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Supply Chain Management Strategies and Methodologies

Experiences from Latin America

Springer

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Preface

Companies compete nowadays in their Supply Chains (SC) and not so much in their standardized production processes; hence, they are of great importance. Owing to the supply chain, a high percentage of the cost of the products they offer is due to logistics matters, which do not increase the product's value, but can cause shrinkage due to accidents and losses.

These high costs of SC activities are mainly due to their globalized production systems, as countries cannot generate all the inputs required for a final product. Therefore, many components in a product come from other countries, allowing companies to generate high-quality products and become specialists with competitive advantages in a unique industrial sector.

One of the most important strategies that companies use is to be geographically closer to their customers, so they establish subsidiaries in countries of consumption or their surroundings, even when the head offices are distant. For example, in the automotive sector, it is possible to observe assembly plants in Mexico, Argentina, and Brazil; however, the suppliers are established in other countries, and the final consumers are mainly in North America, Canada, Europe, and Asia. These foreign companies, established in Latin America, have adopted and applied SC strategies to remain in this globalized market.

The benefits obtained by these companies can be, among others, accelerated innovation in their productive and administrative processes, facilitating human resources management and knowledge transfer, which increases organizational effectiveness and efficiency. Consequently, they gain flexibility and agility in response to SC uncertainties and disruptions. Above all, best supply chain practices allow measuring, controlling, and evaluating production processes to improve them, from raw material procurement to distributing finished products.

This book reports the best SC practices that companies established in Latin America are implementing to generate high-quality products and stay in the globalized market. The book reports the experiences of 67 authors from Latin American institutions in Bolivia, Chile, Colombia, Ecuador, Spain, Mexico, and Peru.

The book comprises 20 chapters integrated into four main sections, according to the SC process, beginning with procurement activities, production process, and distribution. Section 1 integrates four chapters and is named **Part I The Supply Chain in the Procurement** and aimed at the procurement process in SC. The chapters explain SC strategy concepts, provide a literature review on their trends, and discuss authors and institutions researching it. However, also discuss how SC can add value to products and the importance of demand forecasting.

Section 2 is named **Part II The Supply Chain in the Production Process** and it is aimed at activities required during the transformation of raw materials into final products. This section integrates three chapters with topics such as six sigma, just in time, Kanban, leadership and human resources. Section 3 is named **Part III The Supply Chain in the Distribution Process** and integrates seven chapters concerning topics related to finished product distribution, such as inventory management, information systems applied, disruption events, and uncertainty, among others. This section is attractive because some chapters focus on medicines and vaccine distribution, a challenging problem during the pandemic. However, it also includes chapters regarding perishable products and last-mile distribution in urban centers.

Finally, Section 4 is named **Part IV Miscellaneous in the Supply Chain**. This section integrates six chapters that were difficult to associate with previous sections (procurement, production, and distribution) but are very important nowadays. Those chapters refer to literature reviews and unique supply chains, as in the case of hydrogen, tire and battery recycling after the end of the life cycle, delivery policy in urban spaces, and cybersecurity in the supply chain. Those sections and chapters are briefly described in the following paragraphs.

Part I The Supply Chain in the Procurement

Chapter 1 is entitled "Supply Chain Strategies and Methodologies—A Bibliometric Review" by García Alcaraz et al. and reports a bibliometric review regarding supply chain strategies using a database from Scopus. The authors indicate that supply chain strategies began in 1993, with increased publications since then. The most productive authors are Christopher M., Saputra J., and Wang S. However, the institutions with more focus on this topic are the Kazan Federal University (Russian Federation), Terengganu University (Malaysia), and the Management Development Institute (India).

They also indicate that countries such as the United States of America, United Kingdom, China, Indonesia, and India publish the most documents. The journals most interested in this topic are the International Journal of Supply Chain Management, the International Journal of Production Economics, and Supply Chain Management.

Chapter 2 is entitled "Using Meta-Learning in Automatic Demand Forecast with a Large Number of Products", in which a demand analysis is performed using the meta-learning technique, improving the traditional methods for retailed distribution. The authors recommend using several forecasting models and indicate that restricting the set of eligible models to only those that perform well on average leads to better overall performance.

Chapter 3 is entitled "Economic Development and High-Value Supply Chains", in which the authors propose a conceptual framework for the opportunities for regional sectors to create high-value and competitive chains. Findings indicate that the productive regional sectors that can improve their value chains are those related to agriculture and manufacturing, given that the maturity and innovation level is very high in those sectors.

Chapter 4 is entitled "Artificial Intelligence-Based Analysis of Material Supply Costs in ETO Companies Shifting to Mass Customization", and the authors report the application of the Engineering to Order (ETO) technique to support the material supply process in search of excellence. Artificial intelligence (AI) and open-source software are applied to generate forecasts and perform the analysis. The results indicate that the standardization of products impacts the company's performance, reduces purchasing costs, and can increase sales because they reach high-quality levels.

Part II The Supply Chain in Production Process

Chapter 5 is entitled "Lean-Sigma as a Strategy in Supply Chain Management During the COVID-19 Pandemic Crisis-Lessons Learned", where the author describes the most important lessons when applying lean-sigma during the pandemic period. The author reports two case studies for a better illustration and indicates how this technique increases quality and reduces cost, resulting in a quick investment return during disruptive events.

Chapter 6 is entitled "Development of an Expert System Focused on Improving the Supply Chain by Increasing the Availability of Equipment", where the authors develop an expert system oriented to improve the supply chain from the increase in equipment availability. The case study reported focuses on improving the productive time of a machining and injection process based on an intelligent system focused on recognizing fault patterns in electric motors through artificial neural networks. The results indicate that the applied methodology increases the diagnostic capacity up to 99%, which allows them to make more accurate decisions with better machine availability.

Chapter 7 is entitled "Leadership as a Strategy for Flexibility and Resilience in the Supply Chain", where the authors examine transactional and transformational leadership and their impact on flexibility and resilience in the Mexican maquiladora industry. The authors report a structural equation model evaluated with information from 231 responses. Results indicate that both types of leadership impact resilience; however, the transactional style is higher, and flexibility is an important mediator variable.

Part III The Supply Chain in the Distribution Process

Chapter 8 is entitled "Demand and Inventory Management for the Creation of an Automated Information Management System: A Case Study Applied to an Ecuadorian Supermarket", where the authors analyze the inventory management in an Ecuadorian supermarket, integrating partners such as employees, suppliers, consumers, and final sellers. The authors use forecast techniques in every supply chain stage, such as ARIMA, Holt, and Holt-winters. Findings indicate that techniques are easy to implement and facilitate production planning, avoiding shortages when appropriate software is used for fast calculations. However, the authors emphasize the need for reliable data.

Chapter 9 is entitled "Analysis of Failure Modes and Port Disruptions in Port Terminal Operations: A Case Study in the Port Area of Barranquilla, Colombia", where the authors analyze the high uncertainty faced by seaports in globalized times and its effect on national and local economies. Specifically, they analyze the possible events that can cause a work stoppage and offer a port in Colombia as a case study using ISM methodology for the analysis. The author concludes that hurricanes and terrorist acts negatively affect seaport operations, affecting transport due to blocked roads to ports. They recommend planning strategies for preventing those disruptive events and increasing resilience.

Chapter 10 is entitled "A Proposal for the Distribution of Medicines and Medical Equipment in Mexico", where the authors analyze the distribution of medicines during the COVID-19 pandemic in Mexico, focusing mainly on vaccines. They use quantitative methods for the analysis, such as the Clarke and Wright heuristic method, and propose distribution networks based on uncertainty, vaccine freezing requirements, and distances traveled, among others. According to several scenarios simulated, the authors recommend decentralizing some administration activities for fast decision-making and because local and regional authorities have better acknowledgment regarding road availability and general conditions.

Chapter 11 is entitled "Optimization of the Distribution Process with a Multi-criteria Decision Model in the Poultry Industry", where the authors research how a company in the poultry industry can achieve an optimal distribution process and report a case study. The authors report qualitative analysis to detect improvement requirements and critical factors, and the most optimal improvement measure is determined through AHP (analytical hierarchy process). The factors analyzed were distribution cost, transaction cost, warehousing, storage, damage and losses, efficiency, distribution cost, and transaction cost. Food quality and efficiency were the most important factors for the case analyzed.

Chapter 12 is entitled "Geolocation for Tracing the Optimal Route for Claims Attention of Dairy Products", where authors analyze customer claims and the speed for attending to them. They propose prioritizing claims using georeferencing, routing, and forecasting to support the improvement of this process. The authors propose the case of a leading company in the dairy industry as an example to apply the proposed prioritization methodology and quality tools required. The authors analyzed nine zones from the Lima Metropolitan area in Peru, and having just a distribution source, they recommend a route for every zone.

Chapter 13 is entitled "Diagnosis and Improvement of Processes for a Distribution Center in a Mass Production Company", where the authors present the diagnosis and analysis process for the improvement of the warehouse of a distribution center of a Chilean manufacturing company. They detect organizational and infrastructure problems and show how commercial simulation software analysis helps determine the best options to increase the warehouse capacity at the lowest cost. The authors propose to use two pickers and invest in tables to speed up some operations and increase the capacity to process orders by 42.5%.

Chapter 14 is entitled "Vulnerable Regions Distribution of Packed Fresh Food Using Mobile Markets", where the authors declare that the food supply chain is highly sensitive when facing disruptive events, and vulnerable regions' food security is the most impacted. Therefore, the authors propose a new structure for fresh food supply chain distribution in vulnerable and unserved regions of Cochabamba, Bolivia, through the food kits' delivery using mobile markets and considering the social, cultural, geographical, and economic characteristics of the region. However, the authors declare that it is essential to know the customer culture and preferences using surveys to design and plan better distribution routes under disruptive events.

Part IV Miscellaneous in the Supply Chain

Chapter 15 is entitled "Towards the Development of Sustainable Supply Chains for the End-of-Life Tires Management: Insights from a Literature Approach", where the authors report a comprehensive literature review regarding waste management of end-of-life tires. The most relevant challenges for the supply chain due to the environment were also identified. The authors used a comprehensive literature review and indicated that most documents focus on economic concerns, not environmental ones. They also report the need to begin tire recycling research in Latin America because they found only one paper from this region on this topic.

Chapter 16 is entitled "Battery Recovery Supply Chain Design. A Literature Review", where the authors report a systematic literature review regarding battery recovery supply chains. They found 14 documents regarding this topic, identifying the battery type, the mathematical model used, and the environmental and political dimensions. Findings indicate that most documents focused on supply chain design, given that only one was regarding routing; however, all documents analyzed the economic dimension and only thirteen the environmental. Most of the documents came from authors in China, and no documents from Latin America were identified.

Chapter 17 is entitled "Urban Logistic Analysis in the Commercial Area and Proposal of a Policy for Loading and Unloading of Goods in Popayán City", where the authors are focused on characterizing the logistics of the historical center of Popayán, Colombia. They analyze the last-mile distribution practices and information that can be used for decision-making and public policies to improve the efficiency of logistics operations in the study area. The study identified the different economic activities practiced using a methodology proposed by the MIT Megacity Logistic Lab. Finally, discrete event simulation was used for loading and unloading zones' location and time allocation. The authors propose alternative routes to increase 8% the loading and unloading process in Popayan historic center, increasing pedestrian mobility by 18% and signaling by 15%.

Chapter 18 is entitled "Characterization of Hydrogen Supply Chain Design", where the authors seek to identify and describe the actors involved in the operation of the hydrogen supply chain and the decisions each actor must make and the relationships that may exist with other actors. Also, the strengths and weaknesses concerning the case of Colombia are identified as the common problem types, modeling techniques, and solution methods used. The authors emphasize optimization techniques and report challenges and future research to know the social acceptance of hydrogen as a power supply. Also, the best partners' integration, their commitments, and the need for interest in this topic from Latin America are required, given that no papers from this region were identified.

Chapter 19 is entitled "Towards Cybersecure Maritime Supply Chains in Latin America and the Caribbean". In this chapter, the authors declare that Maritime supply chains in Latin America and the Caribbean (LAC) region are immersed in a digital transformation process that is evolving to be highly dependent on cyber-physical systems composed of information and operational technologies. Threats from various actors in cyberspace pose a real menace to the maritime industry in the LAC region; therefore, the prevention of cyberattacks and cyberresilience must remain among the top strategic priorities. This chapter describes such threats and risks, discusses ongoing national and supranational initiatives in the LAC region toward improving cybersecurity in the maritime industry, and provides recommendations for decision-makers and technical staff in charge of maritime supply chain operations.

Finally, Chap. 20 is entitled "Strategy in Supply Chain and Logistic Ecosystems in Megaregion Sonora-Arizona", where the authors show the effort made by higher education institutions, governments, and companies to jointly build the strategy to define the supply chain in two logistics ecosystems as a cooperation response in Megaregion Sonora-Arizona. The chapter analyzes the social, gastronomic, tourism, and business and logistics development opportunity areas. The main results are the constitution of two ecosystems: (1) agrofood and tourism logistic ecosystems and (2) health and tourism, given the low cost in Mexico.

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Part I
The Supply Chain in the Procurement

Chapter 1
Supply Chain Strategies and Methodologies—A Bibliometric Review

Jorge Luis García Alcaraz, Maribel Mendoza Solis, José Roberto Díaz Reza, and Juan Manuel Madrid Solórzano

Abstract Supply chain strategies (SCS) have been gaining increasing interest given the recent disruptive events associated with wars and pandemics, where traditional SCS have proven insufficient. This article presents a bibliometric review of SCSs, analyzing the main trends, authors, institutions, and countries in which they are found, which will allow new SCS scholars to establish direct contact with the literature. PRISMA methodology is used to identify 1430 documents published from 1993 to 2021, and then VOSviewer and Bibliometrix software are used to analyze the information. Findings indicate that the trend of SCS publications is increasing, that its main area of application is Business, Management and Accounting, and that the main authors are Christopher M., Saputra J. and Wang S., who are also the ones who initiated this term two decades ago. Additionally, the publications on the topic are articles, conference papers, and book chapters, indicating that they have undergone a review process. It is concluded that SCS will continue to grow in initiator countries such as the United States of America and the United Kingdom. However, countries such as China and India will start to increase their academic output significantly.

Keywords Supply chain strategy · Bibliometric analysis · Trends · Citations

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1.1 Supply Chain Strategies

Since the Covid-19 pandemic, supply chain strategies (SCS) have gained more visibility and notoriety, highlighting the importance of using SCS that are flexible enough to adapt to potential regional or global contingencies (Woong and Goh 2021). During 2020 and 2021, the demand for medical and healthcare equipment increased considerably, and many companies stopped production and sent their employees home (Liu et al. 2022). This problem generated shortages of many products in supply chains (SC), which led to new paradigms and strategies to address these problems as the SCs collapsed (Sharma et al. 2022). In addition, the world's population has increased considerably, increasing market demand. Therefore, it is beneficial to use a combination of dynamism and technology in CS to help increase the level of competitiveness of an organization regardless of the environment and special conditions one may have, such as Covid-19 (Wesli 2018; Haseeb et al. 2019). To meet this growing demand and abrupt changes in CS, companies must respond by implementing changes and new paradigms in CS that allow them to bring their finished products to customers; this is known as the SC strategy (Chandra et al. 2019).

Therefore, the CS strategy (SCS) refers to a set of technologies and methods to optimize the production of a product or service for the final consumer. The importance of SCS is that it ensures flexible work dynamics that can effectively respond to the demands of the economic system, ensuring the continuity of production, distribution, and consumption of the company's products, which ensures economic income and stays in the market (Sun et al. 2022). However, all CS strategies must focus on customer satisfaction, wider market coverage, and increasing the organization's competitive advantage (Pothiwan and Yuan 2021).

1.1.1 Types of Supply Chain Strategies

A CS includes the activities, facilities, and distribution methods necessary to carry out the entire product sales process, from the purchase of raw materials to their further processing in machines, production, transport, and delivery, to the final consumer. To achieve this goal, companies implement various SCSs, some of which are listed below, depending on their stage.

1.1.1.1 SCS in the Supply Chain

Selecting suppliers. The manufacturer's success depends not only on its production process but also on the raw materials provided by its suppliers. Therefore, selecting suppliers is crucial, focusing on those with quality certifications, a wide reputation in service, and administrative and technological capacity (Ariadi et al. 2021).

Strengthening relationships. Relationships between suppliers and manufacturers should be centered on trust in each other, with sufficient information flow in both directions, and if possible, integrate inventory management systems to automate the requisitioning systems (Kussudyarsana et al. 2020; Sabara et al. 2019).

Manage inventories. Inventories refer to money in storage, so companies must encourage their CS to rotate inventories, add value, and put them on the market as finished products (Blatherwick 1998). They should also encourage the proper use and handling of products in warehouses, as this is where most waste occurs.

Track inventory. **Track inventory** includes knowing how much material is held in warehouses, in what condition, and where it is located, preferably in real-time and through information and communication technologies (ICTs). ICT helps to eliminate errors and increase CS visibility (Nampinyo et al. 2020; Pradhan and Routroy 2018).

Improve transparency and communication. A real-time integrated system that identifies warehouse disputes, errors, and losses allow corrective actions, replenishments, and adjustments (Kucheryavenko et al. 2019; Afanasyev et al. 2019).

Monitor cash flow. Identifying the associated revenue and cash flow changes is important because purchase terms often affect them. Ignoring cash flow can compromise a company's economic soundness (Qasem et al. 2019).

1.1.1.2 SCS in the Production Process

Establish a budget. To correctly manage and control SC, it is important to determine how much to invest in producing a good or service; thus, purchases should be based on accurate information from sales forecasts. This can be done by defining cost rates, monitoring the timing and movement of materials, quantifying inputs and outputs of inputs and energy, and contracting services to manage the production process properly (Sufitrayati and Aliasuddin 2020; Miroshnikova et al. 2019).

Manage lots and prices from a long-term perspective. Continuous evaluation of CS helps visualize the organization's future; therefore, as the business grows, pricing is balanced with the possibility of splitting production batches. In addition, small batch production often allows the customization of products to delight customers (Sinurat et al. 2020; Abed et al. 2019).

Use state-of-the-art technologies. One strategy to improve CS efficiency is the automation and modernization of production systems with the aim of Industry 4.0. For example, the use of ICT, flexible manufacturing systems, machine learning and the integration of robots provide opportunities to improve planning and find solutions to problems quickly and jointly. Similarly, automation of certain processes avoids accidents, errors, and waste, as reflected in the flow of economic resources (Irfan et al. 2020; Kuei et al. 2002).

1.1.1.3 Supply Chain Strategies in Distribution and Logistics Processes

Develop a flexible distribution network. An accurate understanding of how the distribution network allows transport to be adjusted to reduce costs through better routing, prioritization, and delivery times helps improve service. To this end, periodic evaluation and re-planning of distribution routes help understand what dynamics are best for possible contingencies and under what conditions, allowing for flexibility in making deliveries to customers (Sholpanbaeva et al. 2021; Baker 2004).

Use of a comprehensive planning system. The cloud platform allows companies to manage large amounts of data and perform the necessary analyses to develop effective transport planning in real-time without delay. In addition, it allows simulations of different scenarios in which disruptive events may occur, enabling the planning and analysis of the interaction between variables and identifying those critical across the entire CS (Sadler and Sohal 2005; Ivanov 2010).

Real-time monitoring of shipping routes. Knowing the route of each moving unit is critical for companies to understand the carrier's operation and resolve potential disputes in the shortest possible time together with the customer (McKinney et al. 2014; Awad et al. 2020). In addition, making this monitoring process transparent to customers can reduce uncertainty and increase customer satisfaction as they can visualize and track their deliveries (McPhee et al. 2015).

It is important to mention that no two supply chains are the same because they all have companies with different managers and priorities. Therefore, it should be stressed that the established SCSs are the only guidelines and should be adapted to the needs and objectives of their partners. Thus, each company should identify its needs regularly and review, update, and redesign them to support its financial sustainability.

1.1.2 How Can an SCS Be Defined?

Assuming that each company is different, each SCS is different, so each business starts from a series of premises that come from all the members or partners that are reflected in the actions and the way a company works. Therefore, it is necessary to formalize the common objectives among the partners, define priorities, and reach a certain level of formality, which is established through contracts that each partner is expected to do. The main aspects to be considered when defining SCSs are briefly discussed below.

Prior research: Before developing a strategy, it is important to understand the current performance of the supply chain. This means that each of its actions and functions must be recorded and analyzed (Sulaeman et al. 2019; Bakashbayev et al. 2020; Chen et al. 2020; Syahril et al. 2020; Sinurat et al. 2020).

Structural: If the strategy is sound, it must be confirmed that the structural aspects are fully functional in all the network parts (Camanzi et al. 2020). For example, the delivery route of the product ensures the maximum throughput of the transport unit with a low delivery price or ensures the product's availability at the customer's warehouse according to the purchase order.

Function: The strategy agreed to be implemented among the CS partners should allow for repeated testing of the performance of each function or operation; that is, tests should be performed continuously to quantify the parameters, to know whether the established function is being fulfilled, and to take corrective actions if needed (Achmad et al. 2021; Gasimova et al. 2020). To avoid such deviations, these parameters must be capable of identifying areas for improvement.

Implementation: Implementing SCS requires a change in organizational culture, compliance with all agreements, and all partners fulfilling the activities they are responsible for (Roh et al. 2014; Sillanpää et al. 2013). Often, the implementation of SCS requires awareness-raising among members, as changes are often generated that frequently affect the traditional working habits of some of them. Change management ensures strategic success.

1.1.3 Traditional Ways of Improving SCS

One of the questions a manager asks is how to improve CS and its parameters, which certainly has many answers as it depends on the nature of the business, its needs, and its level of integration with partners. However, it is possible to establish some general guidelines that work, which are listed below; however, as mentioned above, some may apply more than others.

1. Streamlining CS (Tarafdar and Qrunfleh 2017)
   - Respond quickly to customer needs and ensure that all members of the CS are well synchronized; therefore, internal and external factors (partners) must be considered.
   - There must be a balance between agility and costs. High agility means more expensive and unique products that customers often cannot afford.
   - Responding effectively to operational contingencies and environmental, economic, or consumer issues will provide a competitive advantage.
2. The automation of a supply chain (Evers et al. 2007; Ashima et al. 2023)
   - Automated solutions increase a company's production efficiency by minimizing human error.
   - Automating the CS helps solve problems such as peak workload and stock-outs.
   - Automated systems can be reprogrammed to perform various activities and are, therefore, multifunctional.
3. Managing the value chain (Suarez-Barraza et al. 2016; Chen 2010)
   - Audit CS processes on an ongoing basis to ensure their efficiency, identify deviations and take corrective action.

- Identify all the key processes in the CS and, for study and analysis, break them down into smaller components to fully understand how they work and to improve them.
- Defining business operations, making strategic decisions to reduce costs, eliminating waste, and increasing profitability, that is, making decisions with a long-term vision.

4. Standardize key processes (Samal and Pradhan 2019; Naslund and Williamson 2007)
   - Identify the objective of the SCS to align it with business objectives and identify the processes to be standardized, thus ensuring uniformity in the production system.
   - Practices such as order and delivery tracking can be standardized using technologies to facilitate real-time tracking and the dissemination of information among partners.
5. Encouraging dynamic inventory optimization (Wang et al. 2018; Jin 2010)
   - Create a flexible accounting system that allows orders to be fulfilled more quickly.
   - Shortages in certain work areas are prevented by predicting inventory locations and shipping them promptly when shortages are detected.
   - Reducing the delivery time of a product to establish a corporate image increases consumer demand.
   - Finding the proper inventory limits for items and components based on consumer demand dynamically and with real-time warehouse visibility. Preferably, inventory management systems should be integrated among CS members.
6. Have a robust supplier assessment plan (Jajja et al. 2016; Ariadi et al. 2021)
   - Evaluate suppliers according to various criteria and attributes from an economic perspective.
   - Develop supplier assessment and audit plans to help suppliers eliminate and replace waste and, where appropriate, find alternatives.
   - Establishing formal partnership contracts with suppliers, although building on the trust many suppliers have earned, is good.
   - Cost-benefit analysis is implemented regularly to prevent problems after payment to suppliers, that is, to ensure after-sales services.
7. Implement demand planning systems (Haikal et al. 2020; Arribasplata et al. 2018)
   - Use quantitative demand forecasting approaches based on historic data and not only on guesses or assumptions.
   - Avoid miscalculations in inventory forecasts due to under or over-forecasting because they can lead to low inventories or much money invested in raw

materials with low turnover, which means money that is not making money and is simply sitting idle.
- Having the right models to predict material demand ensures that the right products are delivered in the right quantities.
- Focus on demand forecasting for the reducing process; product uncertainty does not increase it. This reduction in uncertainty allows for informed business decisions and improved inventory flow.

8. Prioritizing demand (Hines 2014)
   - Not all products are vital, so some star products or services should be identified, always in stock, and analyzed.
   - In addition, not all products target the same market sector; therefore, analyzing demand segments helps identify areas where the company can improve or risk.
   - Demand-based segmentation helps to manage the entire product lifecycle, accurately forecast demand, and stock the necessary inventory.

9. Increasing data transparency (Skilton and Robinson 2009; Kumar et al. 2016)
   - Transparency is synonymous with visibility; therefore, warehouses should be eliminated as far as possible to minimize differences between the status reported by electronic systems and what is physically held.
   - The integration of information technology enables data transparency among CS partners.
   - The transparency and distribution of data facilitate fast and efficient decision-making, often taken by a group of people simultaneously.

10. Review procedures regularly (Alomar and Pasek 2014; Zubareva and Polukhin 2019; Kunnapapdeelert and Pitchayadejanant 2021)
    - Evaluate the operations and performance of the CS frequently, as this allows for identifying areas of opportunity, trends, and patterns such as late shipments, backorders, poor quality, and recurring problems.
    - Inventory management services, their flow throughout the CS, and the electronic logistics management platform help identify problem areas that can be prevented or resolved quickly.
    - Perform scenario simulations to forecast demand under different conditions and disruptive events to anticipate problems and obtain information to optimize overall performance across the CS.

11. Implement emerging technology (Varchenko Olga et al. 2020; Merzlyakova and Goncharova 2020; Bodrova et al. 2019)
    - Adopt advanced technology such as artificial intelligence, radio frequency systems, and robots for moving heavy materials, among others, to stay competitive in the logistics landscape.

   - The future of CS management will continue to include digital solutions that increase efficiency and automate and reduce costs. Comprehensive multi-dimensional automation and logistics systems can help solve operational problems using modern strategies.

12. Start optimization (Kotzab et al. 2003; Durga Prasad et al. 2012)
   - Constantly review the flow of materials through the production system and identify downtimes, delays, and material backlogs to eliminate or minimize them, which may involve redistribution.
   - Identify the key variables of the CS can direct efforts to obtain the best values following the company's needs.
   - Keep in mind that everything that can be measured can be improved, so the first step is to know the situation of the CS and establish new levels in the parameters.

After this introduction on the meaning of SCS and the strategies proposed for its constant business improvement, the various sections of this document continue with a bibliometric review of SCS, analyzing the main trends, authors, institutions, and countries that have most addressed the subject.

1.1.4 SCS Research Trends

The study of SCS is not new; there have been reports since the last century. When reviewing the trends in the number of documents published on SCS, it was observed that it has been increasing. Figure 1.1 shows that the first document that integrates the word "supply chain strategy" appeared in 1993, followed by another in 1994. From 1997 onwards, three documents appeared, an increasing number. A trend line has been added to the data in Fig. 1.1, indicating growth which occurred from 1997 onwards. However, it should be noted that in 2020 and 2021, the period in which the COVID-19 pandemic occurred, the number of documents decreased.

Specifically, many authors have conducted literature reviews regarding the trends in SCS; for example, Stevenson and Spring (2007) reviews these concepts of flexibility as SCS and indicates that it can be applied when there is full integration with customers and suppliers through direct communication, Goldschmidt and Kumar (2016) analyses SCS in cases of disasters and crises in order to be able to respond with a humanitarian supply chain with agility and attention to the population, Pérez-Salazar et al. (2017) reviews the impact of knowledge management as part of the SCS on SCS efficiency rates, which facilitates the management of trained personnel; Routroy and Behera (2017) a literature review of agricultural supply chains and their strategies for transporting perishable products and impacting the health and integrity of consumers; finally, Nabipour and Ülkü (2021) a review analysing the implementation of blockchain technologies as part of SCS, indicating that this is a new trend and that special attention should be paid to it.

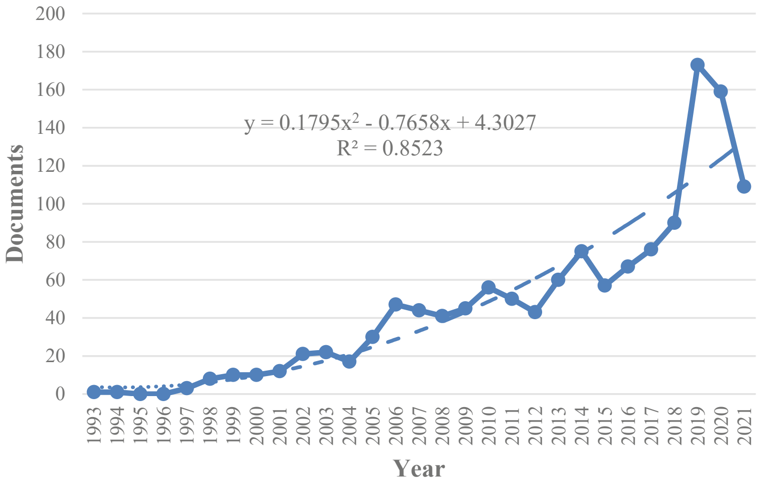


Fig. 1.1 Research trends in SCS

Therefore, several very specific literature reviews have analyzed the impact of some activities or events on SCS, such as blockchain technologies, agility, or specific industrial sectors. In addition, as seen from the 12 points listed to improve SCS, the factors and activities that affect SCS can vary, as their applications range from the sourcing to the production process and end with the distribution of products. Through this material flow, it is possible to improve SCS, so strategies and methodologies are applied. However, the following questions should be addressed:

1. Is the study of SCS of academic and scientific importance?
2. What are the trends in SCS research?
3. If this topic is important, which institutions and countries are researching it?
4. Who are academics who are most interested in or publish in the SCS?
5. What keywords are most commonly used in such research?
6. What are the most-cited or referenced documents in the SCS?
7. Which journals publish the most in the SCS?
8. What are the most cited countries, institutions, and authors?

As there is no concise answer to these questions, SCS and its methodologies are the focus of this chapter. A bibliometric review was conducted on this topic, which can serve as a basis for students and those interested in identifying the main research groups, trends, and the primary authors and institutions in which research is conducted.

After this introduction, Sect. 1.2 presents the methodology used to answer the questions, Sect. 1.3 presents the results, and Sect. 1.4 presents some general conclusions on SCS.

1.2 Methodology

The data analysis was divided into two main activities, which are outlined below.

1.2.1 Identification of References

The PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) methodology is used to identify the papers published about SCSs. It is chosen, as it is defined by Hutton et al. (2016), as a research methodology that enables and facilitates the process of generating bibliometric reviews and meta-analysis reports. In addition, it has been accepted by the scientific community, where several applications of PRISMA can be found. For example, Kim and So (2022) analyzed customer experiences in the tourism industry, and Baarimah et al. (2022) identified methodologies used in rapid response to disasters and used it to study trends, and de Araújo et al. (2022) used to study trends in photodynamic therapies in endodontics, to name a few.

A search was carried out using the equation (TITLE-ABS-KEY (“supply chain strategies”) OR TITLE-ABS-KEY (“supply chain strategy”) OR TITLE-ABS-KEY (“supply chain methodologies”) OR TITLE-ABS-KEY (“supply chain methodology”)) in the SCOPUS database, as it integrates many others (including ScienceDirect). The DIMENSIONS database was also used as a complement to the SCOPUS list of documents. It is important to mention that the analysis was carried out with the number of documents found on October 20, 2022, and that the date readers carry out this consultation again may increase the number of documents.

The references found in the RIS format were downloaded from both databases to begin debugging and eliminating repeated ones, as done in Endnote 8.0 software. Once cleaned, they were integrated into a spreadsheet in CSV format and read in Excel. However, accepted but not published articles were excluded, focusing only on those with a journal number and volume assigned to them. Similarly, the years 2022 and 2023 were excluded, as they affect the adjustment of trend lines, analyzing only up to 2021, which has already culminated.

1.2.2 Analysis of References

Once the database has been cleaned, the data are analyzed using VOSviewer v 1.6.18, which focuses on the following:

1. Identify the main authors researching SCS, institutions, and the countries where they are based.
2. Recognize the main keywords used by authors and editors in SCS documents.
3. Define the most cited documents, journals, authors, institutions, and countries.

4. Co-citations for references, sources, and authors.

A combination of graphs generated by VOSviewer software and others is illustrated in Excel for clarity. It is important to mention that all databases are available in a repository that readers can consult at the following link: http://dx.doi.org/10.17632/cs9zv3tx48.1.

1.3 Results

1.3.1 Identification of Documents

A total of 1987 papers were identified in the SCOPUS and DIMENSIONS databases. However, when the databases were downloaded and cleaned, 477 were identified as repeats and were removed, leaving only 1510. In addition, 79 documents from 2022 to 2023 were removed to obtain a more accurate trend analysis, yielding a total of 1430 documents to be analyzed. Figure 1.2 illustrates the purging process of the database analyzed according to the PRISMA methodology.

1.3.2 The Main Authors

A total of 3196 authors were identified who have published on SCS, and Table 1.1 indicates those with at least three publications. It is noted that Christopher M. leads this area of research, Saputra J. and Wang S. have nine papers each, and Caniato F., Kumar S., Liu S. and Moyano-Fuentes J. have six.

By analyzing the first 1000 authors, 15 clusters were identified in different colors, as illustrated in Fig. 1.3. It can be seen that Wang S. is one of the pioneers, although his network of collaborators is small. Similarly, authors such as Zhang, X; Zhang, J; Wang, X. Goh, M. and Liu, S. lead other very active clusters. For a list of authors, see the supplementary material in Excel in the sheet entitled Authors.

