, AI-based image technology is used to classify garbage for urban waste treatment. In this way, the classification accuracy was improved, labor costs were saved, and the benefits of waste classification were improved (Hong et al. 2021). In the future, there will be more digital transformation–based examples that improve sustainability.

21.7 FUTURE DIRECTIONS IN SUSTAINABLE OPERATIONS MANAGEMENT

Although healthy growth was recorded in the SOM area, there are still issues waiting to be studied. As an example, to improve social sustainability, inclusive innovation can be carried out for goods/services, process/business models, and supply chain innovations (Atasu et al. 2020). Balancing trade-offs between the different elements of sustainability, off-shoring and reshoring effect on SOM (Walker et al. 2014), and the effect of consumers' green behaviors on the improvement of social performances (Hong et al. 2021) are some of the other future directions.

In terms of methodology, in-depth case studies and retrospective studies in different sectors have the potential to explore the SOM field (Walker et al. 2014). New analytic frameworks, tools, and techniques are also an avenue for generating reliable insights based on big data. In addition, new theoretical and empirical research is also needed (Li et al. 2016). Engaging practitioners and/or policy-makers is also highly important (Drake and Spinler 2013).

Inevitably, emerging technologies will continue to affect the SOM area. It is expected that this effect will especially occur in the social aspect of sustainability. Congestion management and retail service optimization are some of the questions that OM researchers can answer in the future. Moreover, these technologies give a chance to collect data from citizens easily to realize participatory decision-making, which is an essential element in sustainable communities (Atasu et al. 2020).

The other future direction is the requirement for interdisciplinary studies. Behavioral decision-making, economics, political science, marketing, materials science, law, public health, chemistry, environmental engineering, toxicology, and sociology are some of the related disciplines that have the potential to broaden the perspective of OM issues (Atasu et al. 2020). It is also an avenue to use objective weighting methods (e.g., entropy) instead of subjective weighting methods (e.g., AHP).

Lastly, in addition to ten major OM areas, project management and forecasting are the other important areas that need to be considered in the SOM context. It is essential to make forecasting precisely to match supply and demand better because the planet, economy, and everyone will suffer from forecasting errors. Rapid response can be an alternative to traditional forecasting (Fantini 2021).

21.8 CASE STUDY

21.8.1 Social and Environmental Issues in the Private and Public Sectors

"My father was a local food manufacturer specialized in 'kadayıf'." Kadayıf is a kind of Turkish dessert made from only flour and water. Although the ingredients are simple, the process is hard, and the output is fragile. I started to work near him in the holidays. Initially, it was a chance for me to spend more time with my father, who works nearly 24/7. I have learned all steps in the work and started to make machine and process improvements. After these experiences, I decided to be an industrial engineer. I also did a double major in chemical engineering and business administration.

In the "Operations Management" lectures, when I asked my students for a strategy to cope with the increased demand, the first response was generally "overtime working." According to the rationality assumption, it is expected that workers will be happy to work in exchange for overtime pay. But in reality, I saw that workers do not want to work overtime. They want to go outside after work and do some shopping. As a result, we worked with my family. This example was an important case for the social side of the most important source: humans. The environmental side of food manufacturing is alike. Food waste becomes a good alternative for animals.

After graduation, I started to work in a municipality as a performance manager. This was a challenge for me to work in the public sector. I needed to measure performance, but first of all, I needed to learn the process. I decided to visit all employees in their working environment (after ten years, I have learned that it is called Gemba in lean philosophy) and drew workflow diagrams. As a result of the project, the motivation of some employees increased after their suggestions about process improvements were realized. The other important issue I remember about the municipality was governance. To give the citizens a chance to be a part of the decisions was an extremely good idea, but to do voting was not easy in that years. Thanks to digital transformation, it became too easy to have all the stakeholders participate in the decision-making process.

These are some examples related to both the social and environmental sides of sustainability. After gaining experience in both the public and private sectors, I advise my students to develop their social skills and to be more conscious of the environment. As shown in Figure 21.1, a balance needs to be ensured between sustainability elements. It can seem incompatible with digital transformation at first glance, but I think we will have more time to be better people by delegating repetitive and harmful work to be digital.

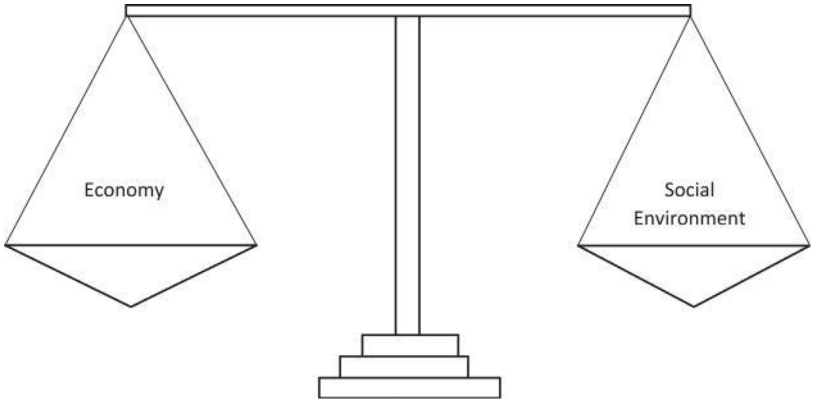

FIGURE 21.1 Balance between the elements of sustainability.

Discussion questions:

1. What are the other strategies to cope with increased demand? Which one will you choose? What are the social/environmental effects of this decision?
2. What was the reason for the visits to draw the workflow diagrams? Why did I not invite the employees to my office?
3. How will realizing governance become easy with digital transformation? Which technologies can be helpful?

These case studies are parts of the real-life story of the author of this chapter (Dr. Nurcan Deniz).

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