However, not all authors have started research on this topic simultaneously, so to know the academic productivity of these authors over time, Fig. 1.4 illustrates the years on the horizontal axis and the names of some of the most important authors on the vertical axis. The name or surname was not identified for many of them; therefore, they were reported as NA in the first line. In the same way, it is observed which of them were active in the year 2021, indicating the number of articles they generated. In this case, Liu S, Lestari F, Chen Z and Maqueira-Marin JM were the ones who, in that year, reported some academic products.

Figure 1.5 illustrates the authors' impact according to the H-index because not all the documents they generated are equally cited. In this case, Saputra J and Christopher M, one of the initiators of this topic, has had the greatest impact on his academic

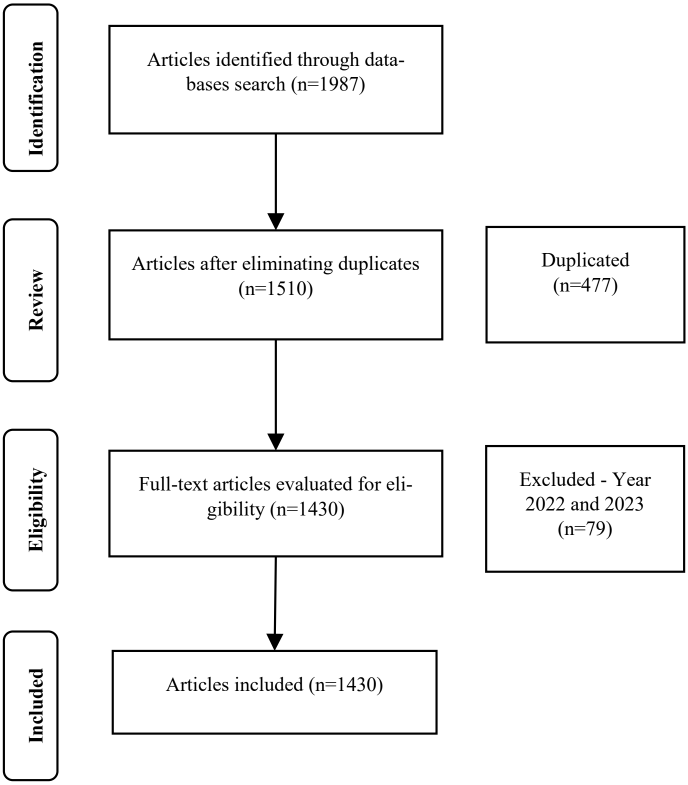


Fig. 1.2 PRISMA methodology for paper identification in SCS

output, indicating that his work has been widely cited. Similarly, Wang S, with an H-index of six, ranks second, while Helmi, Kumar, and Min occupy third place.

1.3.3 The Main Areas of Application of the SCS

The application of SCS is very varied; although it starts in industrial production systems, nowadays, it is possible to observe that SCS is being applied to food production systems, vaccine and drug distribution systems, and the production and distribution of medicines (Tan et al. 2022; Pérez-Mesa et al. 2021), distribution of vaccines and medicines (Prosser et al. 2022; Sarley et al. 2017) distribution of food in periods of health crises, among many others (Raassens et al. 2022) among many others. However, strategies have always aided the decision-making process, and there are many areas of knowledge in this field (Sreekumar and Rajmohan 2019), and there are many areas of knowledge in which they have been applied.

Table 1.1 Main authors in SCS

Authors	Documents
Christopher M., Saputra J., Wang S	
Caniato F., Kumar S., Liu S., Moyano-Fuentes J	
Chen Z., Ferreira L. M. D. F., Godsell J., Goh M., Helmi S. A., Lestari F., Maqueira-Marín J. M., Min H., Naim M., Naim M. M., Qi Y., Sahay B. S., Sundarakani B., Wang W., Wang X., Xie G	5
Bandinelli R., Berrado A., Caridi M., Castelli C., Chandak A., Chen W., Chinnam R. B., Fantazy K. A., Fearne A., Galankashi M. R., Harris G. A., Ismail K., Lau K. H., Lee H. L., Li C., Liu L., Mollenkopf D., Moreira A. C., Potter A., Roth A. V., Russo I., Shankar R., Sharma R. R. K., Snowdon A. W., Soni G., Vanteddu G., Wang J., Wang Y., Zailani S., Zhang J., Zhang X., Zhao X., Zimmermann R	
Bindi B., Birtwistle G., Brun A., Cagliano R., Chen X., Cheung W., Componation P. J., Dalpati A., Darkow I.-L., Elshin L. A., Fani V., Fiorito S. S., Gosling J., Hafeez K., Han C., Hong P., Huang X., Jermsittiparsert K., Jiang H., Kim S. W., Kumar A., Kumar R., Leung J., Liu J., Liu X., Mangla S. K., Mohan R., Morita H., Kim S. W., Kumar A., Kumar R., Leung J., Liu J., Liu X., Mangla S. K., Mohan R., Morita M., Mostafa S., Mustafin A. N., Oliveira-Dias D., Osman A., Pustovarov A. A., Rajagopal P., Randall W. S., Raut R. D., Richey R. G., Roath A. S., Ronchi S Safiullin M. R., Sharma M., Solaiman M., Stank T. P., Stevenson M., Su Y., Tarafdar M., Tate W. L., Towill D., Towill D. R., Tsay A. A., Tsay A. A., Ukolov V. F., Ukolov V. F., Ukolov V. F., Ukolov V. F., Ukolov V. F., Ukolov V. F., Ukolov V. F., Wang C., Wong C. Y., Wright A., Xu J., Yao D.-Q., Yue W., Zhao Y	

Figure 1.6 illustrates the main areas in which the applications of the term SCS have been classified in the documents analyzed. It can be seen that Business, Management and Accounting is the category with the highest level of applications with 30%, followed by Decision Sciences with 18%, and Computer Sciences and Engineering with 15%. To report an easy-to-interpret graph, categories representing less than 1% were integrated into a category called other. Refer to the supplementary material for readers who wish to see the full list of applications.

1.3.4 Types of Documents Published on SCS

One way to understand the consolidation of research topics is to check the type of document in which it is published, and for SCS. Table 1.2 illustrates the distribution and shows that most of the documents identified fall into the category of Articles or Conference papers, indicating that this research area is consolidated as it has gone through a peer review process.

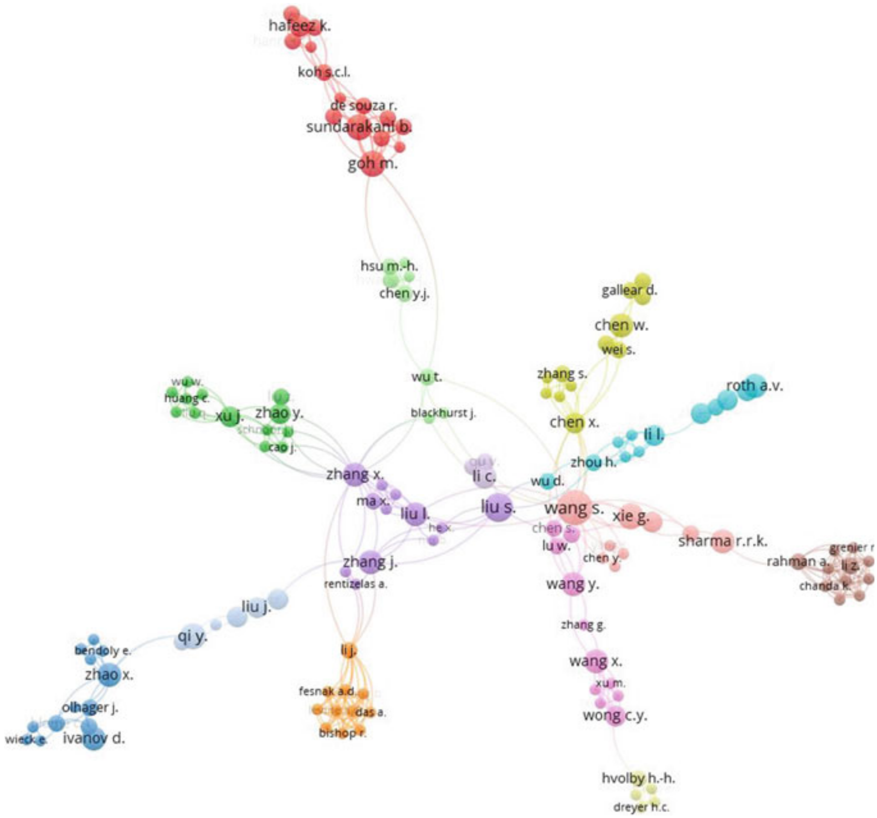


Fig. 1.3 Main authors in SCS

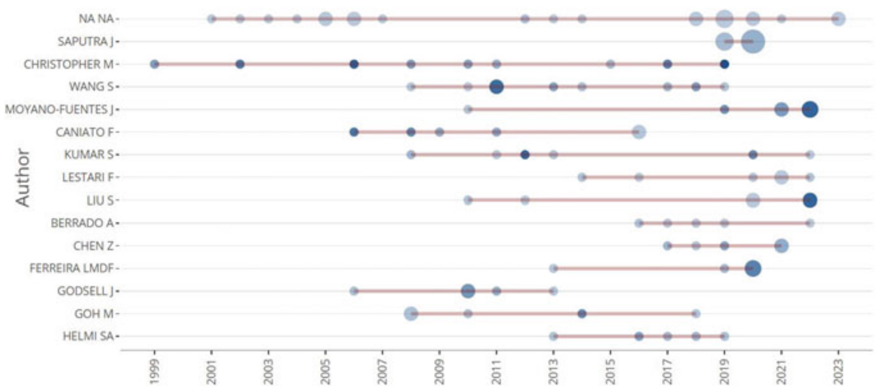


Fig. 1.4 Productivity of authors over time

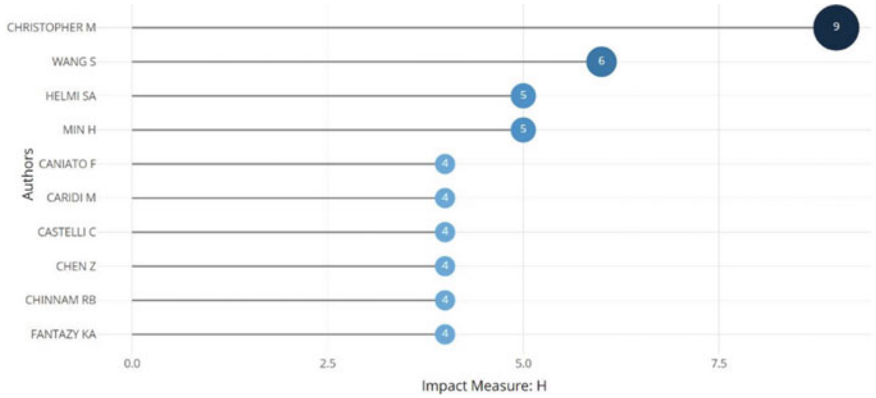


Fig. 1.5 Authors' H-index in SCS

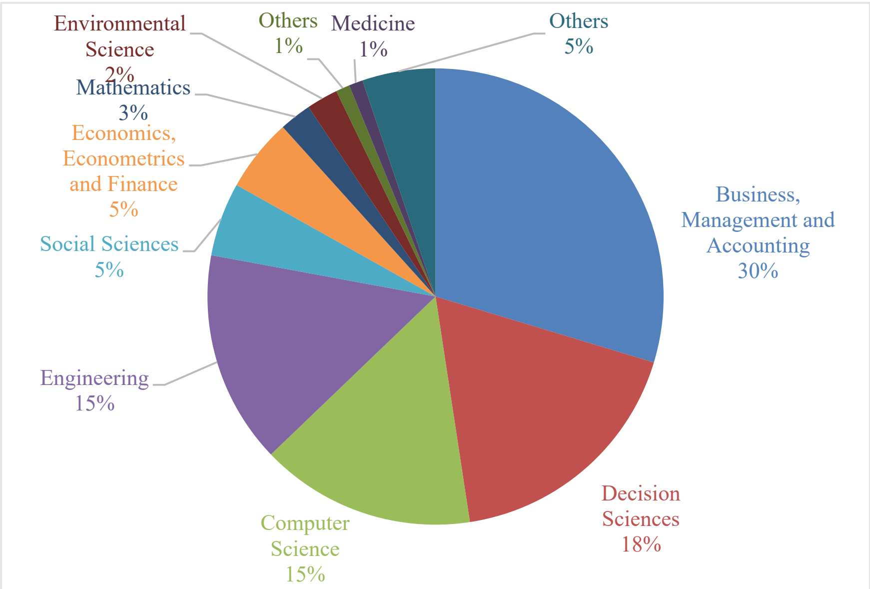


Fig. 1.6 Research areas in SCS

1.3.5 Funding and Sponsors in SCS Research

The design and application of SCS have been of interest to many organizations that have funded many research projects and, as a result, are recognized through publications. Figure 1.7 illustrates the main institutions that have funded this research topic, with the National Natural Science Foundation of China and the Kazan Federal University leading the way. It is noteworthy that, in this case, the Kazan Federal

Table 1.2 Type of SCS documents

Document	Number
Article	893
Conference paper	265
Book chapter	
Review	55
Book	
Short survey	10
Conference review	8
Editorial	
Note	3
Abstract report	1
Erratum	1

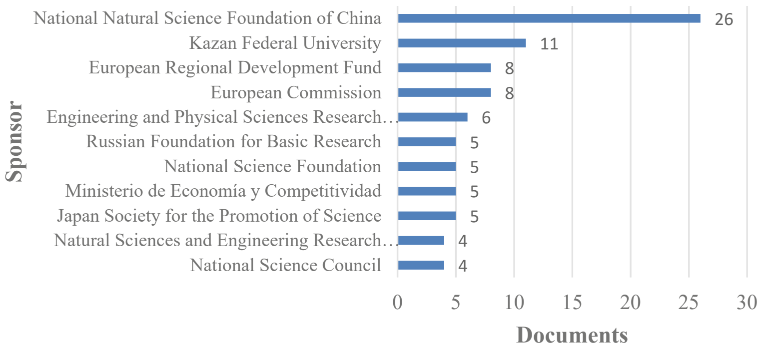


Fig. 1.7 Funding and sponsor institutions for SCS research

University is a university and not a national or international body, such as the European Commission and the European Regional Development Fund, which demonstrates the focus of that institution, as well as the fact that it ranks first in terms of the number of papers published.

1.3.6 The Main Institutions Where SCS Research is Carried Out

A total of 2524 institutions have been identified as the affiliation of the authors researching SCS, as shown in Table 1.3, with the Kazan Federal University of the Russian Federation having published the most papers out of all the others, with 12 papers (three times more than the second-ranked institutions). The next institutions are the Faculty of Business, Economics and Social Development, Universiti

Table 1.3 Main institutions doing SCS research

Organizations	Documents
Kazan Federal University, Russian Federation	
Faculty of Business, Economics and Social Development, Universiti Malaysia; Terengganu, Kuala Nerus, Terengganu, Malaysia; Management Development Institute, Gurgaon, India	
Andersen Consulting, New Zealand; Auburn University, United States; Business School, Nanjing Normal University, Qixia District, Nanjing, 210,023, China; Cardiff Business School, Cardiff University, Cardiff, United Kingdom; Cranfield School of Management, Cranfield University, Cranfield, United Kingdom; Department Of Mathematics, Faculty Of Mathematics And Natural Sciences, Universitas Padjadjaran, Indonesia; Eada Business School, Barcelona, Spain; Faculty of Business, Economics And Social Development, Universiti Malaysia; Terengganu, Kuala Nerus, Terengganu, Malaysia; Kazan National University Of Science And Technology, Russian Federation; Kent Business School, University Of Kent, Canterbury, United Kingdom; Kulliyah Muamalat, Insaniah University College, Kuala Ketil, Kedah, 09,300, Malaysia; Manchester Business School, University of Manchester, Manchester, United Kingdom; Michigan State University, United States; Plekhanov Russian University of Economics, Russian Federation; School of Economics and Management, Tongji University, Shanghai, China; Supply Chain and Logistics Management Research Lab, Department of Business; Administration, School of Business, Soochow University, Taipei, Taiwan; University of Tennessee, United States	

Malaysia; Terengganu, Kuala Nerus, Terengganu in Malaysia; and the Management Development Institute, Gurgaon in India, with four papers. These results are interesting because these two institutions belong to Indonesia.

This analysis shows that many institutions are involved in SCS research and there are no leading institutions beyond those mentioned above, because more than 2,000 institutions have only one document.

However, not all institutions have evolved in a similar manner. Figure 1.8 illustrates on the x-axis the years (timeline) and on the y-axis the number of documents published. It can be seen that many universities have been growing relatively slowly but steadily. However, the number of papers published by the Kazan Federal University from 2018 onwards is striking, and since 2018, it has maintained high academic productivity.

It is also noted that there were several papers where it was impossible to identify an institution of affiliation and that appear as not reported, which unfortunately are on the increase.

1.3.7 *Countries Where SCS Research is Being Conducted*

A total of 122 countries were identified in which an author or institution has generated research in the SCS, and Fig. 1.9 illustrates the top 15. It is clear that, as countries,

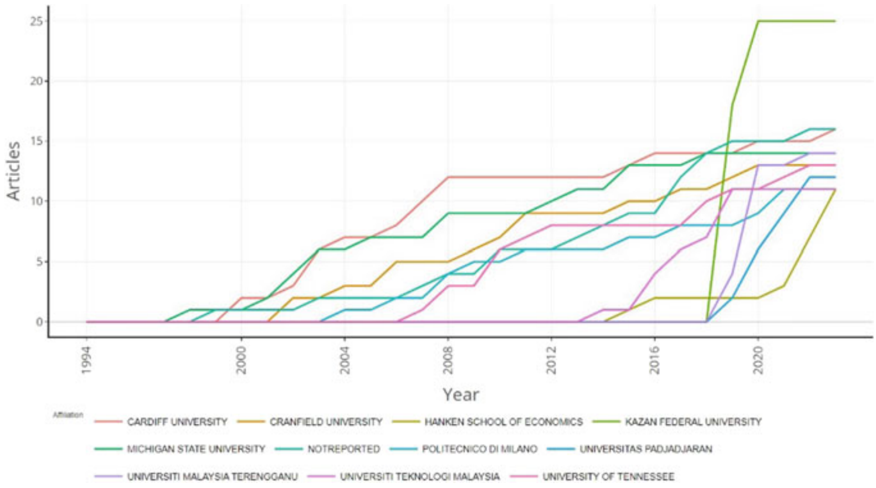
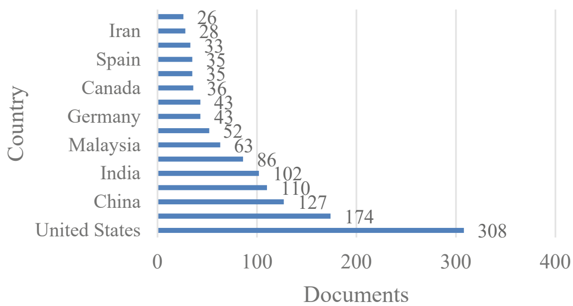


Fig. 1.8 Academic output by the institution on SCS

the United States of America and the United Kingdom have led this line of research; however, countries such as China, Indonesia, and India have a significant scientific output, which is to be expected, as they have many educational institutions and research centers. Countries such as the Russian Federation, which has the institution with the highest academic productivity with SCS, appear in sixth place.

Figure 1.10 shows the relationships between the countries, which have been integrated into 13 clusters, dominated by the United States of America, the United Kingdom, China, India, and Indonesia, and the Russian Federation, which has been excluded from the graph for reasons of symmetry and because it is only related to the United States of America, the United Kingdom, and India. Figure 1.10 illustrates the countries in different colors; in this case, the purple color represents countries with a long history, such as the United States, the Netherlands, Hong Kong, Australia, Taiwan, and Finland, while the countries starting in this line of research are those represented in yellow, such as Oman, Indonesia, Malaysia, and Peru.

Fig. 1.9 Countries publishing on SCS



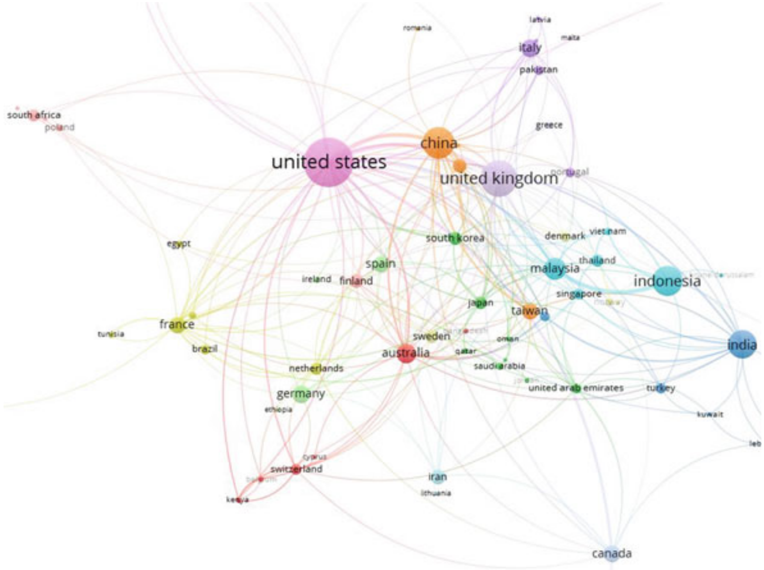


Fig. 1.10 Countries researching SCS and their level of maturity

Figure 1.11 graphically illustrates the distribution of cooperation between countries regarding SCS. It can be seen that in the Americas, the United States collaborates most with other countries, while in Europe, it is the United Kingdom, and in Asia, it is China and India. However, to a lesser extent, countries such as Japan, South Korea, Australia, New Zealand, Spain, and Germany have begun to research this topic and collaborate with other countries.

Figure 1.12 illustrates the timeline of academic productivity in the different countries. It can be seen that the United States, United Kingdom, China, and India have

Fig. 1.11 Relationships between countries in SCS publications

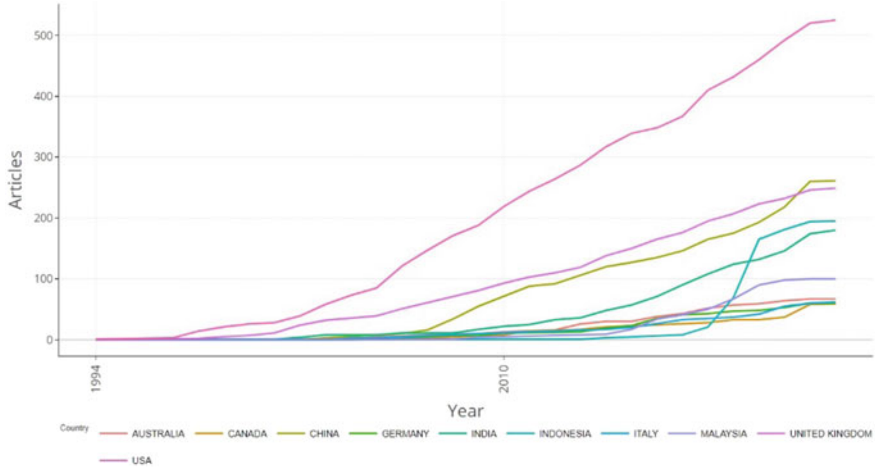


Fig. 1.12 Timeline of SCS publications in pioneer countries

a steady incremental trend. Other countries, such as Iran, Italy, and Malaysia, have recently published papers on SCS and are also on the rise.

1.3.8 Main Keywords

A total of 3338 keywords used by the authors were identified in all the documents analyzed, and Fig. 1.13 illustrates the top 15. Supply chain management (SCM), supply chain strategy (SCS), and supply chain (SC), which rank first, second, and third, stand out.

This analysis is important because it allows us to see that SCS has been related to CS performance, agility, sustainability of its activities, SC integration, lean operations, simulation, and even, in recent times, to Covid-19, where SCs have undergone disruption, so the associated word of risk management is also observed. See the supplementary material in the keyword sheet for a complete list of words.

Figure 1.14 illustrates the distribution of keywords presented at least five times and was integrated into 12 clusters. The keywords represented by purple circles are those initially used in this study, and are represented by supply chain management, retailing, logistics, modeling, integration, and simulation, among others. In contrast, other intermediate words in seniority are represented by green circles, such as agility, leanness, agility, performance, supply chain integration, knowledge management, and operational strategy. Finally, the most recent words are in yellow and refer to blockchain, sustainability, resilience, the Internet of Things, Industry 4.0, covid-19, and big data, among others.

However, not all the words used by authors are used by publishers to index documents in different databases. A total of 3680 different words were identified, and

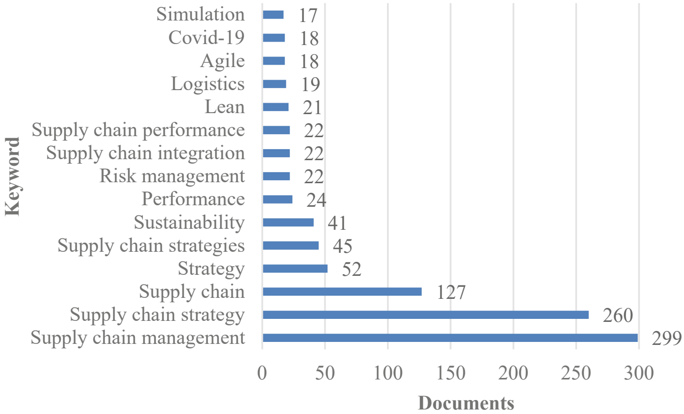


Fig. 1.13 Main keywords

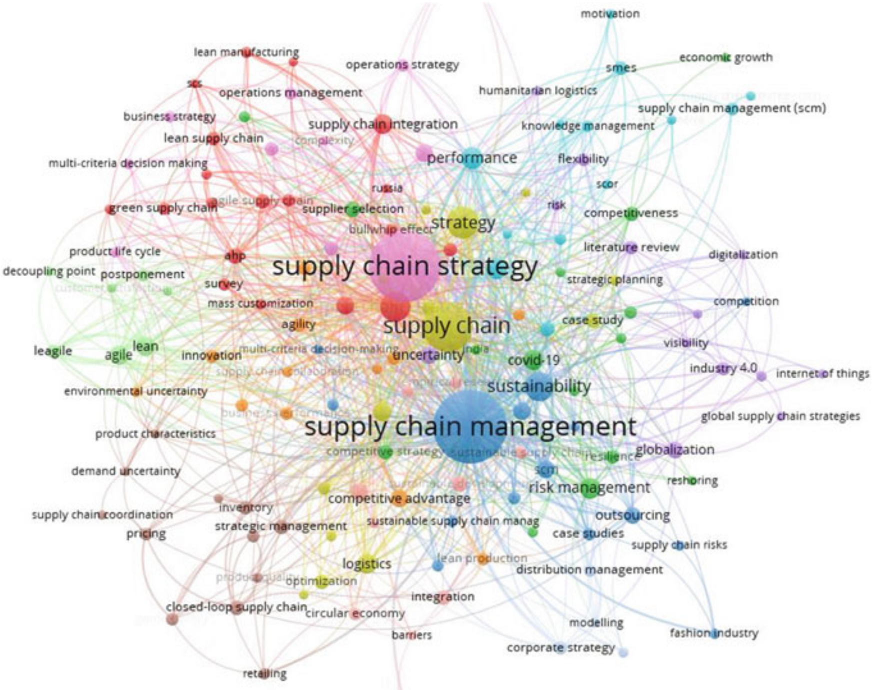


Fig. 1.14 Main keywords used by authors

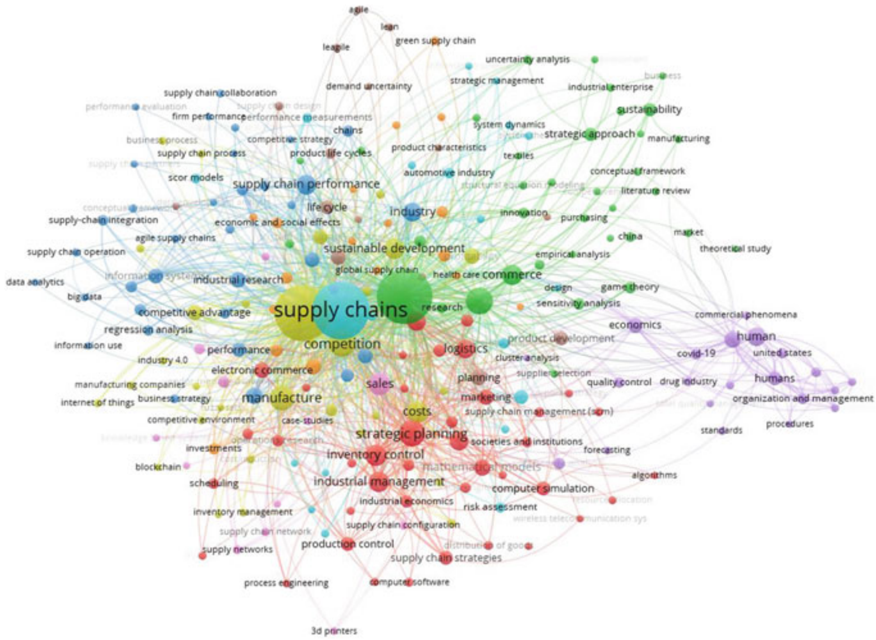


Fig. 1.15 Index keywords for SCS

Fig. 1.15 illustrates the keywords used and appearing at least five times. The most frequently appearing words were supply chains (289), supply chain management (279), supply chain strategy (267), competition (68), decision making (65), strategic planning (61), manufacturing (57), sales (49), inventory control (49), and costs (44). From these words, it can be seen that SCS has been used for better management of SC, improving the competitiveness of SC, facilitating decision-making processes, and, above all, two words are associated with economic aspects, such as sales and costs.

Figure 1.16 illustrates how the word Supply Chain Strategy and Supply Chain Management are among the most important words and how others have evolved or been generated based on those considered to be the origin, indicating the number of occurrences and the percentage they represent. Currently, the keywords related to "supply chain strategies" are China, "supply chains", "agile supply chains", integration, and "corporate strategy". However, other recent intermediate words refer to simulation, supplier selection, sustainable development, the global supply chain, optimization, and strategy management.

When analyzing the evolution of the main keywords used by the authors to index their documents, it can be seen that at least three of them have grown in the number of times they were used per year, which refers to "supply chain management", "supply chain strategy" and "supply chain". Figure 1.17 illustrates the evolution of the first 10 words used by the authors cumulatively.

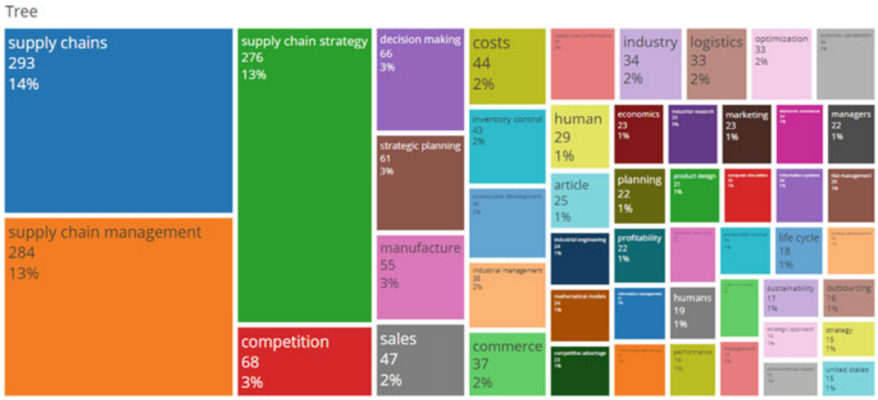


Fig. 1.16 Keyword generation

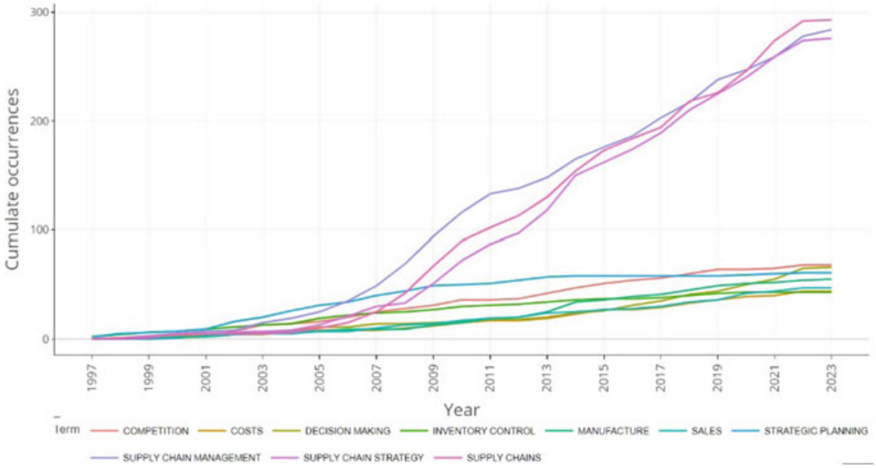


Fig. 1.17 Evaluation of the use of the main keywords

Figure 1.18 illustrates the evolution of the keywords, showing the date when they were first and last used. The circles indicate that they were applied more than once on these dates. For example, it can be seen that recently associated words such as “COVID-19”, “food supply chain”, “Industry 4.0”, “supply chain resilience”, “circular economy”, “uncertainty,” and “sustainable supply chain” are currently being used the most. However, the words that first appeared to be used in this topic are “supply chain management”, “simulation”, “information systems”, “corporate strategy,” and integration.

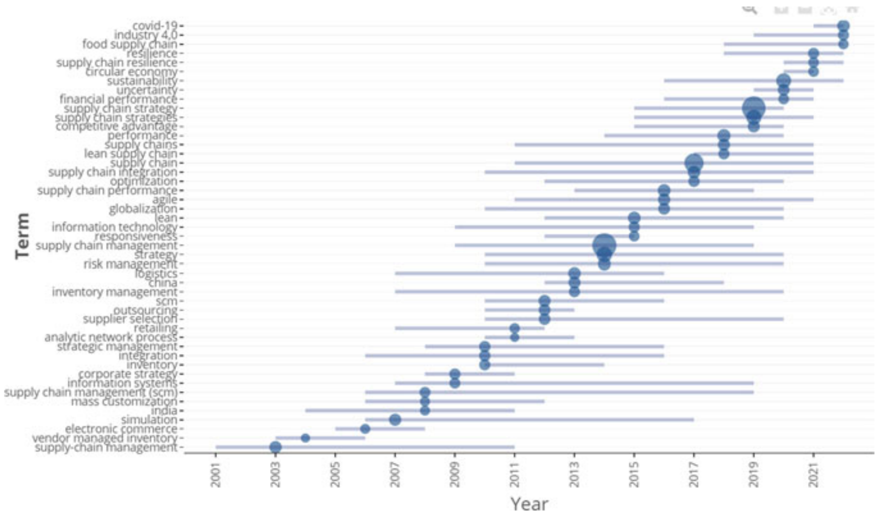


Fig. 1.18 Keyword trends

1.3.9 Most Cited Documents

Of the 1430 papers identified in this analysis, only 1000 have at least one citation, and 430 have not yet been cited, which may be because they have only recently been published. Table 1.4 illustrates the top 10 most cited papers and for the full list in descending order (see the supplementary material). The analysis of the names of these most-cited documents concludes that SCS relates to other aspects of CS, such as integration, agility, rapid response to customers, alignment with uncertainty, social responsibility, flexibility, and environmental aspects, which can be considered as strategies to be applied.

Figure 1.19 illustrates the distribution network of the most cited papers on SCS with at least one citation, which was integrated into 39 clusters. In this case, authors with purple or purple documents are pioneering or older documents, while those represented in green are more recent, and the yellow ones are the most current. Figure 1.19 is interesting, as it shows that many papers with different focuses (agility, flexibility, and customers) have always been the basis for other studies.

1.3.10 Most Cited Sources

A total of 652 different sources, journals, or journals have been identified, and Fig. 1.20 illustrates the 15 most important ones, where it is observed that the Journal of Operations Management and the International Journal of Production Economics are the most important. In the same way, Fig. 1.21 illustrates the distribution network

Table 1.4 Most cited documents

Authors	Document	Quotations
Frohlich and Westbrook (2001)	Arcs of integration: an international study of supply chain strategies	1657
Ben Naylor et al. (1999)	Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain	1087
Vickery et al. (2003)	The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationships	864
Lee (2002)	Aligning supply chain strategies with product uncertainties	843
Rosenzweig et al. (2003)	The influence of an integration strategy on competitive capabilities and business performance: an exploratory study of consumer products manufacturers	619
Narasimhan and Kim (2002)	Effect of supply chain integration on the relationship between diversification and performance: evidence from Japanese and Korean firms	503
Tate et al. (2010)	Corporate social responsibility reports: a thematic analysis related to supply chain management	450
Stevenson and Spring (2007)	Flexibility from a supply chain perspective: definition and review	425
Mollenkopf et al. (2010)	Green, lean, and global supply chains	423
Wang et al. (2004)	Product-driven supply chain selection using integrated multi-criteria decision-making methodology	422

of the main journals integrated into 21 clusters, where those represented by purple mean that they have at least two decades of publishing works related to SCS, those represented by green are journals that have approximately one decade, and those represented in yellow are the most recent ones.

In this case, it is observed that the International Journal of Supply Chain Management, which is one of the most representative journals, is very recent in comparison to others, such as Manufacturing and Services Operations Management and Sustainability, which have been published on this topic for a long time and do so very little.

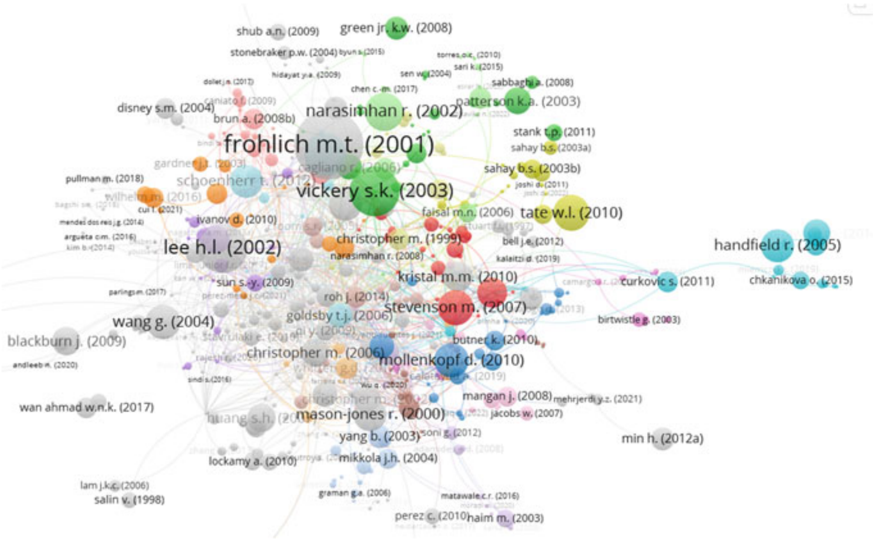


Fig. 1.19 Most cited documents and their authors

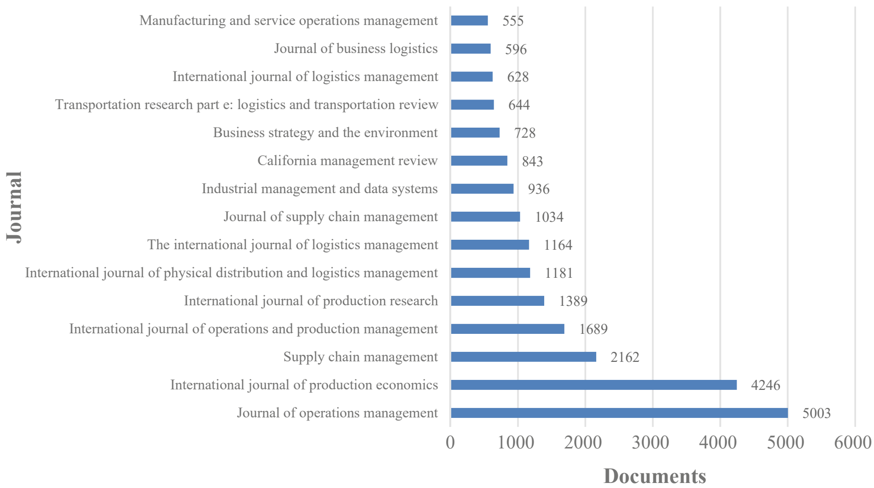


Fig. 1.20 Top 15 most cited sources

1.3.11 Most Cited Authors

Of the total number of authors identified, only 2318 had at least one citation and 1954 had at least two citations. Table 1.5 illustrates the top 15 most-cited authors, the number of papers they have generated, and the total number of citations accumulated in all their papers. In this case, it can be seen that Frohlich M. T. and Westbrook R.

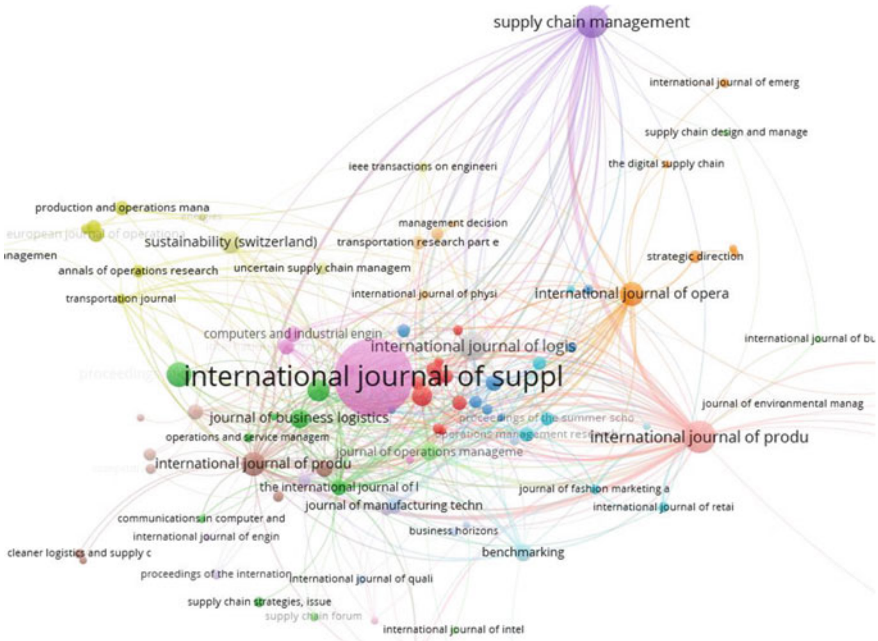


Fig. 1.21 Distribution network of most cited sources

together have generated only two papers on SCS but have accumulated 2036 citations, while Naim M. M. in five papers has accumulated 1319 citations and Christopher M. with 9 papers has accumulated 1118 citations. In addition, Ben Naylor J. and Berry D., together generated 1087 citations in one paper.

The 1954 authors with at least two citations are integrated into 34 clusters, and Fig. 1.22 illustrates their distribution network. When the links they have with other authors are analyzed to determine their academic collaboration network, Christopher M. (386), Qi Y. (352), Towill D. (290), Lee H. L. (283), Zhao X. (266), Qrunfleh S. (265), Tarafdar M. (198), Frohlich M. T. (177) and Westbrook R. (177) are the most collaborative.

1.3.12 Most Cited Institutions

Not all institutions that publish papers are cited. In this case, a total of 1867 institutions have been identified as having at least one paper and receiving at least one citation, while 1612 have at least two and 1444 have at least three. Table 1.5 illustrates the most cited institutions, the country of origin, the document number, and the number of citations they have received. It is important to mention that if the same university has campuses in different cities, they are considered differently as they represent

Table 1.5 Most cited authors

Authors	Documents	Citation
Frohlich M. T		2036
Westbrook R		2036
Naim M. M	5	1319
Christopher M	9	1118
Ben Naylor J	1	1087
Berry D	1	1087
Roth A. V		1031
Lee H. L		919
Tate W. L		873
Calantone R	1	864
Droge C	1	864
Jayaram J	1	864
Vickery S. K	1	864
Huang S. H		713
Rosenzweig E. D		703

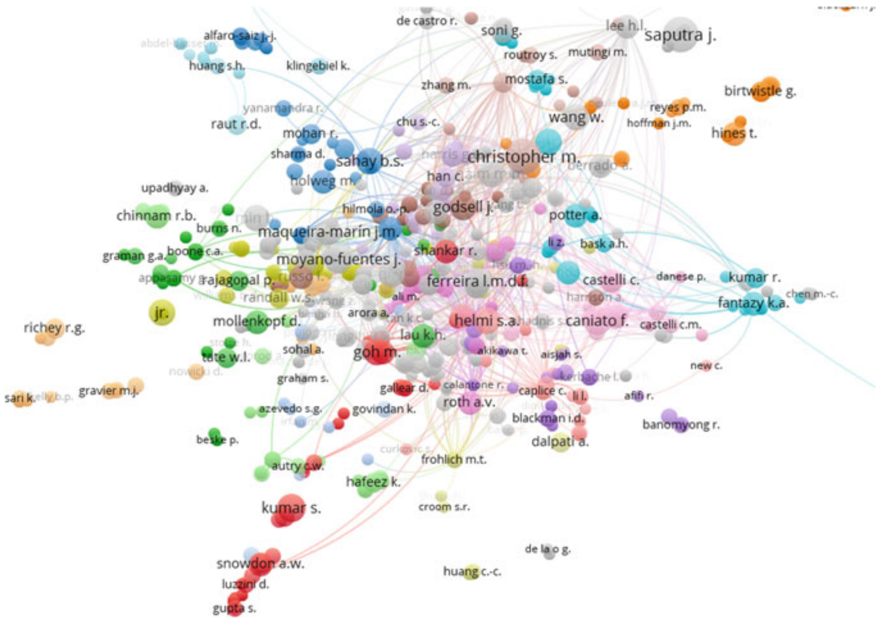


Fig. 1.22 Relationships between the most cited authors

Table 1.6 Most cited institutions in SCS

Organizations	Documents	Citations
London Business School, London, United Kingdom	1	1657
The University of Oxford, Oxford, United Kingdom	1	1657
Formerly Logistics Syst. Dynam. Grp., Bristol, United Kingdom	1	1087
Logistics Systems Dynamics Group, Cardiff, United Kingdom	1	1087
Michigan State University, United States	1	864
University Of South Carolina, United States	1	864
Emory University, United States		703
Univ. North Carolina, Chapel Hill, United States	1	619
University Of Tennessee, Knoxville, United States		551
Michigan State University, East Lansing, United States	1	503
Miami University, United States	1	450
Lancaster University Management School, Lancaster, United Kingdom	1	425
University Of Toledo, Toledo, United States	1	422
University Of Cincinnati, Cincinnati, United States	1	422

different research groups. The list shown in Table 1.6 indicates that universities in the United States of America and the United Kingdom have been cited most frequently; however, when analyzing the number of documents they have generated, it can be seen that many of them have produced only one, and only Emory University and the University of Tennessee at Knoxville have generated two, so it can be concluded that there are no consolidated research groups that continue with this line of research.

1.3.13 Most Cited Countries

A total of 122 countries were identified as having at least one document related to SCS; 90 had at least one citation, while 32 had none. However, only 85 had at least two citations and 83 had at least three citations. Table 1.7 illustrates the top 15 of the 122 countries. The United States of America and the United Kingdom lead the list, with 14,924 and 10,316 citations, respectively, indicating that each of these papers has an average of 48.45 and 59.28 citations, respectively. However, it is important to note that, on the Asian continent, China, India, and Hong Kong stand out in publications related to this topic.

However, these countries have been pioneers in SCS research (Fig. 1.23). They are depicted in purple, indicating that they have been conducting research in this area for more than two decades. Similarly, Indonesia, Malaysia, China, India, and Iran are at least a decade old. More recently, countries such as Bahrain, Mexico, and Oman have begun to study the topic shown in yellow.

Table 1.7 Most cited countries

Country	Documents	Citation
United States of America	308	14,924
United Kingdom	174	10,316
China	128	1790
India	102	1446
Italy	43	1191
Hong Kong	26	1121
Canada	39	922
Germany	43	877
Netherlands	23	845
Taiwan	34	788
Malaysia	63	785
Spain	35	766
Australia	52	734
Sweden	23	603
South Korea	22	592

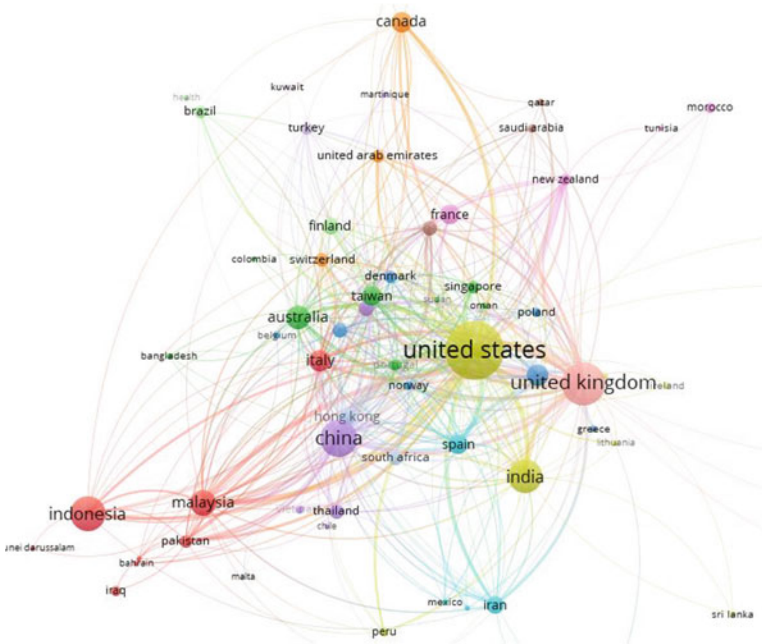


Fig. 1.23 Most cited countries

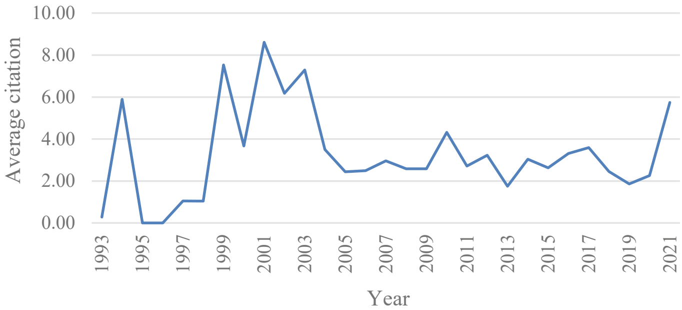


Fig. 1.24 Average citations per year

1.3.14 Average Number of Citations

The evolution of the average number of citations received per year is vital to understanding the evolution and importance of a research topic, and Fig. 1.24 illustrates this trend. It can be seen that immediately after the concept appeared in 1993, in 1994, there was an average of 5.89 citations per article, which were few and far between and a novelty. After that period, it was in 1999 that there was again an increase, being the second highest value with 7.53 citations on average, only after the year 2001 with 8.61.

However, after that period, in 2003, the trend stabilized, by which time there were more documents and authors could resort to new bibliographic consultations. Therefore, in the year 2021, an increase is again observed, which may be because many of the paradigms that were held for SCS have failed since the COVID-19 pandemic; therefore, scholars in this area of research are once again showing greater interest in this topic.

1.4 Conclusions

The bibliometric analysis of the 1430 papers published in the Scopus and Dimensions database on SCS led to the following conclusions.

1. The number of documents published on this topic is increasing, with the first document appearing in 1993; however, in 2020 and 2021, the number of documents decreased, which may be due to the period of health pandemic due to COVID-19.
2. The authors who have published the most academic papers on SCS are Christopher M., Saputra J. and Wang S. (9 papers each).
3. Wang S, Liu S and Zhang X are the authors with the most collaborations and lead established research groups.

4. Christopher M, Cianato F and Gossel are the authors who initiated the generation of academic papers on SCS. However, Christopher M and Wans S are the authors who have had the greatest impact H on others.
5. The main research areas in which SCS has been published are Business Management and Accounting, Decision Sciences, Computer Sciences and Engineering.
6. Most documents published on SCS are articles, conference papers, or book chapters.
7. The largest funders of SCS research are the National Natural Science Foundation of China and Kazan Federal University.
8. The most researched institutions in the SCS are the Kazan Federal University (Russian Federation), Terengganu University (Malaysia), and the Management Development Institute (India).
9. The countries that publish the most on SCS are the United States of America, the United Kingdom, China, Indonesia, and India, which in turn cooperate the most with other countries worldwide. In addition, they are also the ones that have shown an incremental evolution in terms of the number of publications over time.
10. The most used keywords were supply chain management (SCM), supply chain strategy (SCS), and supply chain (SC). However, recently, words associated with COVID-19, outsourcing, integration, agility, and corporate strategy have also been used.
11. The two most-cited papers in this area are Frohlich and Westbrook (2001) and Ben Naylor et al. (1999).
12. The most cited journals are the International Journal of Supply Chain Management, International Journal of Production Economics, and Supply Chain Management.
13. Authors with more than 1000 citations on this topic are Frohlich M. T., Westbrook R., Naim M. M., Christopher M., Ben Naylor J., Berry D. and Roth A. V.
14. Institutions with more than 1000 citations are London Business School (London, United Kingdom), University of Oxford (Oxford, United Kingdom), and Formerly Logistics Syst. Dynam. Grp. (Bristol, United Kingdom), and Logistics Systems Dynamics Group (Cardiff, United Kingdom).
15. The institutions with the most citations in SCS are the United States of America, the United Kingdom, China, and India; however, the former has more than 10,000 citations.
16. Finally, the average number of citations of SCS documents must be approximately three per document.

Finally, due to the current trade war between North American countries and NATO members with China, there is a likelihood that the trends in publications and collaborations between countries on SCS issues will change due to the new geopolitical game between these nations. For example, China and Europe may collaborate more with Latin American countries to improve their supply chains of raw materials and energy resources. In addition, because of the high exchange of consumer goods that will originate from the Tehuantepec isthmus inter-oceanic corridor project in Mexico, it is expected that there will be a large mobilization of goods to different countries, both North America and South America, and among many other countries around the world. Thus, these new trade routes and the geopolitical movement will present challenges in countries such as Mexico for designing low-cost, flexible, and automated supply chains. Therefore, this paper contributes significantly to locating the research groups in this field of study, locating the institutions that have conducted the most research on SC to quickly learn about their contributions and to find applications in upcoming challenges.

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Chapter 2
Using Meta-Learning in Automatic Demand Forecast with a Large Number of Products

Luis Gutiérrez and Marcel Goic

Abstract Demand analysis is one of the cornerstones of any supply chain management system, and most of the critical operational decisions in the supply chain rely on accurate demand predictions. Although a large body of academic literature proposes various forecasting methods, there are still important challenges when using them in practice. The common problem is that firms need to decide about thousands of products, and the demand patterns could be very different between them. In this setting, frequently, there is no single forecasting method that works well for all products. While some autoregressive models might work well in some cases, the demand for other products might require an ad-hoc identification of trend and seasonality components. In this chapter, we present a methodology based on meta-learning that automatically analyzes several features of the demand to identify the most suitable method to forecast the demand for each product. We apply the methodology to a large retailer in Latin America and show how the methodology can be successfully applied to thousands of products. Our analysis indicates that this approach significantly improves the firm's previous practices, leading to important efficiency gains in the supply chain.

Keywords Forecasting · Meta-learning · Time series · Retailing

2.1 Introduction

The retail industry faces a dynamic and competitive landscape that has been confronted with the irruption of digital channels, the emergence of new formats,

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and the increasing use of technology in the value chain. Among the long-term trends consolidated in recent years is the automation of various processes, ranging from inventory management to self-checkout terminals. In this research, we propose a methodology to automate demand forecast at the product-store level, which is an important input for several key processes such as assortment planning or inventory management. For instance, to automate the replenishment of stores from the distribution centers, we need to project how much product will be sold shortly in each store. Accurate forecasting has important consequences for operation performance. If the forecast underestimates the demand, the products will be out of stock, harming sales. If the forecast overestimates the demand, the inventory cost would be unnecessarily high, and it might even force the implementation of aggressive price reductions to reduce stocks.

The academic literature provides numerous methodologies to forecast demand in the retail industry (Ma et al. 2016; Huber and Stuckenschmidt 2020). However, practical implementations of automatic forecasting systems imply important methodological challenges. First, most retailers consider a large assortment of thousands of SKUs in several dozen stores, which require the completion of several thousands of forecasting tasks. Although computational power is not an important barrier to estimating a large number of statistical models, there is a more fundamental difficulty in automating demand forecasting. The underlying time series of sales of different products can be radically different, and there is no universal model to provide the best solution for all cases. While a simple autoregressive model can provide satisfactory solutions in some cases, other cases might require a more comprehensive identification of seasonal components. A common practice to deal with this problem is to either commit to a forecasting model that works well on average or assign human analysts to inspect the series and decide case by case. In this research, we propose a methodology to automatically select the best estimation method for each series, facilitating the automation of critical processes without sacrificing forecasting accuracy.

The need to use different forecasting models comes from the existence of distinct components in different demand series. To illustrate the point, in Fig. 2.1, we display the time series of sales of four different products in our dataset. For product A, we observe very pronounced spikes in demand. As this product belongs to the toy category, those spikes are associated with seasonal events such as Christmas or Children's Day, which are strongly associated with larger purchases in the toy category. For product B, demand is higher in the second part of every year, but that is mainly associated with year seasonality and not with a single event. This pattern is relatively common to items in the clothing category, where the demand tends to be very cyclical. In this set, we also have products with no evident seasonal patterns, such as products C and D. Product C presents large variations in sales. However, those occur at different times of the year, possibly associated with promotions or other unobservable factors. On the other hand, product D presents less variation over time, with almost no acute spikes in the observational period.

Overall, we observe series with very different components requiring different modeling approaches. To automate the forecast, we need to estimate every case

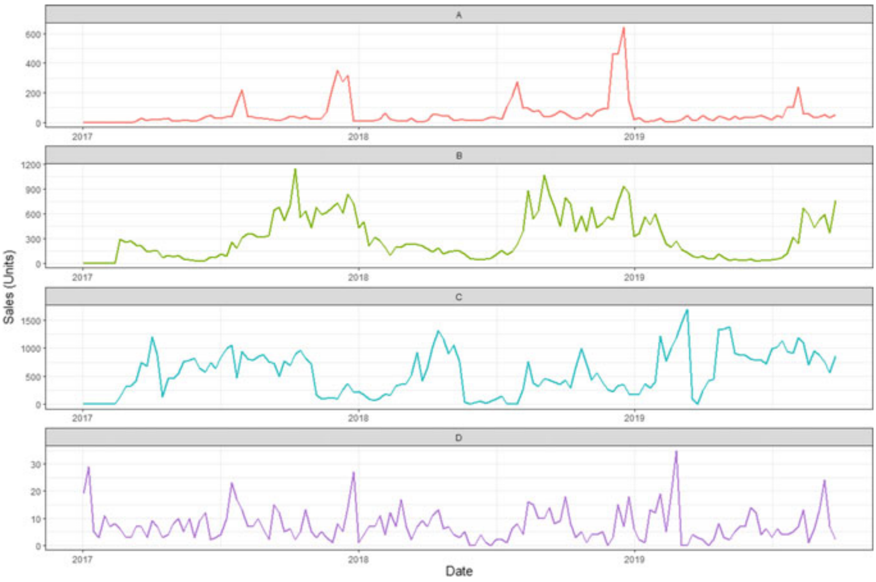

Fig. 2.1 Illustration of several time series with different seasonality and trend components

adequately. However, some models provide better results in some cases, and others perform better in others. Our solution is based on a technique called meta-learning, in which a machine learning model decides the best model to use in each case based on observable characteristics of the series, such as the trend and seasonality strength, as well as the size of the autoregressive components. To calibrate this model, we need to produce many forecasts using different models to identify which performs best under different conditions.

In addition to proposing a methodology to automatically select the best forecasting model for each series, using historical data, we evaluate the impact of utilizing this approach on the accuracy of the forecast, and we demonstrate that it could lead to better results. Furthermore, we conducted a business evaluation using a controlled experiment to compare product sales and inventory levels for products. We used the methodology to decide product replenishment against a control where orders were decided using standard business practices. Here we found that the model can indeed improve operational efficiency in practice. In this project, we developed a predictive model to generate an accurate automatic forecast for various products, thus reducing logistics and inventory management costs in the supermarket industry.

The rest of the article is organized as follows. In Sect. 2, we review the relevant literature. Section 3 introduces the methodology we use to build forecasts for many products. Then, in Sect. 4, we describe the empirical setting and provide descriptive statistics of the thousands of products we consider in the empirical evaluation. In Sect. 5, we present the result, and we conclude in Sect. 6 with the main takeaways of our research and a discussion with some avenues for future research.

2.2 Literature Review

This research is associated with three streams of research. First, from a substantive perspective, we relate to a vast literature exploring efficient demand estimation in the retail industry. Second, from a methodological perspective, our research is connected to recent advances in meta-learning. Lastly, from an operational perspective, we aim to produce forecasts with minimal human intervention and therefore, our research also relates to the literature on retail automation. Next, we discuss these three streams sequentially.

Regarding demand estimation, previous literature has recognized that the forecasting approach depends on the nature of the decisions they support. For instance, Fildes et al. (2022) pose that strategic, tactical, and operational decisions require different methods and data aggregation levels. In this work, we provide product and store-level forecasting to support operational decisions such as order sizes and inventory volumes. Since the introduction of retail scanner data, various methods have been proposed to forecast sales. While a common practice in the industry is using regressions (e.g., Macé and Neslin 2004) or autoregressive time series models (e.g., Srinivasan et al. 2008), recent methodological advances have motivated a large number of investigations using more sophisticated forecasting models. For instance, Ali et al. (2009) compare a variety of autoregressive, stepwise, and support vector regression models to forecast demand in the presence of promotion and found that, with more detailed input data, machine learning models can significantly improve the forecasts. More recently, Spiliotis et al. (2020) compare statistical and machine learning methods to forecast daily demand and conclude that the latter reduces the bias and leads to more accurate predictions. Unlike these systematic evaluations that evaluate the aggregated performance of different forecasting models, our research aims to identify the best model for each case. In addition, while most of these studies consider a few dozen scenarios, our model is devoted to providing adequate demand forecasting for thousands of product-store combinations.

The desire to have estimation methods that can be generalized to multiple prediction instances has a long tradition in the forecasting literature. More than 30 years ago, Mahmoud et al. (1988) already posed that no one sales forecasting method is appropriate for every situation (p. 54). While the problem was identified a long time ago, it was not until the last decade that the literature has provided more systematic approaches to address it. Early approaches to finding general forecasting models within a given domain rely on aggregation methods (for example, Horváth and Wieringa 2008). However, we believe these approaches are better suited for cases with a relatively short number of temporal observations for each unit, which is less of a concern in our empirical application. Another approach to aim for generalizability is using forecasting ensembles, where multiple models and data sources of different types are combined to produce a unified forecast (Wu and Levinson 2021). Our empirical analysis considers ensembles as potential candidates to generate the best predictions. However, we consider the possibility that one model by itself could be the most suitable for specific instances.

The methodology we used to forecast the demand at the product-store level is based on meta-learning. The basic idea behind meta-learning is using a classifying method to select the most suitable model for a given time series (for a similar methodology, see Prudêncio and Ludermir 2004). Unlike ensemble learning, which combines multiple forecasts, we aim to select the best model for each case in meta-learning. With the proliferation of a wide gamut of time-series models, the need for some guidelines to decide on the best modeling approach has become more pressing. Early guidelines mostly relied on visual examination of the series (Pegels 1969) or qualitative rules (Collopy and Armstrong 1992). More recently, meta-learning methods have taken advantage of the important advances in machine learning to use a classification model to decide the most promising approach as a function of a large number of features characterizing a given time series (Talagala et al. 2018). Using a wide range of univariate time series from different domains, Wang et al. (2009) identify six clusters of series that might require different forecasting techniques. Similarly, Lemke and Gabrys (2010) identify an extensive set of features describing the time series and another set of features to characterize the forecasting methods. More recently, Ma and Fildes (2021) applied meta-learning methods in retail and demonstrated that they could significantly improve forecasting efficacy. Although they evaluate meta-learning using a publicly available dataset, we effectively use this approach to support decision-making in the retail industry. In terms of the methodology, we find that the addition of a final step, in which we discard those models with worse performance, could play a critical role in facilitating the classifier to select the best model for each forecasting task.

To conclude this review, our research is also related to previous work on retail automation. Considering the massive nature of retail operations and the high competition in the retail markets, there is constant pressure to systematize and automate processes (Begley et al. 2019). The number of applications that automatize key retail decisions is vast. These include the evaluation of promotional effectiveness with a minimum of analyst intervention (Abraham and Lodish 1987), the dynamic adjustment of store item-level prices (Zhou et al. 2009), and the delivery of automatic responses triggered by consumer actions (Goic et al. 2021) to name a few. The main goal of this research is to provide an automatic demand forecast at the product-store level. Although we expect that automation can lead to better forecasting in the long term, we aim to provide predictions that are, at least, as good as the current business practices that require manual examination of thousands of series.

2.3 Methodology

As illustrated in Fig. 2.2, the proposed methodology consists of four main steps. First, we produce forecasts for many cases using various models and compute error metrics for each model and case (1). Second, we generate several features to characterize each case (2). Third, we use those features to train a meta-learning model that indicates

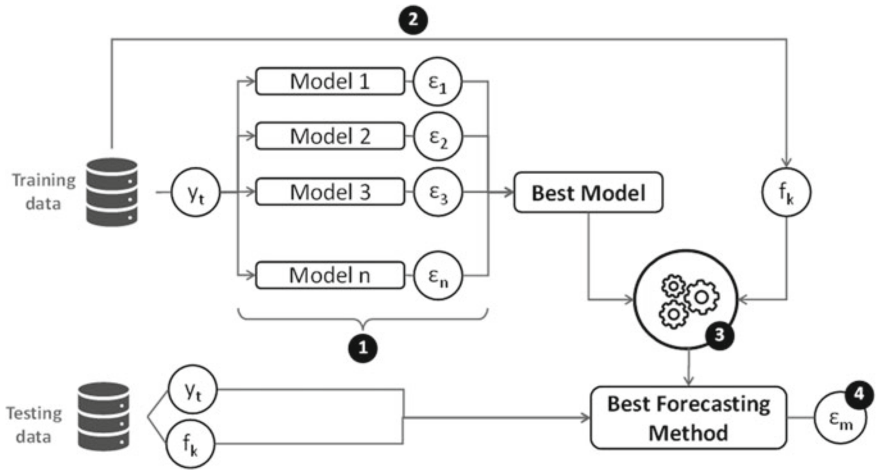

Fig. 2.2 Schematic representation of the proposed methodology

which model leads to smaller errors for given values of features (3). We conclude by applying the results of the meta-learning and evaluating its performance (4).

In the following subsections, we discuss each of these components in more detail: Step (1) is described next in the sub-section "Forecasting with alternative models". Step (2) is described later in the sub-section "Extraction of time series features". Step (3) is presented in the sub-section "Model selection through meta-learning". The evaluation of the whole methodology using the best method is presented in the section "Results".

2.3.1 Forecasting with Alternative Models

We start the methodology by estimating a variety of forecasting models for a large number of products. The objective of this task is twofold. First, it allows us to verify that no single model generates the most accurate prediction for most cases, which provides empirical justification for including a meta-learning process to assign product demand patterns to models. Second, the results of these models work as an input for the calibration of the meta-learning algorithm. In fact, the assessment of the forecasting errors gives us the basis for the construction of classification labels that will be used in the training of the meta-learning step.

The models that we consider in the evaluation are:

- **Moving Average (MA)**: This is the model used by the firm before the implementation of the meta-learning, and it generates the forecast for the next period as a weighted mean of the observed sales in the last two periods (Johnston et al. 1999).

- **Autoregressive Integrated Moving Average (ARIMA)**: On a given period, the values of the time series depend on their lagged values and lagged errors. The series is further differentiated to estimate the model to allow nonstationary processes (Newbold 1983).
- **Holt-Winters (HW)**: This model expands the simple exponential smoothing approach by allowing trends in the forecasting. Thus, the method comprises three smoothing equations for the level, the trend, and the seasonal components (Chatfield 1978).
- **Exponential smoothing state space model with Box-Cox transformation, ARMA errors, Trend, and Seasonal components (TBATS)**: This model uses a combination of exponential smoothing and Box-Cox transformations to accommodate multiple seasonal components automatically. Each seasonal component is modeled by a trigonometric representation based on a Fourier series (De Livera et al. 2011).
- **Time-dertificial neural networks (TDANN)**: This model uses a flexible neural network architecture to model the time series. In this structure, we use lagged values as inputs to the network (Clouse et al. 1997).
- **Seasonal-Trend decomposition using LOESS (STL)**: This model allows the time series's decomposition into three components: seasonality, trend, and residuals. To combine these components, this model uses a robust local regression approach to outliers (Cleveland et al. 1990).
- **Ensemble (EN)**: In this approach, the forecast corresponds to the combination of multiple models. While the literature suggests alternative approaches to combining models, in our case, we simply consider a simple average that often outperforms more complex combination schemes (Bates and Granger 1969).

2.3.2 Model Selection Through Meta-Learning

To select the best model for each time series, we use meta-learning. To perform meta-learning, we need to generate a dataset with all the available time series. For each series, we need (i) a label indicating which model had the most accurate prediction for this series and (ii) several features to characterize them a priori. With these components, the problem translates into a standard classification model. The labels with the best model are obtained from the extensive forecasting with alternative models we explained in the previous subsection. The process of extracting time-series features is explained in depth in the following subsection.

We split the database into training and testing subsets using standard supervised learning approaches. The model is calibrated using the training data and then evaluated in the testing data. In our case, we use a random sample of 80% of the product-store series for training and the remaining 20% for testing. Although there are many alternative methods to perform the classification task, following previous work on meta-learning, we use a random forest model (Talagala et al. 2018). In our case, the random forest is produced, averaging 1,000 trees. We tried alternative specifications with a larger number of trees without observing a meaningful improvement in the classifier's performance.

The labels indicating which candidate is the best model are based on the Mean Absolute Error (MAE). Since the label is used to guide which model performs better for each time series shape, to feed the random forest classifier, we only consider the case in which there is a clear winner among the competing model. Of the 5,000 time series analyzed, there are 1,103 series where there is no meaningful difference in the prediction errors of at least two models, which we discarded from the analysis. Thus, the classification is trained with 3,897 series. It is possible that other methods could perform better without removing those cases from the training set, but this filter proved to lead to better forecasting results for our application.

Another variation in the classifier proved to enhance the meta-learning significantly. Instead of calibrating the classifier to select the best model among all possible methods, we calibrate it to choose between the two models with the best overall performance. Restricting the classification to only those models with the smallest forecasting errors reduces the potential gain of the automation of model selection. In fact, as we will see in the result section, every model provides the best forecast for at least a few cases. Therefore, removing models will lead to a worse possible solution for those series. Notice, however, that the gain in the forecasting capabilities only materializes if the classifier effectively identifies the best model for each series. However, with more labels, the classification task becomes more difficult. Thus, the key tradeoff is between reducing the potential forecasting gains and augmenting the classification errors. As we will see in the result section, in our empirical application, the reduction in the classification error more than compensates for the selection of suboptimal methods, and meta-learning with the best models leads to better results overall.

2.3.3 Extraction of Time Series Features

To calibrate a meta-learning step, we need to connect the performance of all forecasting methods to a series of observable features of the forecasting task. In this project, these observable features correspond to characteristics of the shape of the underlying time series. For instance, we consider the strength of the seasonal and trend components. The basic idea is that some methods might be more suitable to capture those components than others and that the meta-learning step can identify those patterns by observing the performance of several methods in thousands of cases.

We closely follow previous literature on time-series meta-learning to define the list of time-series features to use in the empirical analysis. For each demand series of product-store combination, we compute 15 features such as trend, seasonal strength, and autocorrelation coefficients, as well as metrics of the internal variability such as entropy, spikiness, and maximum level shifts (Talagala et al. 2018; Ma and Fildes 2021). To illustrate how different time series differ depending on the values of these

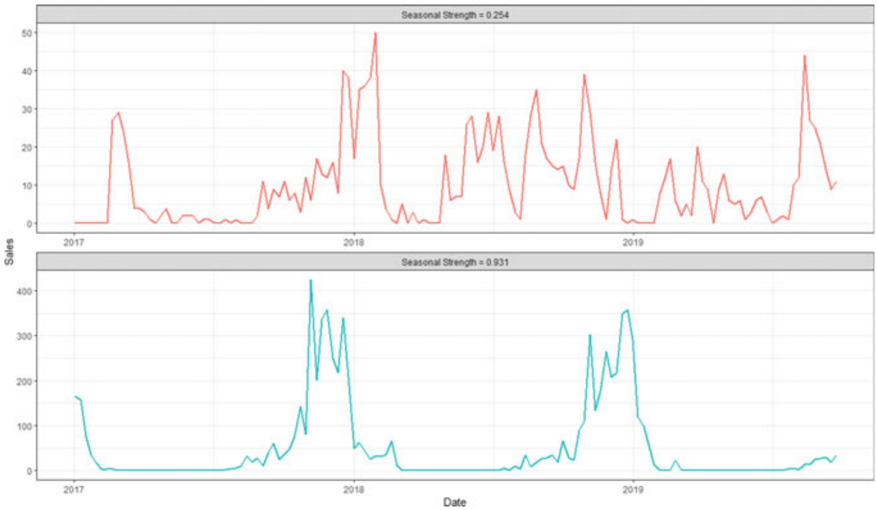

Fig. 2.3 Visual representation of two series of sales with different Seasonal Strengths

features, in Fig. 2.3, we display two series of demand with fairly different values for Seasonal Strength (by construction, the Seasonal Strength takes values in the range [0, 1]). In the bottom panel, we display a series with high Seasonal Strength. In this case, sales during the summer times (November–March, in the southern hemisphere) are much higher than in the rest of the year. In the top panel, we display a series with low Seasonal Strength, and, in this case, it is much more difficult to anticipate what would be the weeks with higher sales. In terms of the forecast, the need for a model that properly controls for seasonality appears to be more critical in the second series.

2.3.4 Execution and Evaluation of Meta-Models

To complete the methodology, we apply the classifier for many products, then evaluate to what extent the resulting predictions improve concerning standard forecasting tools. Considering that we apply the proposed methodology to many products, we need an aggregated performance metric. In our case, we use a weighted Mean Absolute Percentage Error (wMAPE) in which we give larger weight to products with larger sales levels. Our choice is justified because of its scale independence and consistency with the business objective of having more accurate predictions for those products with a larger impact on revenues (Narayanan et al. 2019).

Table 2.1 Descriptive statistics of the demand series for different product-stores combinations

		Weekly sales [units]		Price [CL$]	
Product family	N° Products	Mean	Max	Mean	Max
15	297	24.9	903	5,186	172,914
27	4,703	40.5	4,355	3,221	170,540

2.4 Empirical Setting

From a practical point of view, we are interested in automatizing demand forecasting to use those estimates to feed different operational processes. The focal decision in this research is the daily number of units to distribute from the central warehouses to all stores scattered throughout the territory. On the one hand, considering the limited storage space in the store, demand overestimation could lead to high operational costs. On the other hand, demand underestimation could lead to lost sales due to an out-of-stock. While we formally analyze the inventory reorder process, the forecast could also be used to support other decisions, such as assortment or promotional planning.

We consider 5,000 demand series of different product-store combinations in the empirical evaluation. The time series correspond to 143 weeks of sales from January 2017 to September 2019 for the clothing and toys categories. These series span 200 families of products and 130 stores in Chile. It is worth noting that not all product families are sold in all stores. Due to the constant product introduction, these two product categories are precisely among those the company has faced more difficulties in generating forecasting at the product-store level. The constant variation in the product offering motivates us to forecast at the product family and not at the SKU level. In Table 2.1, we display descriptive statistics of the demand for both product categories.

Statistics from Table 2.2 indicate that most of the series we consider in this numerical analysis correspond to clothing, which tends to have larger sales than the toys category, which also tends to have larger prices. For our analysis, the key insight from these statistics is that the demand series might be fairly different between products, providing further qualitative support to the need for a meta-learning classifier that guides the best model to forecast each series.

2.5 Results

According to the methodology presented in Sect. 3, several components are worth reporting. We first describe the results of the forecasting of all independent standard models. Then we describe the implementation of the time-series feature extractions. These two components are the primary inputs for the meta-learning stage that we

Table 2.2 Forecasting Error across models for the first week

Model	MAE	Sd	wMape (%)
HW	13.7	20.5	33.2
TBATS	15.9	29.3	38.6
NNAR	17.9	25.0	43.5
STL	18.4	27.3	44.5
ARIMA	19.1	35.4	46.4
MA	19.2	25.5	46.5
EN	13.6	21.2	33.0
Mean	16.8	26	40.8

present next. We conclude this section using the forecasting models to evaluate the business impact.

2.5.1 Forecasting Through Standard Models

We first estimate each of the seven forecasting models for each 5,000-time series to complete 35,000 forecasting tasks. The majority of these models require the calibration of hyper-parameters. For TBATS, we need to determine if Box-Cox transformation is required or for the ARIMA models, and we need to decide the number of lags to use. We tune all these hyperparameters using cross-validation.

In this exercise, the forecasts correspond to the daily sales of the last four weeks of the time series. This forecasting window is chosen to match the typical target for inventory reorders. Figure 2.4 illustrates the forecasts of all individual methods for a selected time series. Although the series largely differ in features (trend, seasonality, spikiness, etc.), this example represents a common pattern we find in most series: the predictions are not radically different between models. While this indicates that any model could provide a reasonable approximation, it also suggests that it might be difficult to classify the best model for a given series. Beyond the illustration of a given series, Table 2.2 reports the forecasting errors for the first week of forecasting for all models across the 5,000 series. In this table, we include the MAE we use to compare predictions between models for a given series and the wMAPE we use later to evaluate the performance across series. Consistent with the previous example, these results indicate that all proposed models are competitive, with relatively small differences in the aggregated performance metrics between the best and worst models.

While this indicates that any model could provide a reasonable approximation, it also suggests that it might be difficult to classify the best model for a given series. Beyond the Illustration of a given series, Table 2.2 reports the forecasting errors for the first week of forecasting for all models across the 5,000 series. In this Table 2.2, we include the MAE we use to compare predictions between models for a given series and the wMAPE that we use later to evaluate the performance across series.

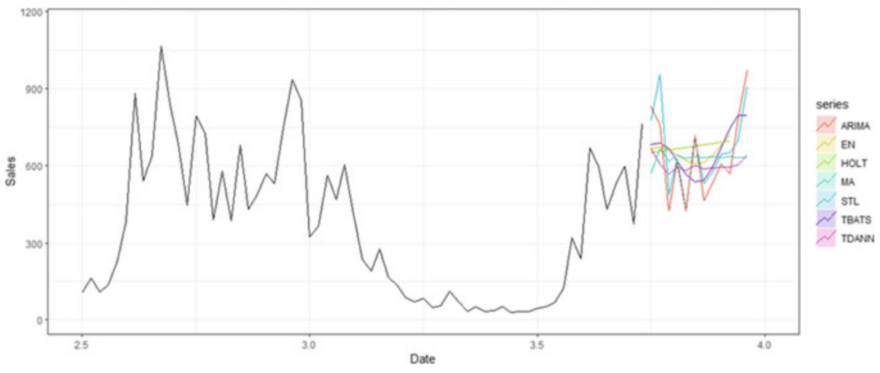

Fig. 2.4 Illustration of alternative forecasting results for a selected series

Consistent with the previous example, these results indicate that all proposed models are competitive, with relatively small differences in the aggregated performance metrics between the best and worst models.

To complement previous results, in Table 2.3, we display the forecasting errors for all four weeks we used in these numerical exercises. As expected, the further the forecasting window is in the future, the lower the accuracy of the prediction. However, the notion that the differences between models are small remains.

Recall that our methodology uses the forecasting results from individual models to calibrate a classification model that determines the best model to predict each series. In this regard, the forecasting of individual models is the primary source to build the labels of the classification model. We use the smallest forecasting error for each case to produce these labels. The frequencies of these labels are displayed in Fig. 2.5, where we further decompose them by week. For instance, the ARIMA model has the smallest forecasting errors in 17.9% of the series in week 1. Similarly, the ensemble produces the best results in 13.7% of the series for the same week.

Considering that we had previously found that the forecast errors were not dramatically different between models, it may not be surprising that we now find that no

Table 2.3 Forecasting errors by week

Model	S1	S2	S3	S4	Mean
HW	13.7	15.7	16.4	19.2	16.3
TBATS	15.9	16.2	16.8	18.2	16.8
NNAR	17.9	18.9	21.7	19.9	19.6
STL	18.4	18.8	21.0	20.8	19.8
ARIMA	19.1	17.5	18.8	19.8	18.8
MA	19.2	18.5	20.4	19.9	19.5
EN	13.6	14.4	15.2	17.0	15.1
Weekly mean	16.8	17.1	18.6	19.3	18.0

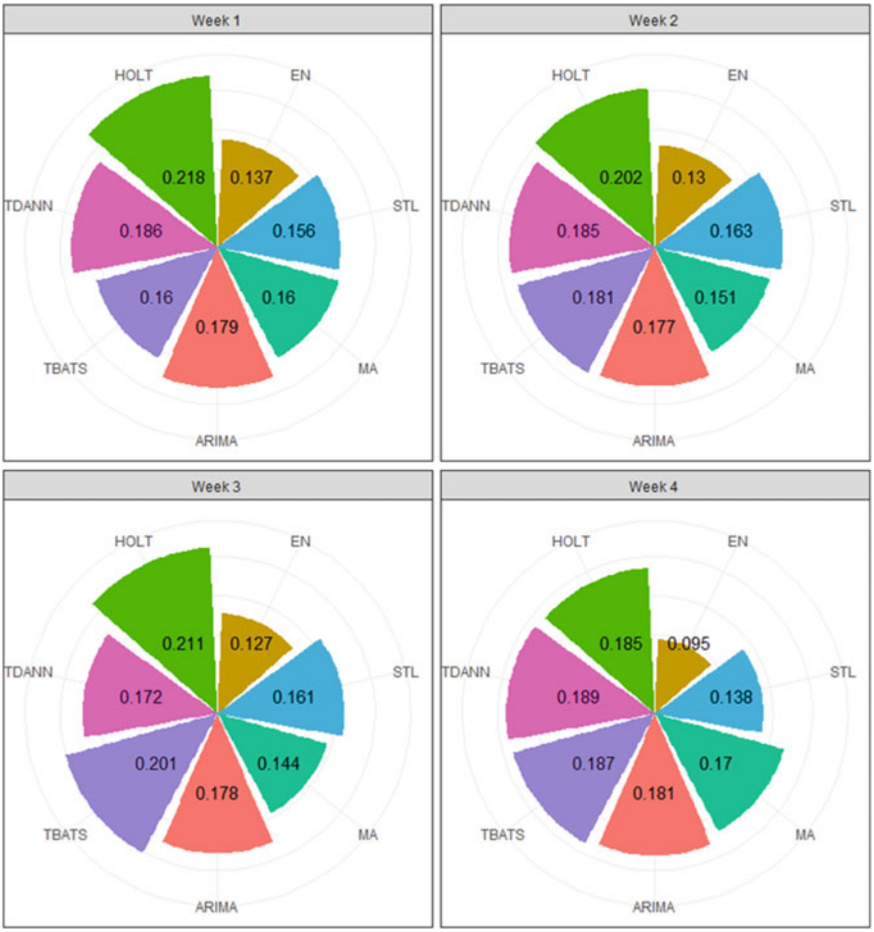

Fig. 2.5 Fraction at which each model provides the minimum forecasting error

model is the best alternative for most cases. It is possible, however, that a particular model could be consistently better, but only by a small margin. The results in Fig. 2.5 indicate that this is not the case and that some models work well for some series, and others predict better in other cases. This is precisely the pattern that justifies the need for a classifier to guide the decision of which model should be used for each specific prediction task.

The comparison across models reveals that the ensemble is the preferred model in the least number of cases. This is somewhat surprising considering that overall is the method with the smallest mean error. To conciliate these two empirical findings, it is worth emphasizing that the ensemble derives from averaging multiple models. Thus, while this approach generates consistently good solutions, it is often the case that there is one specific model that works better for that particular case. While taking averages warrants the production of good models, at the same time, it is influenced by relatively bad models, making it difficult to produce the best solution.

2.5.2 Generation of Features

As the methodology section explains, we compute features closely following what previous literature has used to characterize time series. This extraction considers trends, seasonality, and autoregressive factors, among others. In Table 2.4, we display the list of the time-series features we use for meta-learning, along with their corresponding descriptive statistics. For a complete study of feature extraction, see Wang et al. (2006).

According to the descriptive statistics presented in Table 2.4, except for the spike, the features extracted from the different time series present significant dispersion. Consequently, the observed time series differ in their shapes, providing enough variation to learn about their incidence in the performance of each model.

Table 2.4 List of time-series features for meta-learning with the corresponding descriptive statistics for the case of study

Variable	Description	Min	Mean	Max	Sd
Trend	Strength of trend	0,000	0,131	0,815	0,111
Spike	Spikiness	0,000	0,000	0,001	0,000
Linearity	Linearity	−5,934	0,371	9,025	1,914
Curvature	Curvature	−5,087	−0,381	4,696	1,420
Seasonal	Seasonal strength	0,228	0,600	0,970	0,156
Entropy	Shannon entropy	0,598	0,890	1,000	0,065
Xacf1	First ACF of the series	0,017	0,572	0,938	0,150
Xacf10	SS of the first ACF of the series	0,006	0,924	5,646	0,753
Diff1acf1	First AF of the series differences	−0,651	−0,271	0,348	0,118
Diff1acf10	SS of the first 10 ACF of the first differences	0,039	0,179	0,949	0,080
Diff2acf1	First ACF of the first differences	−0,804	−0,561	−0,031	0,082
Diff2acf10	SS of the first 10 ACF of the second differences	0,159	0,435	1,774	0,135
Eacf1	First ACF of the remainder series	−0,387	0,370	0,842	0,172
Eacf10	Sum of squares of first 10 ACF of remainder series	0,005	0,352	2,150	0,257
Seasacf1	Autocorrelation coefficient at the first seasonal lag	−0,292	0,191	0,589	0,155

SS = Sum of the squares

2.5.3 *Meta-Learning*

Considering this is one of the most critical steps in the methodology, we describe two variants to learn from the best modeling approach to conduct the forecast for each series. Although both versions use a Random Forest to classify, we consider two different sets of models in which the Random Forest must classify. First, we feed the meta-learner with all forecasting models, and then we restrict the classification to the two models with the best overall performance. A perfect classifier would benefit from selecting from a larger set of models. However, more candidates make the classification task more complex, and therefore, which approach would lead to better results is an open empirical question.

Before presenting the results of using a meta-learner to select the best model, in Fig. 2.6, we display the mean value for all time-series features depending on the model with the best performance.

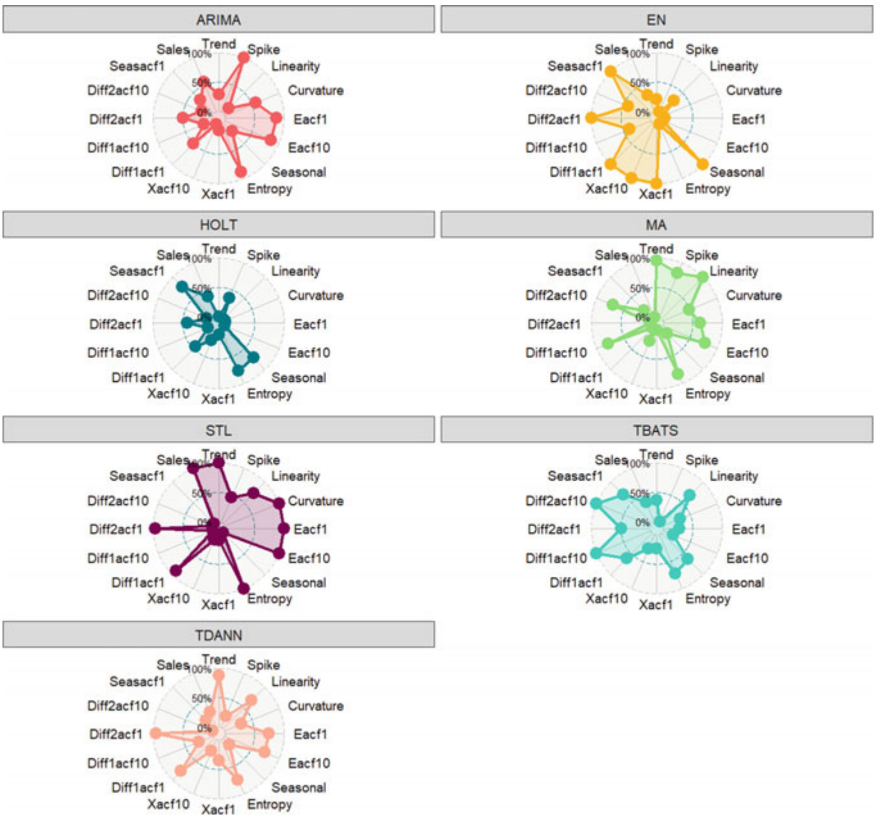

Fig. 2.6 Mean attribute value depending on which is the preferred model

According to these results, we corroborate that some models tend to perform better for specific profiles of attributes. For instance, when STFL is preferred, the underlying time series tend to have large values for curvature, eafc1, and eafc10. Similarly, a moving average is preferred for series with large values for trend, linearity, and spike. These results prove that meta-learning can effectively identify the underlying patterns connecting time-series features and model performance.

2.5.3.1 Classification with all Models

In this first exercise, the meta-learning step must decide the best model among seven competing alternatives. Table 2.5 reports the error of the Meta-Forecast against all other contenders and the fraction at which each model ended up being the best forecast (Win Rate).

Results from Table 2.5 indicate that the meta-forecast, along with the Holt-Winters model has the highest win rate among all. This provides preliminary evidence that using a model classifier can positively impact the system's overall performance. Notice, however, that in terms of the forecasting error, the meta-forecast does not provide the best results and simpler approaches, such as the ensemble or Holt-Winters, perform better on average. This indicates that while meta-forecast is

Table 2.5 Performance of meta-Forecast against individual models (first exercise)

Model	MAE	WMAPE (%)	Win rate (%)
HOLT	12.9	31.8	19.3
TBATS	14.8	36.5	12.8
STLF	17.0	41.9	14.0
NNAR	17.2	42.4	16.5
MM	18.3	45.1	14.2
ARIMA	18.5	45.6	14.1
ENSAMBLE	12.7	31.3	9.2
Meta-forecast	14.9	36.7	19.3

Table 2.6 Performance of meta-forecast against individual models (second exercise)

Model	MAE	WMAPE (%)	Win rate (%)
HOLT	12.9	31.8	19.3
TBATS	14.8	36.5	12.8
STLF	17.0	41.9	14.0
NNAR	17.2	42.4	16.5
MM	18.3	45.1	14.2
ARIMA	18.5	45.6	14.1
ENSEMBLE	12.7	31.3	9.2
Meta-forecast	11.0	27.1	24.9

frequently the best solution, the classifier could make serious classification mistakes and some series were probably forecasted with models with large errors. These results motivate an alternative and more conservative approach in which the classifier only selects among those models that perform well on average, as we explore next.

2.5.3.2 Classification with the Best Two Models on Average

In this second exercise, the classifier only considers two labels associated with the Holt-Winters and the ensemble model that performed better on average. Table 2.6 reports the errors of this new meta-forecast against all other contenders and the fraction at which each model leads the smallest forecasting error (Win Rate).

Compared to the previous case, this new meta-forecaster leads to much better results and overperforms all other models in all relevant metrics. The meta-forecast model not only provides a significant reduction in average error metrics with a wMAPE of 27.1%, which is 4.2% points better than the closest competitor (Ensemble) and more than 18% points better than a simple ARIMA model. These numbers lead the meta-forecast to provide the very best solution in 24.9% of the cases, which is almost 10% more than the closest competitor.

Overall, these results indicate that meta-learning can significantly boost accuracy to make better predictions regarding detailed retail demand sales. However, this gain is not automatic, and it might be necessary to learn the best configuration for the classifier to achieve the best performance.

2.5.4 Business Evaluation

In previous sections, we have shown that the use of meta-learning helps to automate the forecasting process, allowing an algorithm to decide the most suitable model to estimate each combination of products and stores. Furthermore, the resulting forecasts could even lead to more accurate predictions. In this section, we empirically test whether these improvements can be effectively applied in a real setting and evaluate their impact on relevant business metrics.

To measure the impact of the forecasting automation, we evaluate their impact on the process of product replenishment that requires estimating the future demand at the product-store level. Our evaluation is based on a controlled experiment in the clothing department, where a selected group of products and stores operated their replenishment process using the automatic forecasting methodology proposed in this chapter, and a comparable group of products continued their replenishment processes using standard business practices. While in the treatment, we forecast the demand using the automatic meta-learner; in control, the forecast was performed by analysts who calibrate simple autoregressive models, and they can make a judgment call to overwrite the forecast if they consider it necessary. The treatment and control groups

Table 2.7 The daily mean of sales inventory between treatment and control conditions

	Treatment	Control
Sales	277.1	250.5
Inventory	18,644.4	19,096.6

were selected to have similar demand levels pre-treatment, and the experiment lasted two weeks.

Indeed, the automation of the forecasting process brings several benefits that can only be observed in the mid-term. These include more consistent decision-making, the fastest processing, and cost savings associated with the process. For this evaluation, we will focus on the impact that can be measurable in the short term. More precisely, we look at the inventory levels and total sales. We expect that if the forecasting is successful, it should lead to lower inventory levels and more sales. Although we do not expect the forecasting to increase the demand, a more precise forecast should be associated with a smaller number of out-of-stocks and positively affect sales. Table 2.7 reports the daily mean for sales and inventory for this experiment.

The treatment and control groups were selected to be balanced. Therefore, the treatment's larger sales and smaller inventory provide preliminary evidence that the forecast can positively affect both metrics. However, a formal analysis requires detailed control for sales levels and temporal variations. To do so, we exploit the panel data structure of the experimental setting and estimate the following two regression models:

$$\text{sales}_{\text{ist}} = \alpha_i^1 + \beta_s^1 + \gamma_t^1 + \delta^1 \cdot \text{Treat}_{\text{ist}} + \varepsilon_{\text{ist}}^2 \tag{2.1}$$

$$\text{inventory}_{\text{ist}} = \alpha_i^2 + \beta_s^2 + \gamma_t^2 + \delta^2 \cdot \text{Treat}_{\text{ist}} + \varepsilon_{\text{ist}}^2 \tag{2.2}$$

The key variable in this regression is $\text{Treat}_{\text{ist}}$ that takes the value 1 if the product i in store s, in day t was replenished using the automatic forecasting methodology. The dummy variables $(\alpha_i^k, \beta_s^k, \gamma_t^k)$ control for product, store, and day-fixed effects $(k \in \{1, 2\})$. According to our previous discussion, we expect that $\delta^1 > 0$ meaning that the automatic forecasting model increased the sales volume on average, and $\delta^2 < 0$, meaning that the automatic forecasting model decreased the inventory levels. The results of the regression models are displayed in Table 2.8. In the table, we include two versions of the Eq. (2.1) and (2.2) that differ in whether we control for stores or not. In all cases, we reported clustered standard errors by product and day. In the analysis, we observe the sales of all products for all days in the experiment ($N =$ 9,705), but there is an imperfect inventory collection. Therefore we only observe a fraction of them ($N =$ 5,470).

Results from Table 2.8 confirm our hypothesis about the direction of the impact of a successful implementation of automatic forecasting. In fact, we find evidence of a positive effect on sales and a negative effect on inventory levels.

Table 2.8 Regression results for the evaluation of the implementation of automatic forecasting using meta-learning

Dependent Var	Sales		Inventory	
Model	(1a)	(1b)	(2a)	(2b)
Treat	0.573* (0.249)	0.531* (0.235)	−4.87* (2.21)	−5.47* (2.36)
Fixed effect				
Product	Yes	Yes	Yes	Yes
Day	Yes	Yes	Yes	Yes
Store	No	Yes	No	Yes
Observations	9,705	9,705	5,470	5,470

2.6 Discussion and Future Research

Modern retailing faces important challenges. The constant increase in product variety and the growing pressure to increase supply chain processes' efficiency have pushed for demand forecasting automation. Recent advances in data analytics offer a wide range of models that can be applied to improve forecasting. However, the suitability of the models depends on the case, and there is no universal best model. With retailers having to plan inventories of thousands of products in hundreds of stores, manually choosing the best forecasting model is costly and can often be inaccurate.

In our research, we present a methodology that takes advantage of recent advances in meta-learning to select the best model for each forecasting task automatically. In this chapter, we describe the methodology and then numerically demonstrate that meta-learning can significantly improve forecasting accuracy. Furthermore, we apply our approach in a controlled experiment and show that replenishment can benefit by reducing inventory levels and increasing sales. From a methodological point of view, it is important to notice that there is a tradeoff between the use of multiple forecasting models and the difficulty in classifying models in the meta-learning phase. In our case, we found that restricting the set of eligible models to only those that perform well on average leads to better overall performance.

To the best of our knowledge, this is one of the first studies showing that meta-learning can provide value in the retail industry. However, we identify several limitations and avenues for future research. First, we concentrate the analysis on only two product categories (clothing and toys) in a single retail chain. Despite expecting that the main findings generalize to other scenarios, more research is needed to understand the boundaries of the application of this technology. Second, in the empirical analysis, we focused on a limited number of forecasting models. Although our list is representative of the most common forecasting approaches, the list can be enhanced with other models, such as gradient boost (Chen and Guestrin 2016) or Prophet (Taylor and Letham 2018). Third, our application only considers Random Forest as a classification technique.

Further analysis could consider the exploration of alternative classifiers such as Naïve Bayes classifiers (Rish 2001) or Support Vector Machines (Pisner and Schnyer 2020). A final idea for future research is to use meta-learning insights to create customized ensembles. Although we considered a statistic ensemble in our work, creating different ensembles depending on the time series features might lead to further improvements in the forecast.

This research illustrates how recent data analytics and automation advances can impact a regional retailer. While the technology is mature enough to impact today, we expect that this type of initiative will continue playing an important role in improving the operational efficiency in the industry and will become part of the standard way of operating shortly.

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Chapter 3
Economic Development and High-Value Supply Chains

María D. Gracia, Dionicio Morales-Ramírez, and Julio Mar-Ortiz

Abstract The reorganization of the global supply process is giving shape to a new value creation paradigm, where clusters of local producers are becoming the pillars of global supply chains. This phenomenon, known as regionalization, demands the identification of regional productive sectors that exhibit the specialization and dynamism required to create high-value supply chains. Thus, regional development and high-value supply chains are related. In this chapter, we propose a methodological framework to identify the potentialities and opportunities of regional productive sectors to create industrial clusters and high-value supply chains. The State of Tamaulipas (in Mexico) and its municipalities functioned as the region and subregions of analysis, respectively. The results reveal that productive sectors with the more significant potential to create high-value supply chains are the agricultural and manufacturing sectors.

Keywords Regionalization · Supply chains · Economic development · Regional vocation

3.1 Introduction

Regional development and high-value supply chains are closed related (Twomey and Tomkins 1996; Dewhurst and McCann 2007; Silva et al. 2021). Recently, regional development has been increasingly structured around value chains, recognizing the influence of regional and local factors in the global production processes (Bolea et al. 2022).

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Exports indicate participation in global value chains (Johnson 2018). In the global supply process, the components of any product come from different regions in the world. Some productive sectors exhibit a high level of specialization and dynamism that allows them to create industrial clusters of local producers that become the pillars and commercial bridges of global supply chains.

From an economic perspective, the level of specialization and dynamism required by the industrial sectors to create high-value supply chains comes together with regional development. In other words, to impulse regional development in any county is critical to clearly define which industrial sectors have the best possibilities to compete in the international market. In Europe, for instance, regional policymakers strive to develop local clusters to promote regional economic growth mainly through supply chain development initiatives, particularly in regions dominated by branch plants of large multinational enterprises (Brown 2000). The aim is to establish a road map through transformative policies to manage the resources, accelerate industrial growth, and create an environment favorable for innovation in related industries.

In the literature, the relationship between transportation infrastructure, freight traffic, economic market drivers, and regional economic development has been widely studied (Clos and Bolumole 2015; Perevozova et al. 2020); with growing importance in the study of the impact of transportation, logistics, and supply chain management operations to support industrial activities in regional economies. Recently, Silva et al. (2021) demonstrated that in emerging economies, micro and small enterprises' supply chains contribute significantly to regional socioeconomic development, enhancing their resilience to crises because they focus on long-lasting economic activities within the regional ecosystems. Thus, the regional compositions of economic activities are not the only determinant of within-country differences in economic performance (Thissen et al. 2018).

To the best of our knowledge, in the supply chain management community, there is a need for a methodological framework able to identify the potentialities and opportunities of regional productive sectors to create industrial clusters and high-value supply chains, which is the aim of this chapter.

3.1.1 Related Literature

The World Bank defines *economic development* as the qualitative change and restructuring of a region's economy concerning technological and social progress. From a broader perspective, we can consider that economic development is linked to the growth of production but also includes other aspects that affect the quality of life of the population, such as health, employment, and education, as well as conservation and caring for the environment (Sepúlveda 2008). Therefore, to reach economic development, economic growth is a necessary condition, but not a sufficient one. Thus, assuming that regional development depends on the ability to create transversal value in the global productive sectors, before undertaking any productive project, it is critical to have a complete diagnosis that offers a comprehensive vision of the technical, economic, and social potential of the region (Coe and Hess 2010).

Regional development is related to two main concepts: productive vocation and economic potential. Productive vocation is the aptitude, capacity, or special characteristic a locality has for its development. The real and apparent productive vocations differentiate each other. The real productive vocation exists when the capacities of the locality, regarding production and commercialization in the internal or external markets, generate an economic and social benefit for an important part of the locality. The apparent productive vocation exists when, despite unbeatable local production conditions, no market allows them to improve their income. Hence, producers find it challenging to expand the volume or amount of income, causing the production level to remain constant yearly.

On the other hand, economic potential is related to potentialities, which are resources or capital, or both, unused, partially used or misused. Potentialities are activated starting from a good combination of these resources or capitals and responding to a social and economic environment. Using the potentialities can reduce poverty, more significant employment, improvements in well-being, greater citizen participation, and greater social cohesion. In the socioeconomic dynamics, the potentialities assume the approach of the three capitals: natural, human, and physical (which includes financial capital), accompanied by the catalytic role of institutions and social norms, called social capital.

From the supply chain management point of view, the current paradigm of value creation has been taking shape for several years (Notteboom and Rodrigue 2005; Johnson 2018), where clusters of local producers become the pillars and commercial bridges of global supply chains. The reorganization of the global supply process in production chains responds to the regionalization paradigm and is a consequence of at least four factors: (a) the growing concern about the increase in risks in international connections (commercial wars, transport interruptions, natural disasters, etc.) (Adenso-Díaz et al. 2018); (b) the governmental requirements to involve more local producers in international supply chains (Horner and Alford 2019); (c) the growing awareness of customers about the level of sustainability, such as the footprint of transport, products, and services; and (d) the increasing demand of productive sectors to gain flexibility and agility in operations to respond to uncertainty.

The COVID-19 pandemic represented the last century's most fundamental disruption to economic activity. It presents enormous challenges to the world economy, raising the fundamental question of how to reshape global supply networks (Enderwick and Buckley 2020) to move towards a more regional world economy (Panwar et al. 2022). The fundamental idea is to seek a better balance between national and international interests (Rodrik 2019), efficiency and resilience of supply chains (Reeves and Varadarajan 2020), and growth and equity.

The regionalization of production chains, based on a network of industrial clusters, solves various logistical problems related to reliability, flexibility, and cost reduction (Gulledge and Chavusholu 2008; Cedillo-Campos et al. 2021). It maintains the fluidity of regional cargo, given that the production systems are not disconnected from the territories (Guerrero et al. 2014), opposing the latent risk of interregional transport. Therefore, specific territorial variables will play an increasing role when designing, organizing, and operating global supply chains in the coming years (Pla-Barder et al. 2021; Scholvin et al. 2022). Hence, to make decisions under this global industrial reconfiguration, new methods, models, and approaches are needed to recognize and analyze the new variables that improve supply chain decisions based on the new territorial paradigm.

Although there has been much discussion recently about a process of continentalization, regionalization, or Nearshoring of global supply chains, the models and procedures available to make decisions during this new phase remain largely unmapped. Consequently, most of them do not address the essential discussion about which factors related to the territory are significant in promoting regional development and the creation of high-value supply chains.

The rest of the chapter depicts the methodological framework and the case study results, where the State of Tamaulipas (in Mexico) and its municipalities functioned as the region and subregions of analysis, respectively.

3.2 Proposed Methodology

From a methodological point of view, a complete diagnosis and characterization of the region are necessary to identify the potentialities and opportunities of regional productive sectors to create industrial clusters and high-value supply chains. The diagnostic structure must consider the region's socioeconomic and demographic aspects, aiming to identify the economic structure of regional productive sectors. This data comes from economic and population censuses. After identifying the region's economic structure, the study must quantify the potential of regional productive sectors in the second stage. This stage requires using classical economic indices and coefficients or a combination of analytical and data mining techniques. The third step requires identifying the most relevant and promising class of industrial clusters. Finally, the last step in the methodological framework is the strategic choice of relevant clusters with the most significant potential to create high-value supply chains while meeting the values and goals of regional development (see Fig. 3.1).

From a theoretical point of view, this framework considers the convergence of several new phenomena and concepts such as regionalization, productive vocation, economic potential, circular economy, and the interaction between them, as well as the application of analytical tools (analytic hierarchical process, fuzzy multi-objective optimization, and clustering methods) in the regional supply chain decision making. The aim is to understand, from a general perspective, the multisectoral challenges this kind of study represents.

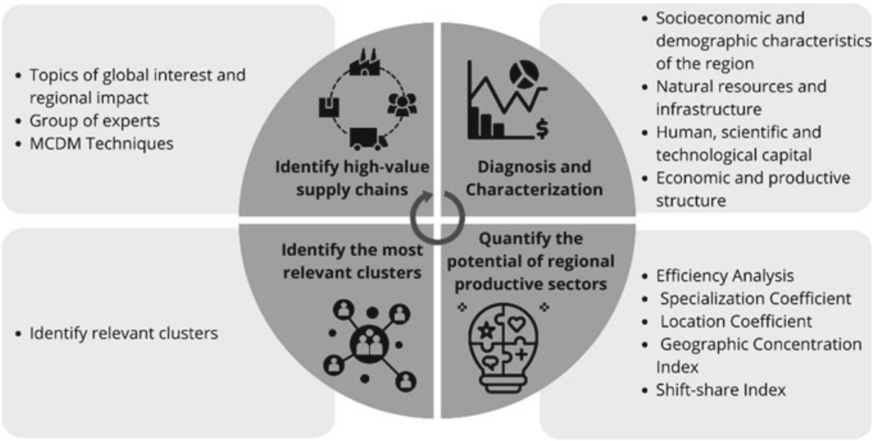

Fig. 3.1 The methodological approach

3.2.1 Stage 1—Diagnose and Characterization of the Region

The preparation of a diagnosis with a territorial approach is a process whose duration and complexity vary depending on the size of the territory, the characteristics that identify it, the variables to be analyzed, and the difficulties or facilities faced when collecting, processing, and interpreting the information. According to Economic Commission for Latin America and the Caribbean (ECLAC, https://www.cepal.org/en), different approaches exist to elaborate diagnoses that consider the territory as the main object of study. However, when the study's objective is identifying strategic opportunities for development, there are advantages to using a comprehensive and participatory diagnosis.

A diagnosis is comprehensive when it manages to characterize the priority variables that determine the development of a region to create sustainable, competitive, and inclusive societies and territories. The participatory perspective of the diagnosis implies involving local actors in its elaboration and decision-making since this produces an appropriation of the process, which guarantees the continuity of the actions.

The structure of the territorial diagnosis varies according to the thematic areas that make up and build the territory's profile. Our diagnostic model considers four dimensions for analysis and 18 thematic axes that collect information on more than 50 variables (see Table 3.1).

Table 3.1 Areas of analysis and thematic axes for the diagnosis

Dimension	Objective	Thematic axis
Socioeconomic and demographic characteristics of the region	Identify how the economic and sociodemographic structure of the region is made up	Geographic aspects Demography and population dynamics Socioeconomic aspects Environment Health Education
Natural resources and infrastructure	Identify what natural resources and infrastructure the region has for its development	Water Land Electrical infrastructure Hospitals Telecommunications and transportation
Human, scientific, and technological capital	Identify what scientific and technological capital the region has for its development	Regional scientific capital
Economic and productive structure	Investigate the economic conditions of the territory of analysis, including its recent dynamics and current situation	Participation in the VACB Structure of the VACB Importance of sectors in the state Dynamics and evolution of the economy by economic sector Analysis by sector Identification of product classes

3.2.2 Stage 2—Quantify the Potential of Regional Productive Sectors

The comparison of productive structures and intra-regional differentiation is required to determine the degree of specialization or vocation. There are a series of methodologies and techniques in the literature whose application depends on information and time availability. To quantify the potential of regional productive sectors, we will rely on economic indies and coefficients using the following terminology:

n Number of economic branches (productive sectors) in the region
m Number of subregions in the region
E_{ij} Value added in branch j in subregion i
E_i Total value added in subregion i
N_j Value added in branch j at the regional level
N Total value added at the regional level.

3.2.2.1 Specialization Coefficient

The specialization coefficient (SC), also known as differentiation, measures the degree of similarity in the economic structure of subregion i regarding the region's economic structure. The SC coefficient measures the specialization degree of a region, assuming a diversified reference distribution in relative terms.

$$\mathrm{SC}_i = \frac{1}{2}\sum_{j=1}^{n}\left|\frac{E_{ij}}{E_i} - \frac{N_j}{N}\right| \tag{3.1}$$

where: $0 < \mathrm{SC}_i < 1$.

Interpretation:

- If $\mathrm{SC}_i \rightarrow 0$, the economic structure of subregion i is close to the economic structure of the region.
- If $\mathrm{SC}_i \rightarrow 1$, the economic structure of subregion i tends towards specialization.

3.2.2.2 Location Coefficient

The location coefficient (LC) measures the locality's degree of productive specialization regarding another territory or region (Saravia and Camargo 2012).

$$\mathrm{LC}_i = \frac{E_{ij}/E_i}{N_j/N} \tag{3.2}$$

Interpretation:

- If $\mathrm{LC}_i < 1$: there is insufficient local production; therefore, it is necessary to import goods and services to supply local demand. The activity is not very localized.
- If $\mathrm{LC}_i = 1$: there is sufficient local production to supply its demand, but there is no surplus to export, we can say that the activity is localized.
- If $\mathrm{LC}_i > 1$: the local economy is specialized in this activity, production is greater than local demand, and therefore, there are possibilities to export.

3.2.2.3 Geographic Concentration Index

The geographic concentration index (GCI_j) expresses the degree of geographic distribution or spatial concentration of a productive sector j. The GCI assesses the concentration of economic activities.

$$\mathrm{GCI}_j = \frac{1}{2}\sum_{i=1}^{m}\left|\frac{E_{ij}}{N_j} - \frac{E_j}{N}\right| \tag{3.3}$$

where $0 < \mathrm{GCI}_j < 1$.

Interpretation:

- If $GCI_j \to 0$, the geographical distribution of productive sector j is close to the geographical distribution of regional production.
- If $GCI_j \to 1$, there is a geographical concentration of productive sector j in the region. The total production sector is less geographically distributed in the region.

3.2.2.4 Motor Products

The motor products class are those that currently contribute the most to the production and employment in the region; this class of products reflects a level of economic weight and growth superior to the other economic activities in the region.

3.2.2.5 Star Products

The star products class has the highest rate of specialization and the most significant possibility of creating production chains; in this class of products, the level of specialization and dynamism is high regarding its behavior at the national level. The Concentration Index (CI) measures the level of specialization and dynamism, considering three variables: Total Employed Personnel (*TEP*), Gross Census Added Value (*GCAV*), and Total Gross Production (*TGP*).

$$\mathrm{CI}_j^{\mathrm{VAR}} = \left(\frac{\mathrm{VAR}_j^{\mathrm{reg}} / \sum_{r=1}^{n} \mathrm{VAR}_r^{\mathrm{reg}}}{\mathrm{VAR}_j^{\mathrm{nac}} / \sum_{r=1}^{n} \mathrm{VAR}_r^{\mathrm{nac}}} \right) \tag{3.4}$$

where $\mathrm{VAR} = \{\mathrm{TEP, GCAV, TGP}\}$. The super indexes reg and nac refer to regional and national environments, respectively.

Interpretation:

- If $\mathrm{CI}_j^{\mathrm{var}} > 1$ and its growth rate between two consecutive periods $(t-1)$ and t is positive, then this product is defined as a star product since it concentrates economic production in an activity in which investments and employment are specialized.

3.2.2.6 Leading Products

The leading products class are those with evidence of containing the most competitive products in the region. A leading product class reflects the competitiveness of economic activity in each region. To measure regional competitiveness, the shift-share index (SSI) considers the same variables as the Concentration Index.

$$\mathrm{SSI}_j^{\mathrm{VAR}} = \mathrm{VAR}_{j,(t-1)}^{\mathrm{reg}} \cdot \left(\frac{\sum_{r=1}^{n} \mathrm{VAR}_{r,t}^{\mathrm{nac}}}{\sum_{r=1}^{n} \mathrm{VAR}_{r,(t-1)}^{\mathrm{nac}}} - 1 \right) \tag{3.5}$$

where $(t - 1)$ and t are two consecutive periods of censed data for the economic variables.

Interpretation:

– If $SSI_j^{VAR} > 0$ indicates that VAR related to the manufacture of product j in the region grows faster than at the national level and, therefore, is more competitive and consequently is a leading product.

3.2.3 Stage 3—Identify the Most Relevant Clusters

Several methodologies exist in the literature to identify industrial clusters (Cruz and Silva 2014). Of the many ideas and concepts that have emerged in the last years, the model proposed by Michael E. Porter is the most widely used as an analysis tool. Porter (2003) defines the concept of a cluster as follows: "*A cluster is a geographically dense group of connected companies and institutions, belonging to a specific field, united by common features and complementary to each other*".

The main characteristic of clusters is that their economic units can operate more efficiently, sharing technologies, infrastructure, pools of knowledge, and common demands. The presence of clusters can be an essential engine of regional competitiveness and innovation, for which it is necessary to identify the limits of the industry of each cluster.

Delgado et al. (2016) re-examined inter-industry relationships using suitable clustering methods based on input–output ratios, job occupations, and job-sharing and facility-sharing patterns, resulting in definitions of reference clusters for the industry. In making these new definitions, the descriptions of the North American Industry Classification System (NAICS) classification codes were used, with 6-digit disaggregation, proposing a new set of reference cluster definitions.

This chapter uses The Regional Development Group of the Tecnológico de Monterrey approach (Vilalta-Perdomo and Koch 2009) to identify the relevant products in the region (with 6-digit disaggregation). In the most promising class of products converge, two or three of the following products: the motor products class, the star products class, and the leading products class.

3.2.4 Stage 4—Identify High-Value Supply Chains

This stage aims to define priorities and identify those clusters with higher potential to create high-value supply chains while meeting the values and goals of regional development. This problem must consider multiple factors (criteria) which are not precisely known, creating vagueness and uncertainty in the decision environment. Therefore, due to the vagueness and uncertainty associated with this decision, we propose to use the fuzzy set theory to model the preferences using the Fuzzy Analytical Hierarchical Process (Fuzzy AHP) and conduct the selection process. The selection process involves selecting the best subset of clusters (regional productive sectors) with a competitive advantage and higher potential to result in high-value supply chains.

3.3 Case Study

Tamaulipas is northwest of the Mexican Republic, having remarkably favorable characteristics such as its coast and border strip. The State of Tamaulipas has an extension of 80,249 km^2, representing 4.1% of the Mexican territory. Forty-three municipalities (subregions) comprise the region, the largest one is Soto la Marina (subregion 037), with 6,422.14 km^2, and the smallest is Ciudad Madero (subregion 009), with 46.6 km^2. According to the last population and housing census, Tamaulipas has 3,527,735 inhabitants, where the proportion between women and men is 50.8% and 49.2%, respectively. The average population growth rate for men in Tamaulipas is 11.94%, and for women, it is 12.71%. The highest growth rate in the last 15 years for men occurred in 2010–2015 with 17.58%, while for women, it was in 2015–2020 with 17.56%. The most recent growth rate (2020–2015) was 6.77% for men and 17.56% for women.

3.3.1 Stage 1: Diagnose the Region—Economic Structure

To identify the economic structure of the region (Tamaulipas) and its subregions (43 municipalities), we perform an analysis of the 2013 and 2018 economic censuses reported by the INEGI (https://www.inegi.org.mx/app/saic/). Specifically, we reviewed the variables corresponding to Economic Units (*EU*), Total Gross Production (*TGP*), Gross Census Added Value (*GCAV*), Total Employed Personnel (*TEP*), and Gross Fixed Capital Formation (*GFCF*).

3.3.1.1 Economic Units (EU)

These are the statistical units on which data is collected. They are engaged in one type of activity permanently in buildings and fixed installations, combining actions and resources under the control of a single owner or controlling entity to produce goods and services, whether for commercial purposes or not. They are defined by sector according to the availability of accounting records and the need to obtain information with the highest level of analytical precision.

3.3.1.2 Total Gross Production (TGP)

It is the value of all the goods and services produced or commercialized by the economic units because of the exercise of its activities, including the value of the elaborated products; the gross marketing margin; the works executed; income from the provision of services, as well as the rental of machinery and equipment, and other movable and immovable property; the value of fixed assets produced for own use, among others. Includes the change in inventories of products in the process. Goods and services are valued at producer prices.

3.3.1.3 Gross Census Added Value (GCAV)

The value of production is added during the work process by the creative activity and transformation of employed personnel, capital, and organization (factors of production), carried out on the materials consumed in the economic activity. Arithmetically, the *GCAV* results from subtracting the Intermediate Consumption from the Total Gross Production. It is called gross because the consumption of fixed capital has not been deducted.

3.3.1.4 Total Employed Personnel (TEP)

All persons who worked during the reference period, depending contractually or not on the economic unit, are subject to its direction and control.

3.3.1.5 Gross Fixed Capital Formation (GFCF)

It is the value of the fixed assets purchased by the economic unit (whether domestic or imported, new or used), less the value of the sales of fixed assets made. As part of the purchase of fixed assets, the value of renovations, improvements, and major reforms carried out on fixed assets that extended their useful life by more than one year or increased their productivity, and fixed assets produced by the Economic Unit for own use.

Table 3.2 summarizes the economic information of the municipalities and the State. The subregions 032 (Reynosa) and 022 (Matamoros) are the municipalities with the largest number of Economic Units. It should be noted that both subregions are on the border with the United States of America.

In Table 3.3, we observe the Gross Census Added Value in the region's different economic activities or sectors.

According to the 2018 economic census reported by INEGI, the sector corresponding to transport, mail, and storage are the most important at the national level, followed by agriculture, animal husbandry and exploitation, forestry, fishing, and hunting, as well as manufacturing industries.

Table 3.2 Economic information from municipalities

Subregion	EU	TEP	GFCF (MDP)	TGP (MDP)	GCAV (MDP)
001	370	1,012	5.792	296.318	243.402
002	972	2,547	66.477	677.034	373.232
003	6,781	56,438	2,081.645	133,971.360	44,041.988
004	197	404	18.748	225.795	137.942
005	98	159	0.038	21.310	14.574
006	82	107	0.050	8.832	5.479
007	737	1,747	12.355	418.095	239.059
008	24	21	0.000	2.625	2.463
009	6,020	33,691	8,779.116	109,208.199	19,407.405
010	39	43	0.120	2.676	1.369
011	118	490	0.185	178.804	84.641
012	1,619	5,043	20.384	1,503.245	715.179
013	73	230	1.094	82.194	51.506
014	174	409	0.735	74.416	47.342
015	719	2,922	16.480	679.772	412.180
016	392	775	2.663	176.638	130.765
017	415	1,223	3.838	529.263	108.428
018	211	344	0.654	54.399	27.824
019	275	663	0.193	186.524	124.127
020	19	5	0.000	0.549	0.121
021	4,254	15,047	54.522	6,875.871	3,556.241
022	17,736	147,208	1,466.172	65,986.766	34,339.548
023	41	56	0.029	19.675	14.913
024	239	535	0.111	53.183	28.555
025	1,725	4,387	21.452	1,281.875	804.539
026	95	148	0.272	9.803	5.419
027	12,635	100,285	1,100.863	47,897.262	28,219.184
028	125	271	0.432	36.209	21.193
029	393	787	1.073	108.156	65.932
030	468	1,133	2.732	246.013	187.166
031	47	98	0.218	26.660	16.888
032	19,224	233,862	8,991.819	153,259.384	91,640.790
033	4,779	20,868	571.698	8,502.839	5,179.026
034	82	144	0.006	32.630	28.098
035	1,607	7,159	43.046	5,351.365	3,092.138
036	2	0	0.000	0.000	0.000

(continued)

Table 3.2 (continued)

Subregion	EU	TEP	GFCF (MDP)	TGP (MDP)	GCAV (MDP)
037	728	2,362	22.858	563.248	397.176
038	13,652	81,686	789.131	35,274.708	19,502.831
039	917	1,818	5.728	290.499	195.509
040	3,262	17,227	308.780	6,978.374	4,955.882
041	10,543	62,609	538.355	21,727.989	14,027.537
042	69	111	0.220	25.315	15.411
043	631	2,743	0.501	1,226.839	676.461
Region	112,589	816,605	24,953.233	609,593.763	275,776.656
National	4,800,157	27,132,927	746,451.840	22,212,249.976	9,983,800.258

MDP (millions of MXN Pesos)

Table 3.4 shows the growth rate of each one of the economic sectors or activities regarding the Gross Census Added Value variable.

According to the 2013 and 2018 economic censuses reported by INEGI, the sector that grew the most in the GCVA variable is *agriculture, animal husbandry and exploitation, forestry, fishing, and hunting*, followed by *information in the mass media* and *wholesale trade.*

Table 3.5 identifies the most relevant economic sectors in the region, considering the GCVA data from 2018.

3.3.2 Stage 2—Quantifying the Potential of Productive Sectors in Tamaulipas

With the information obtained from the economic censuses published by INEGI in 2013 and 2018, we quantify the potential of regional productive sectors using the approach proposed by The Regional Development Group of the Tecnológico de Monterrey to identify the most promising class products.

Table 3.6 shows the twenty-eight products in the motor products class in 2018, contributing the most to regional production and employment. These products exhibit a greater economic weight than other regional economic activities.

Table 3.7 shows the thirty-eight products contained in the star products class. These products exhibit the greatest possibility of creating production chains, as these products demonstrate a greater level of specialization and dynamism than others compared with the national level.

Table 3.8 shows the thirty-one products contained in the leading products class. These products are the most competitive in the region.

Table 3.9 shows the twenty-three products comprehended in the list of the most promising products class. A prelaminar analysis shows that twelve (52.17%) are

Table 3.3 Sectorial participation of the GCAV

Economic activity	National 2018 (MDP)	Region 2018 (MDP)	The portion of regional GCAV regarding national GCAV 2018 (%)
Sector 11 Agriculture, animal husbandry and exploitation, forest approval, fishing, and hunting	19,894.37	871.53	4.38
Sector 21 Mining	944,384.55	34,016.82	3.60
Sector 22 Generation, transmission, distribution and commercialization of electrical energy, supply of water and natural gas through pipelines to the final consumer	217,343.77	2,500.44	1.15
Sector 23 Construction	185,179.21	4,460.79	2.41
Sector 31–33 Manufacturing industries	3,193,797.39	117,274.57	3.67
Sector 43 Wholesale trade	877,495.02	23,111.51	2.63
Sector 46 Retail trade	1,255,312.84	41,110.57	3.27
Sector 48–49 Transport, mail, and storage	356,582.20	16,756.95	4.70
Sector 51 Information in mass media	196,268.58	4,593.17	2.34
Sector 52 Financial and insurance services	862,021.02	924.65	0.11
Sector 53 Real estate services and rental of movable and intangible assets	112,452.29	1,539.93	1.37
Sector 54 Professional, scientific, and technical services	182,806.47	2,238.88	1.22
Sector 55 Corporate	401,484.62	1,571.31	0.39
Sector 56 Business support services and waste management, and remediation services	465,586.85	7,085.79	1.52
Sector 61 Educational Services	136,594.10	3,893.00	2.85

(continued)

Table 3.3 (continued)

Economic activity	National 2018 (MDP)	Region 2018 (MDP)	The portion of regional GCAV regarding national GCAV 2018 (%)
Sector 62 Health and social assistance services	83,652.61	2,278.90	2.72
Sector 71 Cultural and sports entertainment services and other recreational services	51,657.05	558.42	1.08
Sector 72 Temporary accommodation and food and beverage preparation services	300,821.11	6,357.53	2.11
Sector 81 Other services except for government activities	140,466.20	4,631.89	3.30
Total	9,983,800.26	275,776.66	2.76

related to the transformation industry, the manufacture of transport and the manufacture of computer equipment, communication, measurement, and other equipment, the most frequent. Another 13.04% was in the retail trade sector, where the most frequent activity or class was retail trade in self-service and department stores. Similarly, the transport, mail, and storage sector obtained a 13.04% share. Temporary accommodation and food and beverage preparation services obtained a share within these promising products of 8.69%. Lastly, both the business support and waste management services sector and remediation services (4.34%), as well as the educational services sector (4.34%) and other services except government activities (4.34%), each of them obtained the same value.

3.3.3 Stage 3—Identifying the Most Relevant Clusters in Tamaulipas During 2018

Table 3.10 identifies the eleven most relevant clusters in the region where the automotive and the logistic clusters are the most relevant for Tamaulipas.

Table 3.4 GCAV growth rate (2013–2018)

Economic activity	Region 2013 (MDP)	Region 2018 (MDP)	Growth rate (%)
Sector 11 Agriculture, animal husbandry and exploitation, forest approval, fishing, and hunting	269.65	871.53	223.21
Sector 21 Mining	–	34,016.82	–
Sector 22 Generation, transmission, distribution and commercialization of electrical energy, supply of water and natural gas through pipelines to the final consumer	2,386.39	2,500.44	4.78
Sector 23 Construction	3,159.99	4,460.79	41.16
Sector 31–33 Manufacturing industries	68,751.31	117,274.57	70.58
Sector 43 Wholesale trade	9,204.04	23,111.51	151.10
Sector 46 Retail trade	18,105.05	41,110.57	127.07
Sector 48–49 Transport, mail, and storage	10,631.65	16,756.95	57.61
Sector 51 Information in mass media	1,435.73	4,593.17	219.92
Sector 52 Financial and insurance services	910.52	924.65	1.55
Sector 53 Real estate services and rental of movable and intangible assets	847.74	1,539.93	81.65
Sector 54 Professional, scientific, and technical services	1,215.78	2,238.88	84.15
Sector 55 Corporate		1,571.31	
Sector 56 Business support services and waste management, and remediation services	3,932.16	7,085.79	80.20
Sector 61 Educational Services	3,357.53	3,893.00	15.95
Sector 62 Health and social assistance services	1,362.95	2,278.90	67.20
Sector 71 Cultural and sports entertainment services and other recreational services	519.52	558.42	7.49
Sector 72 Temporary accommodation and food and beverage preparation services	3,581.48	6,357.53	77.51

(continued)

Table 3.4 (continued)

Economic activity	Region 2013 (MDP)	Region 2018 (MDP)	Growth rate (%)
Sector 81 Other services except for government activities	3,042.42	4,631.89	52.24
Total	163,387.95	275,776.66	68.79

Table 3.5 Importance of the sectors in the region

Economic activity	Contribution to the region in 2018 (%)	ranking
Sector 31–33 Manufacturing industries	42.53	1
Sector 46 Retail trade	14.91	2
Sector 21 Mining	12.33	3
Sector 43 Wholesale trade	8.38	4
Sector 48–49 Transport, mail, and storage	6.08	5
Sector 56 Business support services and waste management, and remediation services	2.57	6
Sector 72 Temporary accommodation and food and beverage preparation services	2.31	7
Sector 81 Other services except for government activities	1.68	8
Sector 51 Information in mass media	1.67	9
Sector 23 Construction	1.62	10
Sector 61 Educational Services	1.41	11
Sector 22 Generation, transmission, distribution and commercialization of electrical energy, supply of water and natural gas through pipelines to the final consumer	0.91	12
Sector 62 Health and social assistance services	0.83	13
Sector 54 Professional, scientific, and technical services	0.81	14
Sector 55 Corporate	0.57	15
Sector 53 Real estate services and rental of movable and intangible assets	0.56	16
Sector 52 Financial and insurance services	0.34	17
Sector 11 Agriculture, animal husbandry and exploitation, forest approval, fishing, and hunting	0.32	18
Sector 71 Cultural and sports entertainment services and other recreational services	0.20	19

Table 3.6 Motor products class in 2018

Class	Product
312,111	Manufacture of soft drinks and other non-alcoholic beverages
322,210	Manufacture of cardboard packaging
325,180	Manufacture of other basic inorganic chemicals
325,190	Manufacture of other basic organic chemicals
326,110	Manufacture of flexible plastic bags and films
332,810	Metallic coatings and finishes
333,411	Manufacture of air conditioning and heating equipment
334,310	Manufacture of audio and video equipment
334,410	Manufacture of electronic components
335,311	Manufacture of electric motors and generators
336,320	Manufacture of electrical and electronic equipment and its parts for motor vehicles
336,360	Manufacture of seats and interior accessories for motor vehicles
336,390	Manufacture of other parts for automotive vehicles
461,110	Retail trade in grocery, grocery, and miscellaneous stores
462,111	Retail trade in supermarkets
462,112	Retail trade in mini supermarket
468,411	Retail sale of gasoline and diesel
484,129	Other foreign general cargo transport
488,511	Customs agency services
488,519	Other brokerage services for freight transport
517,311	Wired telecommunications service operators
561,330	Supply of permanent staff
611,171	Private-sector schools that combine various levels of education
611,311	Private sector colleges
722,511	Restaurants with food preparation service a la carte or fast food
722,514	Restaurants with service of preparation of tacos and tortas
811,111	General mechanical repair of cars and trucks
812,110	Beauty salons, clinics, and hairdressers

3.4 Conclusions

In this chapter, we propose a four steps methodological approach to identify the potentialities and opportunities of regional productive sectors to create industrial clusters and high-value supply chains. As a case study, the State of Tamaulipas (in Mexico) and its municipalities were considered as the region and subregions of analysis, respectively. The diagnostic of its economic structure reveals that the subregions with the largest number of industries are on the border with the United States. The productive sectors with the greater economical participation regarding the

Table 3.7 Star products class in 2018

Class	Product
114,111	Shrimp fishing
114,119	Fishing and capture of other fish, crustaceans, mollusks, and other species
236,111	Single-family home construction
237,121	Construction of oil and gas distribution systems
238,221	Hydro-sanitary and gas installations
238,222	Installations of central air conditioning and heating systems
311,710	Preparation and packaging of fish and shellfish
311,830	Preparation of corn tortillas and grinding of nixtamal
312,111	Manufacture of soft drinks and other non-alcoholic beverages
315,223	Mass production of uniforms
315,229	Mass production of other outerwear of textile materials
316,999	Manufacture of other leather products, fur, and substitute materials
321,920	Manufacture of products for packaging and wooden containers
321,992	Manufacture of wooden articles and utensils for the home
322,210	Manufacture of cardboard containers
323,111	Printing of books, newspapers, and magazines
323,119	Printing of continuous forms and other forms
326,110	Manufacture of flexible plastic bags and films
326,193	Manufacture of plastic packages and containers for packaging with and without reinforcement
326,212	Tire revitalization
326,290	Manufacture of other rubber products
327,112	Manufacture of bathroom furniture
327,219	Manufacture of other glass products
327,330	Manufacture of pipes and cement and concrete blocks
334,220	Manufacture of transmission and reception equipment for radio and television signals and wireless communication equipment
334,310	Manufacture of audio and video equipment
335,311	Manufacture of electric motors and generators
336,330	Manufacture of parts for steering and suspension systems for automotive vehicles
336,370	Manufacture of die-cast metal parts for automotive vehicles
336,390	Manufacture of other parts for automotive vehicles
464,122	Retail sale of orthopedic articles
468,212	Retail trade of used parts and spare parts for cars, vans, and trucks
484,129	Other foreign general cargo transport
486,210	Transportation of natural gas through pipelines
488,511	Customs agency services

(continued)

Table 3.7 (continued)

Class	Product
523,122	Exchange centers
531,119	Rental without the intermediation of other real estates
611,141	Private-sector technical secondary schools

Table 3.8 Leading products class in 2018

Class	Product
325,180	Manufacture of other basic inorganic chemicals
333,411	Manufacture of air conditioning and heating equipment
333,999	Manufacture of other machinery and equipment for industry in general
334,310	Manufacture of audio and video equipment
334,410	Manufacture of electronic components
334,519	Manufacture of another measurement, control, navigation instruments and electronic medical equipment
335,220	Manufacture of white goods
336,320	Manufacture of electrical and electronic equipment and its parts for motor vehicles
336,330	Manufacture of parts for steering and suspension systems for automotive vehicles
336,350	Manufacture of parts of transmission systems for motor vehicles
336,360	Manufacture of seats and interior accessories for motor vehicles
336,390	Manufacture of other parts for automotive vehicles
337,920	Manufacture of blinds and curtain rods
339,111	Manufacture of non-electronic equipment for medical, dental and laboratory use
462,111	Retail trade in supermarkets
462,112	Retail trade in mini supermarket
466,111	Retail trade of home furnishings
466,212	Retail sale of telephones and other communication devices
468,111	Retail of new cars and trucks
468,211	Retail trade of new parts and spare parts for cars, vans, and trucks
468,411	Retail sale of gasoline and diesel
484,129	Other foreign general cargo transport
484,239	Other specialized foreign freight transport
488,519	Other brokerage services for freight transport
561,110	Business administration services
561,330	Supply of permanent staff
561,620	Protection and custody services through the monitoring of security systems
611,311	Private sector colleges
722,511	Restaurants with food preparation service a la carte or fast food
722,514	Restaurants with service of preparation of tacos and tortas
812,110	Beauty salons, clinics, and hairdressers

Table 3.9 The most promising products class in 2018

Class	Product	MPC	SPC	LPC	Promising
334,310	Manufacture of audio and video equipment	1	1	1	✓
336,390	Manufacture of other parts for automotive vehicles	1	1	1	✓
484,129	Other foreign general cargo transport	1	1	1	✓
312,111	Manufacture of soft drinks and other non-alcoholic beverages	1	1		✓
322,210	Manufacture of cardboard containers	1	1		✓
325,180	Manufacture of other basic inorganic chemicals	1		1	✓
326,110	Manufacture of flexible plastic bags and films	1	1		✓
333,411	Manufacture of air conditioning and heating equipment	1		1	✓
334,410	Manufacture of electronic components	1		1	✓
335,311	Manufacture of electric motors and generators	1	1		✓
336,320	Manufacture of electrical and electronic equipment and its parts for motor vehicles	1		1	✓
336,330	Manufacture of parts for steering and suspension systems for automotive vehicles		1	1	✓
336,360	Manufacture of seats and interior accessories for motor vehicles	1		1	✓
462,111	Retail trade in supermarkets	1		1	✓
462,112	Retail trade in mini supermarket	1		1	✓
468,411	Retail sale of gasoline and diesel	1		1	✓
488,511	Customs agency services	1	1		✓
488,519	Other brokerage services for freight transport	1		1	✓
561,330	Supply of permanent staff	1		1	✓
611,311	Private sector colleges	1		1	✓
722,511	Restaurants with food preparation service a la carte or fast food	1		1	✓
722,514	Restaurants with service of preparation of tacos and tortas	1		1	✓
812,110	Beauty salons, clinics, and hairdressers	1		1	✓

national values are Sector 11 (Agriculture, animal husbandry and exploitation, forest approval, fishing, and hunting) and Sector 48–49 (Transport, mail, and storage). The sectors with the greater growth rate (2013–2018) were Sector 11 (Agriculture, animal husbandry and exploitation, forest approval, fishing, and hunting) and Sector 51 (Information in mass media). While the productive sectors with the greater economic value added in 2018 were Sector 31–33 (Manufacturing industries) and Sector 46 (Retail trade).

When quantifying the potential of regional productive sectors, twenty-eight products were identified to contribute the most to regional production and employment.

Table 3.10 The most promising clusters in the region

Cluster	Products
Automotive	336,320 Manufacture of electrical and electronic equipment and its parts for motor vehicles
	336,330 Manufacture of parts for steering and suspension systems for automotive vehicles
	336,360 Manufacture of seats and interior accessories for motor vehicles
	336,390 Manufacture of other parts for automotive vehicles
Logistics	488,511 Customs agency services
	488,519 Other brokerage services for freight transport
	484,129 Other foreign general cargo transport
Information technology and analytical instrumentation	334,310 Manufacture of audio and video equipment
	334,410 Manufacture of electronic components
Technology for production and heavy machinery	333,411 Manufacture of air conditioning and heating equipment
Food preparation and processing	312,111 Manufacture of soft drinks and other non-alcoholic beverages
Paper and packaging	322,210 Manufacture of cardboard containers
Chemical processing	325,180 Manufacture of other basic inorganic chemicals
Plastics	326,110 Manufacture of flexible plastic bags and films
Lighting and electrical equipment	335,311 Manufacture of electric motors and generators
Business support service	561,330 Supply of permanent staff
Education and talent development	611,311 Private sector colleges

Thirty-eight products were identified to exhibit the greatest possibility of creating production chains, as these products demonstrate a greater level of specialization and dynamism in the region. And thirty-one products were identified as the most competitive products in the region.

The previous analysis identified eleven clusters as the most relevant in the region: where the automotive and the logistic clusters exhibit the larger number of promising products.

As further research, the criteria related to regional development priorities, values, and goals will be identified through an unstructured interview with the main actors of the region's industrial, economic, and social sectors. These criteria will be analyzed using the Fuzzy Analytical Hierarchical Process (Fuzzy AHP) and other multicriteria decision-making methods.

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Chapter 4
Artificial Intelligence-Based Analysis of Material Supply Costs in ETO Companies Shifting to Mass Customization

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Abstract Currently, it is necessary to compete with other strategies, such as Mass Customization (MC), in modern and competitive environments characterized by market uncertainty. Industrial companies that work with engineering-to-order (ETO) production systems need appropriate "supply management" to achieve operational excellence, which allows for remarkable improvements in supply chain performance. The factors and practical improvements in the Supply Management function of ETO companies working in MC environments are identified in this study. These factors and practical improvements affect the raw margin of the operating account and the evolution of the purchase prices of repetitive parts. This paper presents the case of an ETO company shifting to MC strategies by applying the Cross-Industry Standard Process for Data Mining (CRISP-DM) methodology. The findings show that the introduction of component standardization programs has a direct and significant impact on account operations in a company. Thus, the cost of merchandise sold in total sales decreases by 1.34%, and the percentage of repetitive parts purchased increases by 10% if Early Purchasing Involvement (EPI) is used. This involvement employs a multidisciplinary team of design assessments (MTDA), improving more

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than 40% of the value of expenditures over sales, a direct improvement in the raw margin of the company's operating account.

Keywords Engineering to order · Mass customization · Supply chain management · Multivariate analysis · Early purchasing involvement

4.1 Introduction

The term Lean Manufacturing (LM) evolved from Lean Enterprise (Womack et al. 2007) or Lean Thinking (Womack and Jones 2003). It could be defined as "a management system, started by Toyota, which involves all the employees in creating a flow in all the processes to create value for the clients and minimize waste".

The LM principles have led companies, both in production and services, to achieve significant improvements in competitiveness, achieving with its introduction some productivity improvements, quality and services to the clients, influencing the operational improvement of Operations Management (OM) (Gunasekaran and Ngai 2012; Riezebos et al. 2009; Womack et al. 2007). LM has been studied not only for flow-shop production environments but also for job-shop environments characterized by working under low production volumes and with a wide variety of products. As mentioned by Danese (2012) and Henao et al. (2019), the elements that contributed to the success of LM in the Toyota production system remain valid. It can even be said that, in the current context, where quickness and efficiency are crucial, LM can be even more important and effective than in the 1970s and 1980s, when it peaked on Toyota production lines. Most Toyota Production Systems (TPM) or LM applications have been applied to high-production-volume environments and standardized products, which results in visible improvements in costs, quality, and delivery times. Several authors have wondered what would have happened in companies with low production volumes and few standardized products (Cunha et al. 2018; Tu and Lu 2017). They affirmed that the lean "philosophy", a set of general organization and management principles, has helped these companies settle on the path of improvement (Cuatrecasas 2015; Möldner et al. 2018).

Currently, a further step must be taken to develop and complement this philosophy to systems that allow competition in the environments mentioned above, which sometimes leads to Mass Customization (MC) strategies or mass personalization. The term MC was first coined by Davis (1989) and later popularized by Pine (1992). The term MC represents a paradox as it combines the concepts of mass production and handcrafted production, which correspond to opposite business models (Fogliatto et al. 2012; Zhang et al. 2019). These authors explain how, over the years, companies that followed the two generic competitive strategies (competing in terms of costs and differentiation) could not achieve strategic success; that is, they should compete in costs or differentiation, not both (Blecker and Abdelkafi 2006).

Previous research has highlighted the evolution of the MC concept; in this sense, Anzanello and Fogliatto (2011) propose a method to select the best clustering variables to group customized product models into families, similar to group technologies in lean manufacturing. Mason and Lalwani (2008) proposed that Mass Customized distribution is related to logistics support for the supply chain. On the other hand, Yao and Liu (2009) presented an interesting dynamic optimization and multi-target for the supply chain as part of lean manufacturing and aimed to waste minimization.

There are several strategies to fulfill orders: make-to-stock (MTS), make-to-order (MTO), assembly-to-order (ATO), engineering-to-order (ETO), and others (Brabazon and MacCarthy 2006), all of which refer to a particular type of lean manufacturing organization. However, all these methodologies are focused on mass production systems; therefore, the question is how could such an approach be applied to projects that are few or one piece? To contribute to this area of opportunity, this study focuses on the ETO order-fulfillment strategies of machines or high-added-value projects, which are generally unique. The client interacts significantly with suppliers in such production systems, starting from the engineering phase. Usually, they are companies that work under project and multi-project environments instead of lines or assembly lines, which gives them peculiarities that differentiate them from series companies (automotive, white line, and others).

The research field of this article is the Purchasing and Supplying of ETO companies in Mass Customization environments (MC) through the pursuit of Operational Excellence with the improvement of the costs of the suppliers' supplies.

This research uses alternative tools for Operation Management, particularly the methodology Cross Industry Standard Process Model for Data Mining-CRISP-DM (Huber et al. 2019); the software Waikato Environment for Knowledge Analysis-WEKA (Eibe et al. 2016); and "R" for the statistical analysis. In this study, artificial intelligence was used to create two statistical models that measure the effects of several factors of Purchasing and Supplying (supply management) on the change in prices of repetitive parts and the raw margin of the operating account of ETO companies working in MC environments. The M5P algorithm is the basis for decision trees. Recent applications of M5P model trees appear in Lin et al. (2016) for risk identification and in Behnood et al. (2017) for concrete performance in construction.

4.1.1 Organization of the Purchasing Department

According to Huang et al. (2010), companies with a high degree of MC, such as ETO type, are positively affected if they have organic structures characterized by flat, decentralized, and multifunctional employees.

For efficient supply, it is necessary that the purchasing functions and the ordering/management of materials be differentiated. That is, purchasing builds the framework with suppliers, requests offers, negotiates prices, and looks for suppliers, acts as a support function, while the ones that order/manage materials take care of the fulfillment of the issued order in due time, amount, and scope (Kull et al. 2013; Srai and Lorentz 2019).

This aspect is of paramount importance for efficient ETO supply in MC. For empale, Sabri and Shaikh (2010) differentiated the super-process of Supplier Relationship Management (SRM), which has an operational activity called purchase order management (POM), whose objective is to manage the order from its issue until its reception in the delivery place.

Rozemeijer (2008) also highlights the need to differentiate the supply activities of administrative and strategic types, even classifying them into strategic, tactical, and operational. The latter is related to the issue of purchase orders and the follow-up and monitoring of the fulfillment of the order (Bals and Turkulainen 2017). This differentiation helps gain a competitive edge over competitors (Birasnav and Bienstock, 2019).

For ETO environments, the purchasing function is very similar to purchasing in a project. Each project was new and required new suppliers for each order. The products to be bought must be discussed in detail with suppliers, and interaction with the engineering department is necessary and intense. Quality and delivery in due time are more important than prices. Purchasing must respond quickly to changes in project design and planning (Mackert 2019; Yang et al. 2019).

Under such conditions, the supply management function must not work reactively. The work must be made in advance, and it is necessary to get involved before orders are issued to suppliers, or the offer request phase starts. This is known as Early Purchasing, Purchasing Engineering or Early Purchasing Involvement (EPI).

The Institute for Supply Management (ISM) defines Early Purchasing Involvement as a practice involving professionals from Purchasing in developing new products or services. EPI works as a nexus between the departments of Engineering and Purchasing and is part of the design teams. It contributes to the knowledge of the suppliers and the market and the manufacturers' limitations in modifying conceptual designs in the early stages. EPI also looks for new suppliers for new requirements in the initial phases of design, helping and providing support to engineering to make the design oriented to cost (design-to-cost) and thus help fulfill the Objective Cost of the Project.

4.1.2 Standardization of Components and Materials

The concept of a Product Platform involves designing shared elements using multiple product models (Xiong et al. 2018). According to Becker et al. (2019), scale economies are achieved through components more than through final products, and scope economies are achieved using modular components applied over different final products. This is applied to the entire organization through the chain value. Of the five methods used to achieve MC, the best method is modularization (Modrak and

Soltysova 2018). The product's modular design is closely related to the integration of the supply chain and, at the same time, to its efficiency and efficacy in MC environments (Zhang et al. 2019).

This procedure is also applicable to ETO companies and products. The key is to use standardized "components", "common" to several families of final products and "modular", which, through the standardization of the interfaces, allows producing various final products with the same components.

Therefore, the final product, or its parts, must be "standardized" as much as possible and organized by the product family. The objective is to establish product platforms that allow standardization without loss of customization through modularization.

Studying and analyzing product platforms is necessary to modularize the final product before the component standardization phase starts. The standardization of components provides all the advantages of efficient ETO supply.

Cannas et al. (2018) affirm that in ETO companies, performance in terms of deliveries can be improved by reconfiguring the products and processes through modularization and standardization. This allows clients to find products with familiar characteristics to minimize the variety of spare parts, leading to improvements in cost and complexity for the suppliers.

4.2 Methodology

The Model to Measure Supply Costs in ETO companies working in MC environments belongs to the environment of Production and Operation Management (POM). To obtain the model, the methodology CRISP-DM is used (Huber et al. 2019). CRISP-DM has been widely described and used to analyze processes from the initial stages to develop research projects using data mining (Ingvaldsen and Gulla 2012; Sharma et al. 2012; Chen and Huang 2011; Silva et al. 2019; Huber et al. 2019). Figure 4.1 shows the methodology used as a global framework for obtaining the statistical model.

Fig. 4.1 CRISP-DM methodology (Huber et al. 2019)

Along with CRISP-DM methodology, the statistical analysis tool R was used (Sheather 2009; Everitt and Hothorn 2011; Jank 2011; Kabacoff 2011). The RStudio™ package was used to edit the scripts in R; it offers an Integrated Development Environment (IDE) for R and is freely available.

The WEKA software, oriented to data mining, was used. WEKA is a collection of machine-learning algorithms for data-mining tasks. These algorithms can be applied directly to a dataset or called from their own Java code (Eibe et al. 2016; Bouckaert et al. 2010). Model trees M5P were also used, and the association rules algorithm A priori was used to gather knowledge (Behnood et al. 2017; Blaifi et al. 2018).

4.2.1 Business Understanding

The company used as a case study operates in the equipment sector. It focuses on engineering, development, project management, purchasing/supplying components/materials, assembly, installation, and setting up high-value and customized engineering projects. The production system is based on projects; each piece of machinery or facility is different from the others, and they are quite customized. That is, the ETO-type production system was used. The production process starts only once the client issues an order. No machinery is produced for storage, and the strategy to be followed is MTO (Beemsterboer et al. 2016). For the company, the concept of ETO implies that the "degree of customization" of the product to deliver is "pure"; that is, the product is made from a blueprint for each client and is then introduced into the entire value chain. The clients notify the characteristics and specifications they need, and the company under study creates a design based on the specifications requested by the client. A new design is required even if the machinery produced must be introduced in another location with similar characteristics. The work comprises conceptual design, design of details/specifications to industrialize the product, and supply management. Finally, the activities to be performed after receiving the request from the client comprise conceptual and detailed design, production engineering, manufacturing, purchase of materials and components, assembly, and delivery.

Production belongs to the term MTO, which implies that the "degree of customization" of the product to be delivered is "tailored", that is, when a basic design is modified to the needs or specifications of the client. For instance, the size of a machine can be modified based on the same conceptual design.

The company is present in the Versatile Manufacturing Companies (VMC) market, which implies that each order is regarded as an individual purchase in comparison with the Repeat Business Customizers (RBC) market, where the competitive offer is directed to design and create a product repetitively for a reasonable period.

For that purpose, the Supply Chain Management was aligned with the mission and strategy of the company so that the pursuit of "Operational Excellence" supports and contributes to the pursuit of "Strategic Competitive Excellence of the Business" (Duggan 2012; Vartiak and Jankalova 2017). These concepts are the research object in this chapter, oriented to identify Operational Excellence in Supply Chain Management (Bruque-Cámara et al. 2016), which studies the key elements contributing to operations to obtain factors and practices that improve the costs of supplies to improve and optimize ETO supply chain management in MC environments.

4.2.2 Data Understanding

This was an *observational study* to obtain data. This study defines the variables to be used, gathers them, and interacts with them to obtain relevant data. This method can provide accurate and reliable data, thereby reducing the possibility of outliers related to data errors (Moore et al. 2017). However, multicollinearity problems may appear.

Currently, no models show the factors or variables that significantly influence the performance of ETO supply chain management in MC, nor are there models showing to what extent it happens quantitatively. The introduction of EPI through "Multidisciplinary Teams of Design Assessment" MTDA is an objective of analyzing the company's strategic plan. These teams consist of actors from the purchasing departments, engineering, quality, and assembly, who are involved from the beginning of the project and collaborate actively in the conceptual and detailed design phases, checking each blueprint before issuing it. After its practical introduction, some results were improved. However, it is unknown if this factor is statistically significant and relevant and to what extent it influences the cost results of the supplies from the providers.

4.2.3 Data Preparation

The supply chain management of the case study company was monitored and controlled by a control frame. The evolution of the purchase prices of repetitive parts and consumption compared with total sales is a key indicator of the economic management of the company.

Raw Margin is a key economic indicator for any company, and this is calculated by subtracting the costs of the products sold from the company's income.

The cost of the sold products is a key factor in the Raw Margin of the company's operational account. Two factors closely related to the cost of the sold products are:

- Purchasing prices
- Product design. The costs of commercialized products/services are defined in this phase.

The following responses were selected for this study:

- Cost % of sold products (or expenditures) compared to sales
- Evolution of repetitive parts purchase prices

The evolution of repetitive parts purchase prices is measured as the variation percentage of the average purchase price of the period analyzed (quarter, year, among others) of the parts bought repeatedly compared with the average price of such repetitive parts in the previous year.

The purchasing function influences both responses, as it is the unit responsible for negotiating the purchase prices in the companies and collaborating in the product engineering design phases to minimize the Total Cost of Ownership (TCO) (Shabani et al. 2019). The data-gathering period for this research comprised more than four years of monthly observations.

The statistical models identified and quantified the impact of several factors on the evolution of repetitive purchase prices and the raw margin of the operating account of ETO companies that operate in MC environments. Table 4.1 shows the variables included in the statistical and data-mining analyses. There were 26 independent variables and two responses or dependent variables.

The dependent variables analyzed were as follows:

- ***Evo_P_Repe***: % of the evolution of repetitive parts purchase prices
- ***Cons_Ventas_T***: % of expenditures compared to total sales

There are several variables: economic situation, the structure of the Purchasing Department, level of activity, inefficiencies, and financial issues (Strandhagen et al. 2018; Pandit and Zhu 2007). The objective was to have a broad spectrum of explanatory variables to obtain a better explanation of the responses and more accurate models.

This study shows and analyzes the value of each variable. For confidentiality reasons, the data were standardized between 0 and 1. There have been some missing data since the periodicity of the data gathering has not been 100% fulfilled. Specific quarterly data have been extended for longer periods, as with the variable *Evo_P_Repe* or *Cons_Ventas_T*.

4.2.4 Modeling

The models that quantitatively explain the dependent variables are presented in this section.

This section deals with the work in several ways, one of which is creating regression models using continuous dependent variables. Another method will create classifier models with categorical response variables, complementing the modeling phase using association rules. Association rules express behavior patterns between the data

Table 4.1 Independent variables and answers for the statistical and data mining analyses

	Denomination	Description	Frequency	Type	Category
Independent variables	Year	Year of the data mining	N/A	Categorical	N/A
	Month	The month of the data mining	N/A	Categorical	N/A
	n_Planos	Number of blueprints issued for the purchase	Monthly	Numeric	Activity
	IPRI	Index of industrial prices. Presented in percentages. Source INE	Monthly	Numeric	Economic situation
	IPI	Index of industrial production. Index values over 100	Monthly	Numeric	Economic situation
	PMI	Purchasing Managers Index. Index = 50 implies no change; Index > 50 implies a decrease; Index < 50 implies a decrease	Monthly	Numeric	Economic situation
	MTDA	Multidisciplinary Teams of Design Assessment. MTDA = Yes; MTDA = No	N/A	Categorical	Organizational
	n_D_Stock	Number of days of the stock of raw materials and materials in use	Monthly	Numeric	Logistics
	Stock	Economic volume in € of stock	Monthly	Numeric	Logistics
	n_Buyer	Number of buyers	Annual	Numeric	Structure UCA
	n_Buyer_Ap	Number of buyers plus suppliers	Annual	Numeric	Structure UCA
	n_Mod_ext	Number of modifications of a blueprint that affect issued orders	Monthly	Numeric	Inefficiencies

(continued)

Table 4.1 (continued)

	Denomination	Description	Frequency	Type	Category
	n_Lineas_Compo	Number of purchase lines of components	Monthly	Numeric	Activity
	Vol_Compo	Economic volume in € of components purchase	Monthly	Numeric	Activity
	Fact_Compo	Invoiced volume in € of components by the suppliers	Monthly	Numeric	Activity
	n_Lineas_Sub	Number of subcontract purchase lines	Monthly	Numeric	Activity
	Vol_Sub	Economic volume in € of subcontract purchase	Monthly	Numeric	Activity
	Fact_Sub	Invoiced volume in € of components by the suppliers	Monthly	Numeric	Activity
	n_Lineas_URG	Number of purchase lines treated as Urgent	Monthly	Numeric	Inefficiencies
	Vol_URG	Purchase volume in € purchased as urgent	Monthly	Numeric	Inefficiencies
	n_Facturas_NOK	Number of invoices received from the suppliers	Monthly	Numeric	Activity
	Repe	% of the economic volume of parts that were also purchased in the previous year (repeated) over the total purchase volume of the period taken as reference	Annual-quarterly	Numeric	Sales mix and standardization of references
	n_Prov	Number of suppliers	Annual	Numeric	Purchase management
	n_Sub	Number of subcontractors	Annual	Numeric	Purchase management

(continued)

Table 4.1 (continued)

	Denomination	Description	Frequency	Type	Category
	HE	Number of extra hours for the buyers	Monthly	Numeric	Activity
	HF	Number of training hours	Monthly	Numeric	RRHH
Answers	Cons_Ventas_T	Percentage of the expenditure account compared to total sales	Monthly	Numeric	Financial
	Evo_P_Repe	Percentage in the evolution of purchase prices of repetitive parts in the current period compared to the prices of the previous year	Annual-quarterly	Numeric	Supply chain management

based on the appearance at the same time of values of two or more attributes; that is, relations among variables can be obtained to gain knowledge from the data (Orallo et al. 2010).

4.2.4.1 Regression Models for the Response Evo_P_Repe

Model Tree M5P for Evo_P_Repe

The algorithm M5P shows the regression trees by dividing the observation space and obtaining a linear regression model for each leaf. The tree M5P was structured with eight nodes and nine leaves, and the nodes refer to *Year, IPRI, Cons_Ventas_T, PMI, Vol_URG, n_Buyer,* and *Repe*. Nine linear regression models (LM1 to LM9) were obtained for each of the nine tree leaves.

The M5P model distinguishes different linear regression models based on the year of data gathering, whether they coincide or are below or above years *A3, A4*, and *A5*. Different linear regression models are distinguished in the second level based on the *n_Buyer* value (7.5). At a lower level, the models were distinguished based on *IPRI* (0.25) and *PMI* (51.25). In the last level, the models based on the variables *Cons_Ventas_T* (37.19%), *Vol_URG* (233.17 k€), and *Repe* (27.93) are found. Table 4.2 shows the statistical data of the described model.

Table 4.2 Statistical results of the M5P models

ITEM	Evo_P_Repe	Cons _Ventas_T
Correlation coefficient	0.9769	0.8665
Mean absolute error	0.3069	0.9784
Root mean squared error	0.3791	0.3869
Relative absolute error	24.8433%	39.0175%
Root relative squared error	21.0939%	48.4774%
Total number of instances	52	52

Multiple Linear Regression with R for Evo_P_Repe

Linear regression models allow for analyzing regression problems with more than one regression variable intervention. Usually, when these techniques are applied to create models, problems such as variable selection, the autocorrelation of errors, multicollinearity, and linear dependence appears. These aspects must be considered when creating the final model. As shown in Table 4.3a, the model has a reasonable adjustment, and the Akaike criterion was used. It also meets the ordinary least squares (OSL) assumptions for regression.

Although VIF = 4.1 < 10, there is a multicollinearity problem, as phi = 2091 > 1000; therefore, it is necessary to use the regression method over the Main Components to eliminate it (Montgomery et al. 2012).

Likewise, the regression is performed over the Main Components of the eigenvectors corresponding to the ten entry variables that influence the linear regression model for *Evo_P_Repe* (Montgomery et al. 2012).

If the eigenvectors are close to a unit, the original regressors are orthogonal; however, if the eigenvectors are equal to zero, it implies a perfect linear relationship between the original regressors. Multicollinearity exists if one or several eigenvectors are near zero. For this reason, several components with eigenvectors near zero were eliminated to solve the multicollinearity problem. Regression is performed over the remaining main components to obtain the biased estimators of the regression coefficient of the model presented in the previous section (Montgomery et al. 2012).

According to Montgomery et al. (2012), there is an alternative strategy for selecting the elimination order of the main components. The main components, as regressors, are orthogonal; therefore, the elimination order will be determined by a "t-test". The "t values" are put in order, and the components considered for elimination will start with the lowest "t value" in magnitude. Two proposals were obtained from the studied model (Table 4.4a), eliminating the least significant vectors. The best commitment solution among the three metrics was selected: Residual Sum Square (RSS), predicted residual sum of squares (PRESS), and Corrected Sample Standard Deviation (CSSD).

The selected proposal (number 2) eliminates the main component, whose alpha is set to zero, and PC10 (Montgomery et al. 2012). The regression model was constructed below the rest of the main components, as shown in Table 4.5.

Table 4.3 Statistical data of the multiple linear regression models

	[a] Multiple linear regression complete for Evo_P_Repe				[b] Multiple linear regression for Cons_Ventas_T and with MTDA = YES			[c] Multiple linear regression for Cons_Ventas_T and with MTDA = NO		
Item	Estimate Std	Std Error	t value	Pr(>|t|)	Item	t value	Pr(>|t|)	Item	t value	Pr(>|t|)
(Intercept)	−9.119e+00	5.552e-01	−16.426	<2e-16***	(Intercept)	23.582	7.44e-14***	(Intercept)	75.619	<2e-16***
Year A3	−2.210e+00	1.320e-01	−16.744	<2e-16***	n_Planos	−1.666	0.115240	n_Planos	1.286	0.218
Year A4	9.825e-02	1.578e-01	0.623	0.536875	IPRI	3.536	– 0.002747**	IPRI	8.640	3.29e-07***
Year A5	2.570e-03	1.750e-01	0.015	0.988357	n_D_Stock	3.666	0.002089**	n_D_Stock	−1.678	0.114
n_Buyer	1.187e+00	4.530e-02	26.214	<2e-16***	n_Lineas_Compo	2.330	0.033229*	n_Buyer	−28.562	1.72e-14***
n_Mod_ext	1.184e-03	9.628e-04	1.230	0.225827	Vol_Compo	−5.686	3.38e-05***	n_Mod_ext	1.735	0.103
n_Lineas_Compo	−1.311e-04	5.165e-05	−2.537	0.015068*	Vol_Sub	2.225	0.040832*	n_Facturas	−1.707	0.108
Fact_Compo	−3.672e-07	9.276e-08	−3.959	0.000293***	n_Lineas_URG	4.690	0.000246***	Repe	0.752	0.464
n_Lineas_Sub	3.288e-03	1.336e-03	2.460	0.018202*	n_Facturas	5.404	5.85e-05***	Evo_P_Repe	45.534	<2e-16***
Repe	1.581e-02	7.864e-03	−2.011	0.050968	Repe	−3.556	0.002635**	n_Facturas_NOK	−1.144	0.271
n_Facturas_NOK	4.161e-03	1.718e-03	2.422	0.019931*	n_Facturas_NOK-	−4.067	0.000897***			

(continued)

Table 4.3 (continued)

	[a] Multiple linear regression complete for Evo_P_Repe				[b] Multiple linear regression for Cons_Ventas_T and with MTDA = YES			[c] Multiple linear regression for Cons_Ventas_T and with MTDA = NO		
Item	Estimate Std	Std Error	t value	Pr(>|t|)	Item	t value	Pr(>|t|)	Item	t value	Pr(>|t|)
Residual standard error	0.2852 on 41 degrees of freedom				0.8067 on 16 degrees of freedom			0.168 on 15 degrees of freedom		
Multiple R-squared	0.9795				0.8715			0.997		
Adjusted R-squared	0.9745				0.7912			0.9951		
F-statistic	195.7 on 10 and 41 DF				10.85 on 10 and 16 DF			545 on 9 and 15 DF		
p-value	<2.2e-16				2.268e-05			<2.2e-16		

Table 4.4 Proposals that meet the premise of eliminating less significant vectors

[a] *Evo_P_Repe*				[b] *Cons_Ventas_T* and with *MTDA* = YES				[c] *Cons_Ventas_T* and with *MTDA* = NO			
Proposal	SSres	s	PRESS	Proposal	SSres	s	PRESS	Proposal	SSres	s	PRESS
[1]	3.334	0.28518	5.6151	[1]	10.410	0.80665	31.645	[1]	0.42336	0.16800	1.2433
[2]	3.393	0.2842	5.2008	[2]	10.4561	0.784261	28.2894	[2]	0.5044	0.1775	1.2272
				[3]	10.7304	0.772099	26.1010				
				[4]	11.1992	0.767747	22.8600				

Table 4.5 Statistical data of the regression models compared to the main components of the models

[a] Regression to the main components complete of the model Evo_P_Repe					[b] Regression to the main components complete of the model Cons_Ventas_OK and with MTDA = YES			[c] Regression to the main components complete of the model Cons_Ventas_OK and with MTDA = NO		
Item	Estimate Std	Error	t value	Pr(>|t|)	Item	t value	Pr(>|t|)	Item	t value	Pr(>|t|)
(Intercept)	−1.66327	0.03942	−42.19	<2e-16^{+}	(Intercept)	252.409	< 2e-16^{+}	(Intercept)	1155.218	<2e-16^{+}
Z[,c(1:9)]PC1	−0.41272	0.02208	−18.69	<2e-16^{+}	Z[, c(3:6, 8:10)]PC3	−3.413	0.002920^{-}	Z[, c(1:4, 6:9)]PC1	−41.098	<2e-16^{+}
Z[, c(1:9)]PC2	0.41842	0.02919	14.334	<2e-16^{+}	Z[, c(3:6, 8:10)]PC4	−2.670	0.015135*	Z[, c(1:4, 6:9)]PC2	−8.378	3.03e-07^{+}
Z[, c(1:9)]PC3	−0.86016	0.03554	−24.20	<2e-16^{+}	Z[, c(3:6, 8:10)]PC5	4.763	0.000135^{+}	Z[, c(1:4, 6:9)]PC3	24.900	3.19e-14^{+}
Z[, c(1:9)]PC4	0.84171	0.03987	21.109	<2e-16^{+}	Z[, c(3:6, 8:10)]PC6	−3.842	0.001100^{-}	Z[, c(1:4, 6:9)]PC4	−23.625	7.23e-14^{+}
Z[, c(1:9)]PC5	0.12730	0.04276	2.977	0.004814^{-}	Z[, c(3:6, 8:10)]PC8	4.685	0.000161^{+}	Z[, c(1:4, 6:9)]PC6	−13.842	2.53e-10^{+}
Z[, c(1:9)]PC6	0.89043	0.04803	18.540	<2e-16^{+}	Z[, c(3:6, 8:10)]PC9	−3.729	0.001422-	Z[, c(1:4, 6:9)]PC7	2.877	0.011*
Z[, c(1:9)]PC7	0.23802	0.05910	4.028	0.000231^{+}	Z[, c(3:6, 8:10)]PC10	5.136	5.87e-05^{+}	Z[, c(1:4, 6:9)]PC8	−15.478	4.77e-11^{+}
Z[, c(1:9)]PC8	−0.20690	0.07268	−2.847	0.006804^{-}				Z[, c(1:4, 6:9)]PC9	−31.797	6.86e-16^{+}
Z[, c(1:9)]PC9	−0.20893	0.08371	−2.496	0.016580*						
Residual standard error	0.2843 on 42 degrees of freedom				0.7677 on 19 degrees of freedom			0.1776 on 16 degrees of freedom		

(continued)

Table 4.5 (continued)

[a] Regression to the main components complete of the model Evo_P_Repe					[b] Regression to the main components complete of the model Cons_Ventas_OK and with MTDA = YES			[c] Regression to the main components complete of the model Cons_Ventas_OK and with MTDA = NO		
Item	Estimate Std	Error	t value	Pr(>|t|)	Item	t value	Pr(>|t|)	Item	t value	Pr(>|t|)
Multiple R-squared	0.9791				0.8618			0.9964		
Adjusted R-squared	0.9746				0.8108			0.9946		
F-statistic	218.8 on 9 and 42 DF				16.92 on 7 and 19 DF			548.5 on 8 and 16 DF		
p-value	<2.2e-16				6.24e-07			<2.2e-16		

Each main component of a linear model is the variable of the initial model from which the main components are obtained, and the coefficients of this model are listed in Table 4.6.

The most relevant variables are *Year, A3, n_Buyer*, and *Fact_Compo.* From these variables, the following conclusions can be drawn.

Selection of Regression Models for the Evo_P_Repe Response

Finally, Table 4.7 was used to select the regression models based on the criteria of the best metrics.

The model selected is the third "c" of Table 4.7, corresponding to the Linear Regression Model of the Main Components (based on the linear regression model "b" for Y = *Evo_P_Repe*). The selected model does not present multicollinearity problems; moreover, it is the best commitment solution for adjusting the model (R^2 adj, R^2), SSres, and s. For further interpretation, the classifier models (trees J48) and the association rules will be considered, which will help complete the analysis.

4.2.4.2 Regression Models for the Response Cons_Ventas_T

After several analyses, using linear regression, the best models were obtained based on MTDA (two models according to MTDA = YES/NO). In the case of model trees M5P, better results were obtained by working with only one model.

M5P Tree Models for Cons_Ventas_T

The M5P tree of the linear model had three leaves and two nodes. The linear models were classified based on Year (A2) and *n_Buyer_Ap* (12). Table 4.2 shows the statistical data of the model.

Multiple Linear Regression with R

1. For *Cons_Ventas_T* and with *MTDA* = YES
   As shown in Table 4.3b, the best model is obtained using the Akaike criterion. The model met the OLS regression assumptions. Although VIF = 9,93 < 10, there is multicollinearity when PHI = 3072 > 1000. To solve this problem, it is necessary to use the regression method of the Main Components.

   Four proposals were obtained from the studied model, eliminating the least significant vectors (Table 4.4b). The best commitment solution among the three metrics was selected: PRESS, s, and SSres.

Table 4.6 Coefficients of the models

[a] Modelo de Regresión Evo_P_Repe		[b] Modelo de Regresión Cons_Ventas_OK and with MTDA = YES		[c] Modelo de Regresión Cons_Ventas_OK and with MTDA = NO	
Item	Beta	Item	Beta	Item	Beta
(Intercept)	−9.165764	(Intercept)	35.24702	(Intercept)	61.30041
Year A3	−2.247148e+00	n_Planos	−1.654484e-03	n_Planos	0.0003985219
Year A4	2.216502e-02	IPRI	−1.324279e+00	IPRI	0.3740944218
Year A5	−1.136066e-01	n_D_Stock	9.020117e-02	n_D_Stock	−0.0085177176
n_Buyer	1.192764e+00	n_Lineas_Compo	7.603280e-04	n_Buyer	−2.1256984112
n_Mod_ext	1.314715e-03	Vol_Compo	−1.922395e-06	n_Mod_ext	0.0024245069
n_Lineas_Compo	−1.085370e-04	Vol_Sub	7.370588e-07	n_Facturas	−0.0006096395
Fact_Compo	−3.001551e-07	n_Lineas_URG	4.858187e-03	Repe	0.0083923181
n_Lineas_Sub	3.285792e-03	n_Facturas	1.222291e-02	Evo_P_Repe	2.0806445196
Repe	−1.616627e-02	Repe	−1.337708e-01	n_Facturas_NOK	−0.0023959361
n_Facturas_NOK	2.934270e-03	n_Facturas_NOK	−4.391145e-02		

Table 4.7 Regression models considered for *Evo_P_Repe*

	PHI	SSres	s	PRESS	R^2adj	R^2
(a) M5P model	X	X	X	X	0.9769	X
(b) Regression lineal	2091	3.335	0.285	X	0.9795	0.9745
(c) Regression PC s/b	X	3.393	0.284	5.200	0.9791	0.9746

Proposal number 4 implies the elimination of three main components (PC1, PC2, and PC7) and then performs the regression over the rest of the main components (Table 4.5b) to eliminate the main components that cause multicollinearity problems (Montgomery et al. 2012). Each main component is a linear model of the variables of the initial model from which the main components are obtained, and the coefficients of this model are listed in Table 4.6b.

More relevant variables will provide the conclusions, such as n_Facturas, n_Facturas_NOK, Vol_Compo, and n_Lineas_URG.

2. (b) For *Cons_Ventas_T* and with *MTDA* = NO

The best model obtained using the Akaike criterion is presented in Table 4.3c.

Since there are possible doubts regarding the OLS regression assumptions, a specific test proved the fulfillment of these assumptions (Kabacoff 2011). A test was conducted (K–S test) to evaluate the normality of the residues, which did not show any relevance; thus, it was invalidated.

Although $VIF = 10{,}43 < 10$, there is multicollinearity as $PHI = 7006 > 1000$. It is necessary to use the regression method of the Main Components to solve the problem.

Proposal number 2 (Table 4.4c) implies the elimination of the main component (PC5) and then performs the regression over the rest of the main components (Montgomery et al. 2012). The results are listed in Table 4.5c. Each main component is a linear model of the variables of the initial model from which the main components have been obtained, and the coefficients of this model are listed in Table 4.6c.

The more relevant variables are *n_Buyer*, *Evo_P_Repe*, and *IPRI*, and conclusions were drawn from them.

Selection of Regression Models for the Response Cons_Ventas_T

Table 4.8 shows the regression models considered. The selection is based on the best metrics criteria, which, in this case, correspond to the models "c" and "e". The models selected do not present multicollinearity problems, and it is the best commitment solution between the adjustment of the models (R2adj, R2), SSres, and s.

Table 4.8 Regression models considered for *Cons_Ventas_T*

	PHI	SSres	s	PRESS	R^2adj	R^2
(a) M5P model	X	X	X	X	0.8665	X
(b) Regression MTDA_YES	3072	10.411	0.8067	X	0.0.8715	0.7912
(c) Regression PC MTDA_YES s/b	X	11.199	0.7677	22.86	0.8618	0.8108
(d) Regression MTDA_NO	7006	0.423	0.168	X	0.997	0.9951
(e) Regression PC MTDA_NO s/d	X	0.504	0.1776	1.227	0.9964	0.9946

4.2.4.3 Classifier Models with Categorical Response Variables

This section proposed classifier models with categorical response variables with "descriptive" aims instead of "predictive". For this purpose, the Tree J48 algorithm was used.

Classifier Models for the Response Evo_P_Repe

The tree J48 makes partitions based on the variable *n_Buyer* (8) in the first level and *n_Buyer* (7) in the second level. Subsequently, it continues by classifying it based on *n_Prov* (557), *Fact_Compo* (249.859 k€), and *Repe* (29.8). This tree had five nodes and six leaves. The model has an acceptable adjustment value, as seen in the Kappa metrics (Table 4.9a) and confusion matrix (Table 4.10b). The confusion matrix indicates the number of predicted observations in classes a, b, and c corresponding to the real data classes. Out of the 52 observations, $4 + 3 = 7$ observations do not belong to the diagonal of the matrix; that is, the model does not classify them correctly. By contrast, the model classifies $16 + 13 + 16 = 45$ observations (corresponding to the diagonal of the matrix). The statistical Kappa measures the model's goodness of fit; its highest value is 1. In this study, the Kappa value was 0.7973, which is considered an acceptable value close to 1 (Livadiotis 2017).

Classifier Models for the Response Cons_Ventas_T

The tree J48 partitions are based on year (A2) in the first and n_Buyer_Ap (11) in the second. Later, it continued the classification based on *n_Planos* (1274) and *Repe* (19.4). The tree has four nodes and five leaves.

The statistical Kappa measures the model's goodness of fit (Table 4.9b); its highest value is 1. The Kappa value was 0.7955, which is considered acceptable if it is close to one (Livadiotis 2017). The confusion matrix in Table 4.10b indicates that the model is acceptable.

Table 4.9 Kappa metrics

Item	[a] Evo_P_Repe	[b] Cons_Ventas_T
	Valor	Valor
Classified Instances	45 (86.5385%)	45 (86.5385%)
Incorrectly Classified Instances	7 (13.4615%)	7 (13.4615%)
Kappa statistic	0.7973	0.7955
Mean absolute error	0.0891	0.1127
Root mean squared error	0.2951	0.2844
Relative absolute error (%)	20.114	25.4452
Root relative squared error (%)	62.6263	60.3454
Coverage of cases (0.95 level) (%)	88.4615	92.3077
Mean rel. region size (0.95 level) (%)	34.6154	48.7179
Total Number of Instances	52	52

Table 4.10 Confusion matrix

[a] Evo_P_Repe				[b] Cons_Ventas_T			
a	b	c	Classified as	a	b	c	Classified as
16	4	0	a = '(-(-inf – 1.563333]'	18	2	0	a = '(-inf-37.7153]'
3	13	0	b = '((−1.563333 – 0.763333]'	4	12	0	b = '(37.7153–40.8324]'
0	0	16	c = '(0.763333-inf)'	1	0	15	c = '(40.8324-inf)'

4.2.4.4 Association Rules

This study uses the association rules algorithm "A priori" to gain knowledge of the data from the relationship between variables. The working environment was WEKA. All variables were transformed using discretization, except for the categorical variables *MTDA* and *Year*. Three classifications of values were established: High, Medium and Low. The rules were selected by eliminating variables and modifying the algorithm's properties "A priori".

4.2.5 Evaluation

The models obtained have a "descriptive" purpose and help quantify the effects of the independent variables on the responses *Evo_P_Repe* and *Cons_Ventas_T*. Given that prediction is not the purpose, it is unnecessary to validate the models only to select those with a better adjustment that meets the OLS regression assumptions.

At the time of model creation, WEKA directly validated the model. The regression models were constructed using ten-fold cross-validation, confusion matrix in the case of classifier models, and coverage and trust in the case of association rules (Eibe et al. 2016; Naik and Samant 2016).

4.3 Results and Discussion

This section describes the regression model coefficients, classifier trees, and association rules for responses Evo_P_Repe and Cons_Ventas_T.

The statistical Tables 4.3 and 4.5 showed that in the models selected, the coefficients are significantly different from zero and are measured by the values of "p" according to 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '. Simultaneously, relevance was measured according to the models with normalized coefficients, and the importance of the coefficients themselves was studied.

4.3.1 Evo_P_Repe Response

Linear model (c) was selected (Table 4.7). The most relevant variables were *Year A3, n_Buyer, and Fact_Compo* (Table 4.11).

The evolution of repetitive purchased parts increased by 1.19% for each buyer incorporated. This describes the reality, but it does not make sense to use it to conclude, as it belongs to the first months of the research, it coincided with a greater number of existing buyers, and the *Evo_P_Repe* indicator was very high.

If the invoicing of components increases by 1 M€, the prices of repetitive parts drop by 0.3%. The more parts of the components that are bought, the better the purchasing conditions. Closely related, if 1.000 purchase lines increase the purchase of components, the improvement in repetitive part prices is 0.1%.

If the percentage of the repetitive part increases by 10%, the prices of such parts improve by 0.16%. The importance of standardization of parts is relevant. The classifier model for *Evo-P_Repe* explains that if there are fewer than seven buyers and the number of suppliers is lower or equal to 557, the evolution of repetitive parts purchases becomes low.

If the number of buyers is less than or equal to seven, the number of suppliers is higher than 557, and the volume of component invoices is higher than 2.5 M€. The evolution of repetitive parts purchases is low.

Suppose the number of buyers is less than or equal to seven. In that case, the number of suppliers is higher than 557, the volume of component invoices is lower than or equal to 2.5 M€, and the percentage of repetitive parts purchases is higher than 29.8%. With the evolution of repetitive parts, prices have decreased.

Table 4.11 Interpretation of the coefficients of model *Evo_P_Repe*

Denomination	Description	Type	Category	Significance	Relevance	Coefficient
Intercept				***	High	−9,17E+00
Year A3	Third Year of the research	Categorical	Economic situation	***	High	−2,25E+00
Year A4	Fourth Year of the research	Categorical	Organizational		Low	2,22E-02
Year A5	Fifth Year of the research	Categorical	Logistics		Low	−1,14E-01
n_Buyer	Number of buyers	Numeric	UCA Structure	***	High	1,19E+00
n_Mod_ext	Number of blueprint modifications that affect issued orders	Numeric	Inefficiencies		High	1,31E-03
n_Lineas_Compo	Number of component purchase lines	Numeric	Activity	*	Medium	−1,09E-04
Fact_Compo	Invoiced volume in € of components by the suppliers	Numeric	Activity	***	High	−3,00E-07
n_Lineas_Sub	Number of subcontracting purchase lines	Numeric	Activity	*	Medium	3,29E-03
Repe	% of the economic volume of parts also bought in the previous year (repeated) compared to the total purchase volume of the period under study	Numeric	Standardization of references	(.)	Medium	−1,62E-02
n_Facturas_NOK	Percentage of wrong invoices issued by the suppliers	Numeric	Inefficiencies	*	Medium	2,93E-03

4.3.2 *Cons_Ventas_T Response*

In this case, models (c) and (e) were selected from Table 4.8, considering the presence of MTDA. The impact of the existence of MTDA is quite significant on response *Cons_Ventas_T*. While observing the interception points of the linear regression models selected in Table 4.6b, c, in case all the dependent variables equal zero, that there is MTDA, the value of the response *Cons_Ventas_T* is 35.2; but if there is no MTDA, the value goes up to 61.3. Multifunctional Teams of Design Revision (early purchasing involvement-EPI) relate to the improvement of more than 42% of the expenditures compared to a company's sales; that is, it is directly related to the improvement of the raw margin of its operation account.

4.3.2.1 Regression Model with MTDA = YES

The most relevant variables are n*_Facturas, n_Facturas_NOK, Vol_Compo*, and n*_Lineas_URG* (Table 4.12). It is mainly from these variables that conclusions will be drawn.

If there is an increase in *IPRI* of 1%, expenditures compared to sales in the operating account drop to 1.32%. This does not seem to have any sense but explains what happened during the research, possibly due to factors such as the existence of MTDA, the improvement of materials purchase prices, and the mix of sold products.

If the Components' purchase volume increases by 1 M€, there is a reduction in expenditures compared to sales of 1.92%. If the number of purchase lines issued as urgent increases by 10% (56 lines on average), expenditure compared to sales increases by 0.27%. However, if the percentage of repetitive part purchases increases by 10%, expenditures are reduced by 1.34 compared to sales. The effect of the number of incorrect invoices received from the supplier is not considered; it is unnecessary, as it is a defining factor of what has happened in the company under study when there has been MTDA.

4.3.2.2 Regression Model with MTDA = NO

The more relevant variables are *n_Buyer, Evo_P_Repe*, and *IPRI*, which appear in Table 4.13 for different scenarios. It is mainly from these variables that conclusions will be drawn.

If the *IPRI* increases by 1%, expenditure compared to sales increases by 0.37%. If an additional buyer is incorporated, expenditure compared to sales drops by 2.13%, and if the evolution of repetitive parts purchase prices increases by 1%, expenditure compared to sales increases by 2%.

Table 4.12 Interpretation of the coefficients of the model *Cons_Ventas_T* and with *MTDA* = YES

Denomination	Description	Type	Category	Significance	Relevance	Coefficient
Intercept				***	High	3,52E+01
n_Planos	Number of new blueprints issued for the purchase	Numeric	Activity		Low	−1,65E-03
IPRI	Index of Industrial Prices. In percentage. Source INE	Numeric	Economic situation	**	Medium	−1,32E+00
n_D_Stock	Number of days of the stock of raw materials and materials in use	Numeric	Logistics	**	Medium	9,02E-02
n_Lineas_Compo	Number of component purchase lines	Numeric	Activity	*	Medium	7,60E-04
Vol_Compo	Economic volume in € of purchase of components	Numeric	Activity	***	High	−1,92E-06
Vol_Sub	Economic volume in € of purchase via subcontracting	Numeric	Activity	*	Low	7,37E-07
n_Lineas_URG	Number of purchase lines issued as Urgent	Numeric	Inefficiencies	***	Medium	4,86E-03
n_Facturas	Number of invoices received from the suppliers	Numeric	Activity	***	High	1,22E-02
Repe	% of the economic volume of parts also purchased in the previous year (repeated) over the total purchase volume of the period taken as reference	Numeric	Standardization of references	**	Medium	−1,34E-01
n_Facturas_NOK	Percentage of wrong invoices issued by the suppliers	Numeric	Inefficiencies	***	High	−4,39E-02

4.3.2.3 Classifier Model

The analysis of the classifier model shows that the percentage of expenditures compared to sales is high in *Year A2*. For *Years A3*, *A4* and *A5*, if the number of buyers and suppliers is over 11, the number of blueprints issued as the new purchase

Table 4.13 Interpretation of the coefficients of the model *Cons_Ventas_T* and with *MTDA* = NO

Denomination	Description	Type	Category	Significance	Relevance	Coefficient
Intercept				***	High	6,13E+01
n_Planos	Number of new blueprints issued to purchase	Numeric	Activity		Low	3,99E-04
IPRI	Index of Industrial Prices. In percentage. Source INE	Numeric	Economic situation	***	Medium	3,74E-01
n_D_Stock	Number of days of the stock of raw materials and materials in use	Numeric	Logistics		Low	−8,52E-03
n_Buyer	Number of buyers	Numeric	UCA Structure	***	High	−2,13E+00
n_Mod_ext	Number of blueprint modifications that affect issued orders	Numeric	Inefficiencies		Medium	2,42E-03
n_Facturas	Number of invoices received from the suppliers	Numeric	Activity		Medium	−6,10E-04
Repe	% of the economic volume of parts also purchased in the previous year (repeated) over the total purchase volume of the period taken as reference	Numeric	Standardization of references		Baja	8,39E-03

(continued)

Table 4.13 (continued)

Denomination	Description	Type	Category	Significance	Relevance	Coefficient
Evo_P_Repe	Percentage of the evolution of purchase prices of repetitive parts of the current period compared to the prices of the previous year	Numeric	Supply chain management	***	High	2,08E+00
n_Facturas_NOK	Percentage of wrong invoices issued by the suppliers	Numeric	Inefficiencies		Low	−2,40E-03

is lower than 1274, and the percentage of repetitive parts purchased is higher than 19.4%. The percentage of expenditures compared to sales becomes low.

4.3.3 Summary of the Most Significant Results for the Responses Evo_P_Repe and Cons_Ventas_T

As a summary of the results for ETO companies working under MC, the following can be said:

- If the purchase of components increases by 1 M€, the prices of repetitive parts drop to −0.3%.
- If the purchase of components is increased in 1.000 purchase lines, the improvement in the price of repetitive parts becomes −0.1%.
- If the percentage of repetitive parts increases by 10%, the prices of those parts will improve by −0.16%.
- The association rules show a relation between the good results of the evolution of repetitive parts purchase and Deliveries with *PDP* (Percentage of Defective Parts). Hence, the supplies' quality, price, and time consuming work in tandem; they are not contradictory.
- When Early Purchasing Involvement (EPI) is used, the following occurs.
  - There is a 42% improvement in the Expenditure account compared with the Sales of the company, with a direct impact on the Raw Margin of the Operation account.

  - If the volume of Components purchases increases by 1 M€, there will be a reduction in expenditures compared to sales of −1.92%.
  - If the number of purchase lines issued as urgent increases by 10% (56 lines on average), expenditures compared to sales increase by 0.27%.
  - If the percentage of repetitive parts purchases increases by 10%, there is a reduction in expenditures compared with sales of −1.34%.
  - If the number of days of stock of raw materials and materials in use increases by ten days, expenditures compared to sales increase by 0.9%.

- In the case of Early Purchasing Involvement (Advanced Purchasing—MTDA) is not used:

  - If an additional buyer is incorporated, expenditures compared with sales are reduced by 2.13%.
  - If the evolution of repetitive parts purchases increases by 1%, expenditures compared with sales will increase by 2%.

Using the practices applied in the case study company, the expenditure improvement compared to sales (*Con_Ventas_T*) was −12.18%. The improvement in repetitive parts purchase prices in the same period is −4.28%, and considering the market (utilizing *IPRI*), the improvement would be −16.08%.

4.4 Conclusions

The use of multivariate analysis and statistical and data mining techniques have helped to gain knowledge from the data gathered for more than four years of research. This research has shown which variables affect the most in the responses that measure the product costs of the supplies from the supply chain management; it also quantifies those effects in an ETO company working in MC environments.

The tools R and WEKA have been remarkably important, as well as the methodology Cross Industry Standard Process Model for Data Mining-CRISP-DM, the Multiple Linear Regression techniques, tree models M5P, and classifier trees J48. In addition, the software was easy to use and free of charge, downloaded from the original manufacturer and distributor.

The models obtained are "descriptive", not "predictive", as the objective of this chapter is not to predict but to understand, interpret and quantify the entry variables and their effects on the evolution of the repetitive parts purchase, as well as on the raw margin of the operating account of ETO companies working in MC environments.

Similarly, the best practice is to introduce and implement these improvements. The following is a summary of the conclusions and best practices.

4.4.1 Introduction of Lean Thinking, Reduction of Stocks and Urgent Orders

From a logistics perspective, if ten days are added to the stock of raw materials and materials in use, the relationship between expenditures and sales is 0.9%. That is, the efficiency of applying "Lean" Principles is proved; with a lower inventory, the expenditures compared to sales are lower.

Inefficiencies and wastes in operations affect the performance of the supply chain. The application of the Kaizen principles leads to improvements in costs and purchase prices. If the number of purchase lines issued as urgent increases by 10% (56 lines on average), expenditures compared to sales increase by 0.27%.

The association rules showed a relationship between quality, price, and time consumption, and they were not contradictory. If the situation is good, it is general for all indicators and closely relates to a proper organization without waste.

The organization of Purchasing has a direct impact on the improvement of expenditures compared with sales of the operating account. It can also be seen as the importance of freeing buyers from an order issuing administrative tasks to devote more time to management regarding supplier relations and negotiation, or just that the Purchasing Department is adequately dimensioned.

If there is no Early Purchasing Involvement (EPI), an additional buyer is incorporated, and the expenditure compared to sales is reduced by −2.13%.

4.4.2 Standardization of Components and Materials

The role of the standardization of components is significant because if the percentage of repetitive parts purchases increases by 10%, the prices of those parts improve by −0.16%. In addition, if Early Purchasing Involvement is used (EPI through MTDA) and the percentage of repetitive parts purchased increases by 10%, there is a reduction in expenditures compared to sales of −1.34%.

4.4.3 Early Purchasing Involvement (EPI)

EPI influences the evolution of costs and prices. The lack of MTDA and communication is significant in ETO supply in MC and helps eliminate functional silos.

When EPI is used, the following improvements occur.

- A 42% improvement in the expenditure account compared to the sales of the company directly affects the Raw Margin of the operating account.
- If the volume of Components purchases increases by 1 M€, expenditures will be reduced compared to sales of −1.92%.

- If the percentage of purchase of repetitive parts increases by 10%, expenditures will be reduced compared to sales of −1.34%.

When EPI (along with MTDA) was not used, the results were related to the following issues:

- If an additional buyer is added, expenditures compared with sales are reduced by −2.13%. If EPI is not used, it is necessary to have more buyers, which results in lower work efficiency.
- If the evolution of the purchase prices of repetitive parts increases by 1%, expenditures compared to sales increase by 2%. This result indicates that without EPI (and MTDA), the impact of a 1% price increase in the repetitive part leads to a 2% increase in expenditures compared to sales on the operation account. Therefore, the importance of EPI was proven.

4.4.4 Purchase Management to Improve Prices. Negotiation

One of the best practices of the Purchasing Department is price management via Negotiation (Canbulut and Torun 2019). For the negotiation to be effective, buyers can seek support from levers such as:

- Taking advantage of the purchase volumes to increase because of an increase in the company's activities.
- Taking advantage of the purchase volumes to increase due to the centralization of purchase management using purchase categories, where buyers' specialization by purchase categories leads to increased volumes and improved prices.
- Taking advantage of the component's standardization programs for negotiations and achieving long-term Purchase Agreements.

For any company, the purchase price management of the Purchasing Department is important and directly affects the company's profits or losses. This is achieved by utilizing classic client-supplier negotiation techniques, among other actions.

Throughout this research and using the models, if the Components purchases increased by 1 M€, the prices of repetitive parts dropped to −0.3%. If the Components purchase is increased in 1.000 purchase lines, the improvement in the prices of repetitive parts becomes −0.1%. If Early Purchasing Involvement (EPI) is used, if the Components' purchase volume increases by 1 M€, the expenditures will be reduced compared to sales of −1.92%.

In conclusion, in terms of the practical implications for ETO companies working in MC (or shifting to that strategy), the model's results help those companies to be more competitive through the pursuit of Operational Excellence by improving the costs and prices of supplies. With the model results, companies can focus on the practices described in this paper, particularly the less developed ones, which will help them know the extent to which the effective introduction of those practices is influential.

This study provides quantitative research that measures the evolution of costs and prices of the purchase of supplies in ETO companies working in MC and highlights the best practices to improve that response.

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Part II
The Supply Chain in the Production Process

Chapter 5
Lean-Sigma as a Strategy in Supply Chain Management During the COVID-19 Pandemic Crisis-Lessons Learned

Noe Alba-Baena

Abstract The World-Class Manufacturing Systems were tested for their adaptability and flexibility during the COVID-19 outbreak imposing restrictions and disrupting the supply chains. This chapter describes using Lean-Sigma for three case studies addressing the lessons and critical tools for overcoming uncertainty and challenges in a Latin American facility. Case 1 describes actions for expected sales increasing in a home-improvement product processing. The challenge, in this case, was addressed by using the eight wastes of Lean manufacturing. It is also supported with a layout redistribution and 5S, observing improvements in productivity levels and new technologies upgrading the process connectivity to elements of industry 4.0. Case 2 is a medical product; rapid demand and sales increment is the scenario to decide to adopt a dial-processing system with a robotic arm to automate four activities of the process. Adopted actions increase quality levels by 50% and a more significant efficiency in implementations, which reduces costs from 5.33 to 0.9 IEU/pc taking only two weeks for the ROI. Case 3 shows developments on a new health-related product, using DMADV of DFSS and reengineering as critical strategies for increasing the usability of equipment and resources available in the production area, resulting in a quick ROI and the newcomer successfully introduced to the market.

Keywords COVID-19 · Supply chain · Production system · Productivity

5.1 Introduction

Critical moments in life can show us the level of our strengths and weaknesses, and the reaction time in confronting the unknown can help us in measuring our readiness, adaptability, and flexibility and will help to measure our ability to take advantage of opportunities. During an economic crisis, Enterprises face the same

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challenges, and managers must help the company keep its profitability or balance the effect of a crisis. Forecasting or futuristic vision and experience can help prepare for such critical moments. The management strategies are used to adapt to the market conditions, requiring managers to take advantage of the moment and use the best tools available to make a profit or survive during these periods.

Managers must consider that the faster the response to critical changes, the more profitable the decision. Such considerations have occurred to managers and markets in recent decades, facing a different economic crises, wars, sanction blockades, and political collapses. However, a supply chain total disruption has not been experienced by the markets since the Second World War (WWII). Supply chain disruptions like the ones occurring between 2020 and 2022, with the COVID-19 pandemic crisis, created an instant need for new products (medical supplies) and the lack of demand for other products or services; at the same time, creating restrictions in the supply chain by constraining the export and importation of goods and raw materials, and the disruption of the regional and international transportation systems. During the mentioned period, management strategies were also tested, for their adaptability and flexibility, showing that some succeed better than others in reacting to sudden changes in the market conditions. For the decisionmaker, these conditions were present daily during the COVID-19 pandemic.

During the pandemic period, manufacturers suddenly had to reorganize their work and infrastructure, reviewing departmental layouts to support social distancing while must adapt recent technologies and strategies such as remote work, for managing and making decisions with immediate repercussions on operational and above all, economic efficiency (Ivanov 2021; Ardolino et al. 2022). There were several key factors in achieving a level of profitability, some by taking advantage of the given opportunity: first, the efficiency in using strategic tools to understand the moment; secondly, by understanding the market conditions, the cultural reaction of the society, and how this reality affects the organization. Then, to have the ability to measure the organization's capability to adapt and to use its resources and supply chain strength to take advantage of these conditions. Finally, using the proper engineering tools to adjust production rates and modify the production systems and manufacturing processes.

As in the rest of the dedicated manufacturing regions, the supply chains linked to the Paso del Norte region were immediately shocked after the COVID-19 pandemic. Suppose we consider that most of the operations in this region are close to or final assembly points for many products before entering the USA market or getting distributed worldwide (such as automotive components, medical products, aerospace, and energy supplies). In this context, several disruption points were listed by Ardolino et al. (2022). These include 1. The weakening demand for several types of products (Automobile, public transport, and textile products) 2. Sudden rising demand for strategic products (thermal scanners, ventilators, face masks, sanitizers, PPE, and essential food items) 3. The Failure of supplies due to the lockdown policies, creating uncertainty in the raw material supply 4. Impacting ability to ship and receive products on time due to shortages and logistics bottlenecks 5. Ensuring workforce capacity to assemble and ship products restricted by staff turnover.

The sudden changes occurred later than in China and the other primary components' fabricating regions. The affected supply chain force managers to hold orders and stop the production processes or to face the sudden demand increase for different products. The growth in backorders from the supply chain and the forced acceptance of incoming no longer required raw materials or components (previously ordered and shipped by the vendors) created a jam in the warehouses. However, the efforts to stop the materials no longer needed for products on hold kept arriving from vendors were unsuccessful. The materials from orders in transit continued to fill the warehouses with components and parts no longer required from the supply chain. As the investment continued to pile up in warehouses instead of the production and manufacturing areas for many businesses, it was the leading cause of temporary closures and led to permanent closure for some. All this happened while the production requirements changed daily, and the reaction time to these changes represented the principal reduction of profits and the increment of the logistics chaos. The global supply chain had a specific crisis coming from the very initial links, the COVID-19 outbreak. Due to the growing number of COVID-19 cases, lockdowns, and government-imposed restrictions, particularly in Malaysia and Vietnam, demonstrate the disruption of even the most reliable and well-maintained supply chains (i.e., Automakers) due to simple components such as harnesses and microchips (Bloomberg 2021; Ivanov 2021).

Managers encountered overwhelming requirements for newly essential products and saw some products in the market as customer targets (such as triple layer and KN95 masks, fitness equipment, personal computers, Etc.). The requirements and priority of COVID-19-related products force the supply chain to move materials and resources toward fabricating these products. In some cases, it caused the production systems to respond to exponentially growing demand. In other cases, it forces companies in ventures from exploratory production to create new flag products for their facilities. The requirements for these COVID-19 products increased dramatically, while others lost their importance (school supply equipment, leisure equipment, and several more services). Managers have then to decide on implementing a manufacturing repurposing, decide and define how to use Remote work, how to adapt Workplace redesign and workforce reorganization and create Business models thru innovation and strategic changes (Ivanov 2021). Managers keep observing with chained arms while the abrupt fall of the requirements takes their operations to the ground.

Moreover, the global supply convulsion stopped the general supply chain flow. Many components were kidnapped in warehouses worldwide, stopping further linked production processes and shooting down more of the production of several demanded and essential-needed products. In the best scenario, managers face the reality of lacking or limited resources to fulfill the arriving purchase orders. At the same time, an increased accumulation of on-hold or canceled orders from customers for products with raw materials and components available in the warehouses.

In several cases, there were strenuous efforts to keep the mobilization of components for those few products that kept their production rates. Other measures included using raw materials and equipment available in the stock (for these or other projects), increasing orders to relatively close vendors, or self-subcontracting conditions where the warehouse has available raw materials. Under such a scenario, the short-capitalized Entrepreneur ventures and operations with limited investment buffers suffer to a greater degree than those well-grounded enterprises. Equipment investments and projects were on hold or modified to adapt and react to the COVID-19 pandemic period crisis. Resources increase their value and costs and become less available. Also, if considering the case of complex operations (which requires a lengthy training process and experience), letting go of skilled and experienced personnel was more than an immediate economic loss. It was the loss of longtime investments and losses in the development, havening the entire productive systems in jeopardy.

According to Farooq et al. (2021), the frequency and severity of different disasters like the COVID-19 pandemic and SARS, MERS, AIDS, and others have gained the interest of researchers and scholars because the effects of these outbreaks the economic impacts have been worsening, causing unprecedented losses. All Supply Chains at different levels (local and global) collapse while impacting and disturbing business operations on a large scale. Companies get affected and face challenges in ensuring the logistics and manufacturing operations continuity. The recent epidemic outbreak shows that these events will repeat and will expect to occur as forecasted for the near future. Early detection of major disruptions, the learning of quick responses, and reconnoitering points can increase the readiness for implementing remedial actions and can allow industries to lower the impact of current and future shocks. In their words, the possibility of a near-future outbreak created the urgency to insist on building reliable and sustainable system designs, having fast-responder production systems and a reliable & flexible supply chain to achieve robust operations, and improved logistics for accessing the actual customer. Given the importance of this topic and the supply chain's readiness, this chapter describes the lessons learned from three different case scenarios, portraying the flexible reaction of a managerial group and the critical tools used. Also, it documents the follow-up of the leading strategies and methods used in an operations facility between the beginning of the second quarter of 2020 to the first months of the second quarter of 2022. This period can be considered the main of the COVID-19 outbreak.

5.1.1 Supply Chain Disruptions

A literature review can show that the mainstream of the lessons learned after the COVID-19 pandemic is more related to economic on social aspects; however, the operations and activities related to the production systems remain mainly in the shadow. They are generally discussed through advice or general considerations instead of practical studies or clear examples, as mentioned by Eldem et al. (2022). The same author highlighted that the automotive-industry operations suffered significant losses due to the COVID-19 pandemic. These industries were and still are affected due to their dependence on China's production outcomes. During this pandemic over the last decades, China has been considered the global supply chain center. The shortage of raw materials and spare parts, availability in transportation, availability of labor, and demand fluctuations were not only challenges for the automotive industry but all the members of the intricated global supply chain. The observations described by Eldem et al. (2022) also apply to the three case scenarios exemplified in this chapter and are part of the lessons learned from the COVID-19 pandemic. Demonstrating that flexibility and adopting the best practices are the more reliable way to avoid or mitigate the negligible impact on any business activities.

Four main adaptation strategies can be highlighted: intertwining, scalability, substitution, and repurposing. Moreover, the strategies described by Ivanov (2021) and Ardolino et al. (2022) were used independently as a managerial reaction in the example cases. The three case studies showing the practicality of these strategies as solutions in a manufacturing facility are shown later in this chapter. As previously mentioned, during the COVID-19 pandemic, the different management strategies were also tested for their flexibility and adaptability and to keep the profitability of the production systems. In general, Management strategies show different negative results, having as a common characteristic the reacting time, which was well behind the expected value. Moreover, World Class Manufacturing Strategies (WCMS) such as Lean Manufacturing and Six Sigma were tested for their reaction time and adaptability to sudden changes in the production systems to match the market needs. Even before the COVID-19 pandemic, success rates are reported in the literature at unexpected levels of 40% for Six Sigma projects and 30% for Lean Manufacturing projects (Roser 2017).

During the COVID-19 pandemic outbreak, the WCMS exhibited weaknesses, such as the lack of flexibility and their related managerial strategies. The need for the WCMS for a stable flow in the supply chain and predictable sales make them fail to accommodate during the outbreak reality. Moreover, efforts to move production rates to the proper levels were considered waste. In this way, the main goals of the WCMS were not ready for the sudden changes in the global markets.

As mentioned by Tissir et al. (2020) and primarily discussed by Sarkis et al. (2020), the coronavirus put under question the general strategy of lean management, especially one of the pillars, Just in Time (JIT). The strong relationship and interdependence of the members in the supply chain in JIT have demonstrated its weaknesses. Despite being used to improve efficiency and production flexibility, just in time delivery systems shown to be highly vulnerable to the high operational stress caused by the COVID-19 disruptions.

The Lean Manufacturing strategy's non-readiness can be justified by the Lean manufacturing focus on keeping the flow of the production rates. Failure rates of the Six Sigma methodology were scored mainly by the characteristic emphasis of Six Sigma on the continuous improvement of the production systems. Successful implementations of the Six Sigma methodology require stable production rates to reach their maximum potential. Failure rates of the Six Sigma methodology were scored mainly by the characteristic emphasis of Six Sigma on the continuous improvement of the production systems. Then, because of the unstable conditions expected during any crisis and COVID-19, the successful implementation rates continued to decrease, accounting for many users struggling to react efficiently to the pandemic market conditions.

For example, as described by Bloomberg (2021), Automaker's attempt to be Lean reduces waste, eliminates redundancies, and works with vendors outside the regional hubs. The automakers considered that it is more efficient compared to the opportunity loss worldwide, as is the case of controlling inventory levels to a minimum to reduce waste because of inventory. The COVID-19 pandemic experience has created questions about the managerial and market strategies, our definition of efficiency, the values to prioritize to be efficient in terms of inventory flow, what it means to maintain a minimal inventory, and how to invest in a more resilient approach for the post-pandemic time. By using a convenient tight lead-time, for example, of 6 to 8 weeks with the vendors' Supply chains, the Lean systems proved to have a significant dependency on the supply chain health, and their strength depends on the weakest link in the chain. The pandemic outbreak shows that the WCMS is more vulnerable to external shocks with the described strategy. Then, a redefinition of the term waste in the Lean manufacturing strategy is needed. Furthermore, reevaluating the redundancy concept will be crucial to the future adaptability of WCMS. After the initial analysis, the conclusions remark that every system needs a degree of redundancy to remain resilient to dramatic changes and become more critical if the system faces a near-future crisis (Sharma et al. 2020).

5.1.2 Strategic Approaches for the Supply-Chain Disruptions

It is considering that conditions such as sudden changes in product demand, the lack of or reduced raw materials availability, transportation disruptions, and own resources shortages can create case scenarios for decision-making. These scenarios can be mapped with a decision chart or decision tree, helping the manager prepare to act more efficiently in front of the changes and challenges during a crisis. Using a decision chart during a critical time, the manager can change his mindset from the administration of stable, predictable processes and their decisions to more dynamic or complex conditions, where an adaptable administration is needed to adjust the processing systems.

As seen in Table 5.1, a sales order can be related to a decision chart. The Demand-availability decision chart shown in this Table illustrates how a purchase order comes from the customers; the gathered data sets the base for creating a management action plan. The scenario, when the most straightforward, is the more profitable and most desirable condition, is when the required product has a stable demand. A catalog product is to have the materials, equipment, and resources available, then be able to schedule its production with reasonable rates and produce them with the delivery conditions for reaching the customer warehouse on time. This scenario creates conditions for maximum profit or value added to this production system. For the manager, such conditions fit for using a managerial strategy such as Lean manufacturing and

Table 5.1 Product demand-availability decision chart

Requested product	Catalog product?	Production availability	Delivery conditions	Production rate	Decision
Yes	Yes	Yes	Yes	Stable	Schedule
Yes	Yes	Yes	Yes	Increased	Adjust the production system and Schedule
Yes	Yes	Yes	Yes	Decreased	
Yes	Yes	Yes	Yes	Initial	Design the production system and schedule
Yes	No	Yes	Yes	Increasing	
Yes	No	Yes	Yes	Decreasing	

configuring the production process into an assembly line arrangement with the proper strategic tools to eliminate waste while keeping a stable production flow.

Also, in Table 5.1, other conditions are shown, and a second scenario occurs when it is required to increase or decrease the production rate. The gradual or unexpected reduction in sales reflected in the production orders can be part of the natural or accelerated Ramp-up or Ramp-down in the life cycle of a given product (see Fig. 5.1). The "natural" product lifecycle and behavior can be modified and disrupted by an early decline or an extension in the life cycle of a given product. Figure 5.1a shows the conventional life cycle, compared to Fig. 5.1b, which represents the product lifecycle during the pandemic crisis due to COVID-19 or any other significant disruption. In the case of an abrupt extension in the life cycle of a given product may be the opportunity to use strategies such as the continuous improvement and optimization of the production conditions. However, more significant investments are calculated and expected when the product demand increases if the life cycle extension also increases the product demand to the point that forces investments in manufacturing equipment, labor training, and facilities.

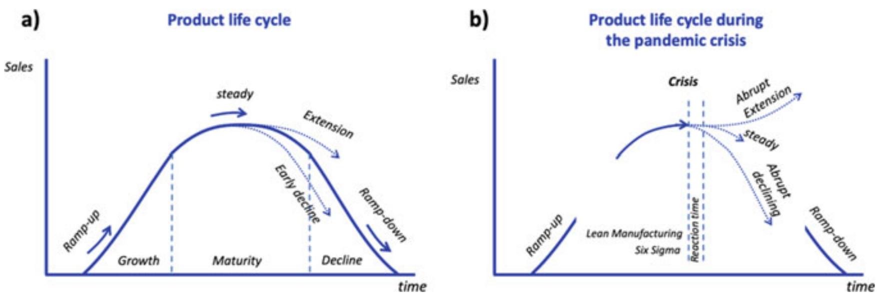


Fig. 5.1 Product life cycle representations of the **a** conventional and **b** modified due to a crisis

Conditions like these can take the production system to an assembly line or a continuous process that requires highly specialized equipment with significant investments, creating a white elephant to comply with the customer's needs (making a financial burden to maintain). Such inconvenience takes resources that can also delay the introduction of new products and investments. On the opposite side, a fast decline or fast Ramp-down creates the sub-utilization of the resources, labor, and equipment, causing a drop in the OEE (Overall Equipment Effectiveness) measurements. Here it is possible to switch to a production system based on group technologies or automated batch production, merging the ramp-downing product with other members of the same family or with similar processing steps.

As previously discussed by Alba-Baena et al. (2020), the use of strategy, activities, and tools helped in the integration, and an automation adaptation was the critical factor for adjusting the production rates while keeping the OEE values as expected. In the case of the COVID-19 scenario, the decrease may be part of the market's reactions to the conditions created. The first action in the production process is to make a Plant redistribution to accommodate more than one product. When the reconfigurations are insufficient, and the decreasing production rate keeps falling over the expected, menacing the system's profitability, it is convenient and appropriate to shift the product to a reconfigurable batch system. Here engineering tools such as DFM, DFA, programmable electromechanical configurations, automation, and robotic systems (or mechatronics systems) help adapt during ramp-down conditions, especially the automated and robotic systems provide an ROI fast enough to catch the production rates and sales profits. If the sales for this product grow or have a later recovery, then the proposed configuration is duplicated to catch up with the increase in sales.

The same actions are to follow in the case of the recovery of the natural climb of a given product. For the case of the natural ramping-down, the steps are to adjust the production rates by reducing production groups as described by Alba-Baena et al. (2020). The last section in Table 5.1 shows the cases when an opportunity presents to invest in a new venture. Some considerations for taking the opportunity include measuring the opportunity loss (OL), ROI, time for R&D, introduction and ramp-up times, forecasted sales behavior, and the production system capabilities. Here the recommended strategy is like the proposal for the ramp-down conditions by pushing to design the production system based on automated and robotic systems. The production system must be flexible enough to grow or contract with the production rates following the sales behavior. Another characteristic of this system is that it has a fast ROI and the advantage of easy readiness for industry 4.0 and its management strategies. Moreover, given the lessons and impacts of the COVID-19 crisis, Kumar et al. (2020) states that this is the right time for industries to adopt and implement industry 4.0 and to invest in digital technologies in manufacturing, to adopt virtual capability-building programs and urgently review of human resources policies for social sustainability.

Other scenarios may include no demand for Catalog products with existing production kits. Then it is necessary to calculate and consider it as passive capital. If there is a sales demand for Catalog products, but there are incomplete production kits, reschedule, place it as backlog, and consider it passive capital. When there is demand for an Opportunity product, but there are Incomplete production kits, it is possible to calculate the stagnant worth and the Expected Opportunity loss (EOL). Also, suppose there is a lack of demand for an Opportunity product with complete production kits. In that case, it is possible to calculate the acquired success of this investment and the distance (positive or negative) to the ROI (return over investment). Also, availability is restricted by programming, maintenance, repairing processes, Labor skills for using this equipment, and layout arrangements. Then, the production capacity can be related to the possible production rates and the inventories, together defining or redefining the production logistics, scheduling, programming, and production outcome. Once the product is ready for dispatch, new challenges are presented, such as local transportation availability, international customs restrictions, international transportation conditions, and the customer's warehousing availability.

5.1.3 Strategies for Overcoming the Supply Chain Commotion

Recent developments show alternative strategies for the decision-making process under restrictive environments to address the described conditions and confront sudden changes in the requirements. With methods and techniques more flexible and adaptable methods and techniques, the use of Lean Sigma as a problem-solving strategy has been used successfully before and during the COVID-19 pandemic. Figure 5.1 shows a schematic of the Lean Sigma strategy, which uses Lean manufacturing and Six Sigma to solve manufacturing process problems. Uses Lean manufacturing tools to solve visible issues, increase efficiency, and eliminate waste. Then, while the problem requires a deeper analysis, this strategy takes advantage of the Six Sigma approach, using more statistical tools and strategic resources to solve costly and complex problems.

As seen in Fig. 5.2, the primary strategy of the Lean-Sigma approach is to use a sequence of tools moving from the lean manufacturing tool kit and starting with the elimination of the eight wastes, using the 5S method, Kanban and other tools. Then, the solution strategy moves to the Six Sigma tool kit as the complexity of the problem rises, and the root cause hides deeper from the analyst's sight. Then, the Lean-Sigma solving methodology helps in reaching the solutions thru the five basic steps: (1) Identify and Measure the problem, (2) conduct a Root Cause Analysis, (3) Solve the problem, (4) Verify the solution, and have a (5) Control plan, see (Estrada-Orantes and Alba-Baena 2014).

Following the same Fig. 5.2, the strategic approach in Lean-Sigma starts with using the E-Strategy to eliminate the common causes, as Estrada-Orantes et al. (2019) proposed, where two phases are involved in this strategy, a diagnostic phase and a solution phase. A quick diagnostic identifies and eliminates common obstacles in keeping the production process flow. Following Fig. 5.3, the fundamental questions

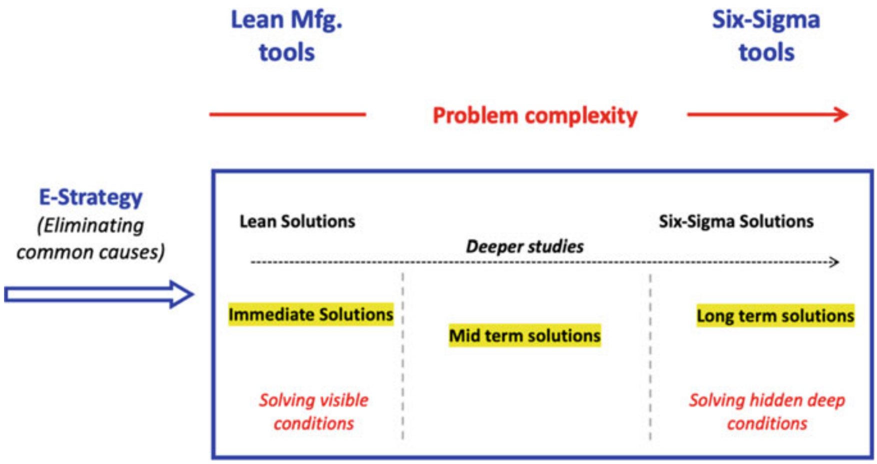


Fig. 5.2 Schematic of the Lean-Sigma strategy

originating from the root cause analysis are as follows: (a) Are prints and drawings correctly defined and used? (b) Are the tools and operating conditions working properly? (c) Is the measuring system correctly used and calibrated? (d) Is the process variation in the expected statistical control? and (e) Is the process capability in the expected values? Moving the sight from the common causes to deeper causes thru more profound analysis and statistical elements, while the solution requires complex analysis. The Lean-Sigma E-Strategy eliminates the "waste of time" and resources by adding them as needed to find a solution.

By eliminating the familiar and straightforward causes, the second phase implements the solution phase of the E-strategy paired with the Lean-Sigma approach. The solution phase includes statements related to the sequence of steps in the Lean Sigma methodology. The first statement is "let the process speak" by gathering data, then "listen to the process" by making a root cause analysis. The third step is to "talk to the process" (by running experiments) and "Find the main factors" affecting the

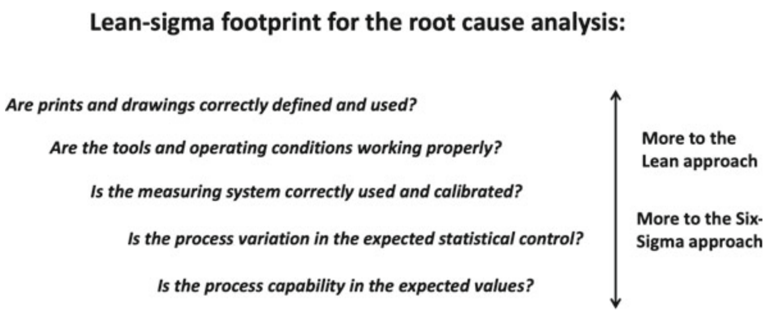


Fig. 5.3 Adapted schematic of the E-strategy tool of Lean-Sigma

conditions of the production process. Step 4 asks the leader to "develop a solution for the main factors" (a DOE, for example), and Step 5 "Validates the solution for the main factors" Finally, it is necessary to "implement the solution and update the action plan."

To describe the scenario of that stressed supply chain is necessary to extend the production-system tracking to include acquiring resources transportation, vendors' warehousing, product delivery transportation, and warehousing at the customer site (see Fig. 5.4). Figure 5.5 shows the decision-making process during this stressed supply chain condition; in the Figure, the decision is to filter and divide the products in manufacturing positions from the catalog and the newcomers as opportunities.

The demand for such products and requirements can be constant as expected, increase because of the new conditions, or the requirements constrained because of the same conditions. The inventory of it is defined (for this chapter) as a set of components, parts, raw materials, and other resources to fabricate a product. Then, these resources constitute "production kits." These may be incomplete due to different conditions such as: being in stock in the company's warehouse, part of the safety stock, the working process, expected arrivals, as placed orders, or the backlog. In parallel, the production capability includes the personnel, equipment, and Management to produce that product. In general, labor and managerial personnel's availability weakness due to absenteeism, health issues, health risks, personnel moving from their regular task to a different one, adjusted working schedule, and inefficiencies due to inexperience or a training and learning process. Equipment availability includes the sequence of machinery and tools for production using the kits.

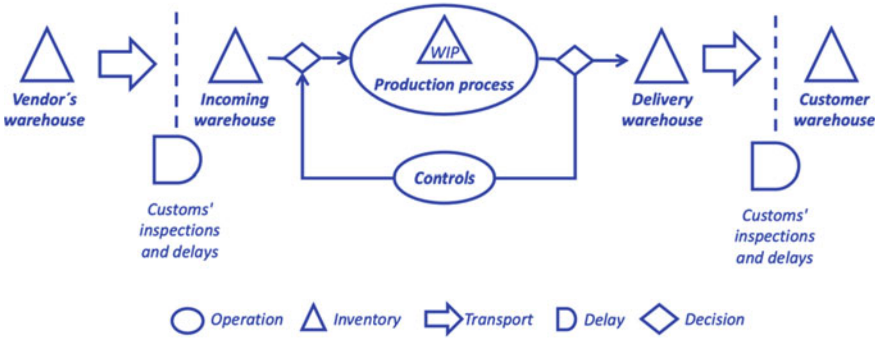


Fig. 5.4 Extended production system

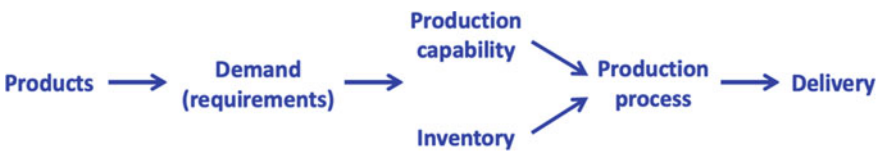


Fig. 5.5 Decision-making process flow

5.2 Case Studies

An American corporation has a facility located in the "Paso del Norte" region, a strategic region that includes Juárez (Mexico), El Paso (Texas, USA), and Las Cruces (NM, USA). A business venue dedicated to the final assembly of several product families related to home improvement and medical products. A key factor for the success of this company is that the administration takes advantage of the experienced local labor, the flexible mentality of the local talent, and the Management. They are willing to adopt different manufacturing strategies and have dynamic and diversified operations. Among such processes, several products these facilities assemble different home improvement products, medical products, and other health-related products. Three case studies and their production processes are selected to describe the different scenarios and approaches for adapting to the COVID-19 pandemic conditions; they represent three different case scenarios occurring during this timelapse. For this report, the COVID-19 pandemic is between the second quarter of 2020 and the third quarter of 2021. From when the first COVID-19 cases were outbreak in Texas, national governments (from Mexico and the USA) announced actions to the time official reports showed a reduction to a minimum of daily deaths and active cases of COVID-19. The cases are examples of products to be fabricated, assuming that the supply chain keeps moving raw materials and components to complete a final product; labor and other resources are also available. Then, to simplify that description of the given cases, for this report, the production rates are correlated to the demand, and sales, considering that a demanded product is fabricated and sold.

5.2.1 Case 1

The first case focuses on a home improvement product assembly from which the graph in Fig. 5.6 shows the tracking of the sales for three quarters before the described pandemic period to the time of this report. The same Figure correlates the events of the pandemic to the market reaction and acceptance of this product. As can be seen, before the second quarter of 2020 (during the pandemic period beginning), this product had a stable production rate of 2200 lots/wk. Occurred until the middle of the fourth quarter of 2020, when a slight rise in demand was justified because of the yearend season. However, the increasing rates in product demand and sales for this product continue in a steady growth of 2400/Q for the next three quarters of 2021. As marked in Fig. 5.6, the sales reach peaks above 300% from the base (2200 lots/wk). This dynamic and change created new challenges and opportunities for improvement and made this production system more efficient. Later, the end of the second quarter of 2021 coincides with the slower drop of sales rate of 700/Q in production and sales of this product occurring up to this report, having moments of sales dropping down to 50% below the expected 2200/wk. In the second quarter of 2020 and after, the pandemic crisis affected the entire supply chain, and these

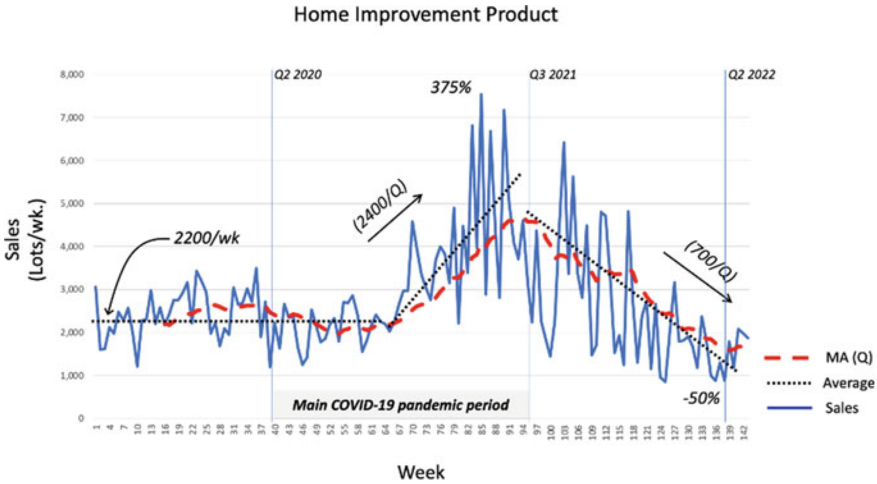


Fig. 5.6 Sales graph for case 1, a home improvement product

facilities faced a shortage of resources, imposed lockdowns, and uncertainty in labor availability and counts. The forecast shows the potential for an increase in sales of this product. By the end of the next quarter, the market will confirm this, and sales will rise at the rates previously mentioned; the Management has two quarters to react to the sales increment.

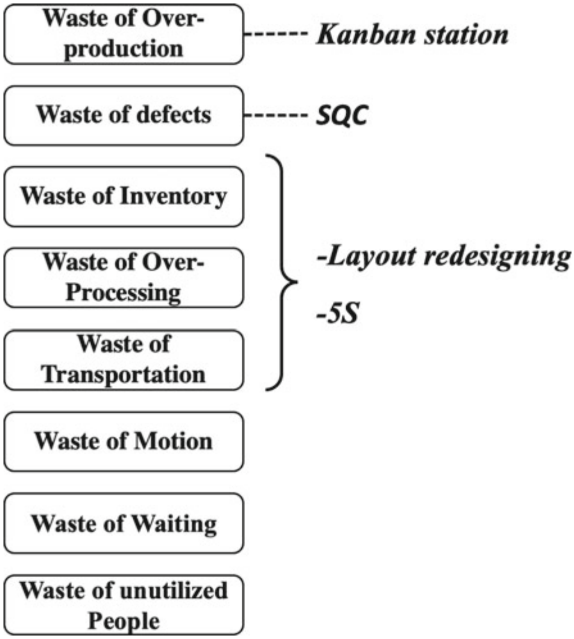
Considering that the disruptions in the supply chain affect the fabrication of this kind of product, taking advantage of raw materials available because of the disruption in the supply chain of other similar products then mostly overcomes the challenges for keeping sales. At the same time, changes occur during the COVID-19 pandemic crisis. Many conditions and challenges were happening at the same time:

- The less available labor
- The shorter shifts
- The lockdowns
- The piling on the inventory warehouse of unnecessary materials or components
- Abrupt changes in customer-placed orders (cancellation, increment, renegotiation, and others).

The first step in increasing the efficiency of the process is by using the eight wastes of the Lean manufacturing strategy; this is happening by eliminating any observed "waste" or anything that does not add value to the product (or anything that a customer would be willing to pay for).

The eight-wastes approach relates to the activities or strategies used to overcome the described conditions. Figure 5.7 shows the sequence of actions employed as part of the solution for case 1. Following the line of the 8 Wastes of the Lean manufacturing strategy (see Fig. 5.7), it is possible to describe first the "Waste of Over-production" or processing too soon or too much than required is confronted by using tools for reacting

Fig. 5.7 Wastes of the Lean manufacturing strategy



faster to the market requirements. The "Waste of defects," errors, mistakes, and reworks encountered using quality improvement tools. The "Waste of Inventory," or Holding inventory more than required, is the most significant challenge. Warehousing the arriving components and raw materials for the disrupted production schedule is addressed by using the extra cargo containers available to move and select the materials at the warehouse for immediate use.

The "Waste of Over-Processing" became a critical factor in increasing productivity, analyzing the available resources and production activities, rethinking the process flow diagrams and work-in-process flow, and transportation between operations for eliminating or merging activities and wastes in the production processes. Then, actions in eliminating the "Waste of Transportation" and the "Waste of Motion" (Movement of people that does not add value to the product) are the most visible results by redesigning the layout of the production floor (see Fig. 5.8).

During this time, the "Waste of Waiting" among employees and customers is unparallel increased by the government lockdowns, restrictions, and delays at the international borders. Waitings led to less availability of transportation vendors, creating unexpected waiting times in the supply chain; hiring more transportation personnel and merging cargo containers and logistics reduced distribution and negotiation with the customers to help facilitate this waste of waiting. Moreover, "Waste of unutilized People" is the most common waste observation during the COVID-19 pandemic crisis. Due to the shortages of labor availability and production cuts, experienced employees are rearranged from their habitual activities or lose track of their actions by doing Home-Office work or filling up other positions, diminishing their

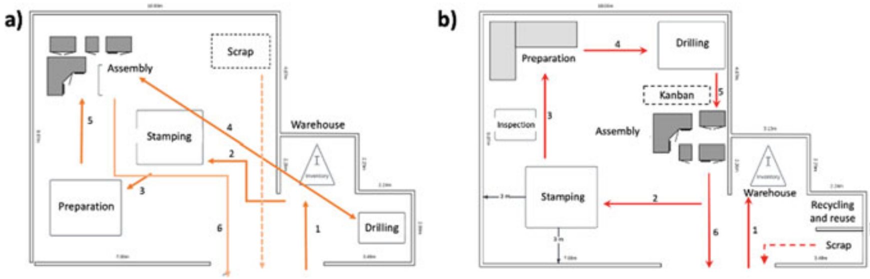


Fig. 5.8 The layout of the fabrication process for a home-improvement product, comparing the flow, **a** before and **b** after changes

outcomes. The human resources team created a series of fast training courses to efficiently adapt the employees to their new roles to address this waste. The IT team also helped create the most efficient communication system to keep all employees updated with the required information for making decisions properly. Also, the management group created scheduled team meetings to keep track of the significant changes in the production processes, the updates in the critical strategic elements, and the tracking of the market behavior and forecasting changes.

Figure 5.8b presents the modifications in the fabrication process for case 1. Where results of the implementation of the eight-wastes elimination and complimenting the described strategy, the team uses the 5S methodology and a Kanban station to complement the logistics control and add an inspection station to ensure quality control and reduce the variability in the quality factors. Figure 5.9 compares activity times for two operations shown in Fig. 5.8, the preparation area and the milling area. In this Figure, the activities are coded and numbered in the sequence of the process activities. Those activities eliminated from the process have an average time of 0.0 s after implementation and waste elimination, as seen for activity prep 6 and Mill 1.

All the activities show a reduced time (i.e., see prep 2 or 4 in Fig. 5.9a) or an increment (examples of this are Mill 2 or 5 in Fig. 5.9b) depending on the arrangement in the reconfigured layout. The resultant 51 and 54% increment in the productivity rates in these two operations outcomes is an increment of 25% in the total process productivity. After the implementation, several results are listed and highlighted; for example, the average production rate of 2200 lots per week barely satisfies the sales in the first quarter of 2020. however, after the implementation, the production time reduces by 25%. To make the production process more efficient and to be ready for the increase in sales, a robotic XY table (from a different project.) is adapted to be part of the preparation area and paired with waterjet equipment to increase the production rate.

Based on the average production rate at bottleneck operation (the "Preparation" area totals in Fig. 5.9), the productivity increases by 200%, and average sales for the first two quarters of the pandemic crisis can be satisfied with the active labor of 1.5 shifts/wk instead of the initial three working shifts/wk. Then to be ready for the expected Yearend sales and the quick sales rate increase in 2021. As a result, these a)

Wastes elimination in: Preparation area		
	Average Time (seconds/lot)	
Actiiviity	Initial	After
Prep 1	23.6	3.7
Prep 2	5.9	5.4
Prep 3	5.7	5.7
Prep 4	20.3	12.4
Prep 5	49.8	49.9
Prep 6	11.8	0.0
Prep 7	11.4	14.9
Prep 8 (transp)	63.7	2.1
Totals	**192.2**	**94.1**

b)

Wastes elimination in: Milling area		
	Average Time (seconds/lot)	
Actiiviity	Initial	After
Mill 1	35.5	0.0
Mill 2	0.6	39.9
Mill 3	8.4	1.0
Mill 4	10.2	7.6
Mill 5	1.5	11.7
Mill 6	22.8	1.5
Mill 7	27.9	22.8
Mill 8 (Transp)	80.9	1.1
Totals	**187.8**	**85.5**

Fig. 5.9 Comparison between the initial times and after waste elimination of the **a** preparation and **b** milling areas

actions created the flexibility and readiness to comply with the average sales of 4300 lots per week. Production rate is expected and required from the beginning of Q4 2020 to the end of Q2 2021. with the capability to be contracted easily to one shift to fulfill the sales requirements of the current year in an average of 1700 Lots/wk.

5.2.2 Case 2

The second case is a medical product which is one of the flagships of these facilities and has a production rate of 61,000 pieces per week before the second quarter of 2020 (see Fig. 5.10). During the pandemic period (as expected), the demand and sales increased dramatically at a rate of 13,000 per quarter, reaching a production rate above 200% of the regular weekly rates before the pandemic period.

A sudden drop in sales happened after the third quarter of 2021 (130,000/Q), attributed to different factors: relaxed COVID-19 measures, market saturation, general supply chain recovery, and new competitors or competitors' recovery. The drop in sales reaches levels close to 60% below the base weekly production rates; after one quarter, the sales recovered to 49,000 per week at the time of this report. Let us briefly forecast the rapid increase in production demand for this medical product, and some preventive actions were in place during the rampage of customer demands. Initial studies show that waste elimination and improvements were not enough to comply with the customer's needs, deciding to design and install an automated process. Figure 5.11 shows the schematic of the production process before and after the implementation. Figure 5.11a shows the assembly process of the main component, where a moving band takes the different pieces between four operators sequenced to integrate and deliver the main component at a production rate of

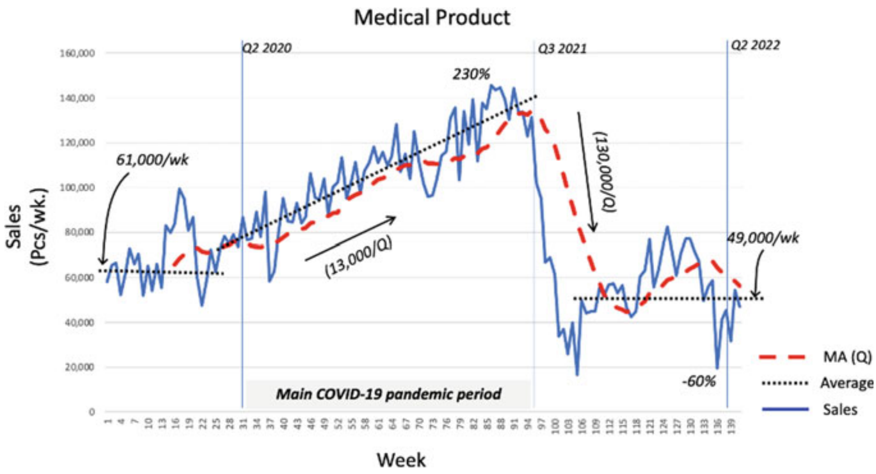


Fig. 5.10 Weekly sales chart for case 2, a medical product

550 pieces per hour, having a quality level measured with a Cpk of 1.56. Then the component is transported in batches to the next step in the final product assembly line.

On the other hand, Fig. 5.11b displays a schematic of the implemented component assembly process, which uses a dial processing system coupled to a robotic arm to automate and perform the four integration activities of the main component. Besides this, an operator helps the input and output of the pieces and components, two-thirds reducing the used space. The transportation time reduces the piece assembly process's total time and the delivery of the final product.

The implementation's production rates move to an average of 1500 pieces per hour, with the quality levels measured in terms of process capability in a Cpk of 2.07. Finally, Case 2 shows the results of selecting a strategic technology to increase productivity rates from 550 to 1200 pcs/h., Also, as seen in Fig. 5.12b, the quality levels increased by 50%, reaching a statistical Cpk value of 2.07. the overall performance on the main quality factor measures centered on the target value, and the

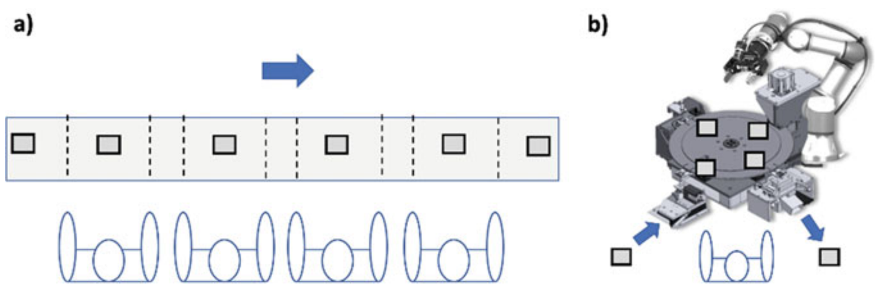


Fig. 5.11 Schematic of a change in the production process implemented for case 2

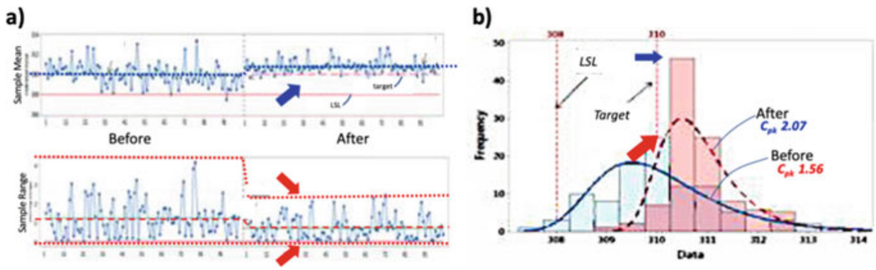


Fig. 5.12 Principal quality values before and after implementations in case 2

variability reduces (Fig. 5.12a, top graph). as seen in the same Fig. 5.12a lower graph. Because of this readiness and the efficient, quick implementations, the operational cost reduces from 5.33 to 0.9 IEU/pc (IEU, Internal Economic Units), having a successful ROI of two weeks.

5.2.3 Case 3

The pandemic also created opportunities for introducing and developing new products, exploring new ventures, and increasing the usability of the equipment and resources available. For production purposes, a health-related product is proposed and studied. A market study with a customer expectations survey is analyzed and used to determine the feasibility of this product. Due to the uncertainty of the COVID-19 pandemic period length, other considerations such as the expected product life cycle length (based on the predicted pandemic time), time for the return on investment (ROI, as quick as possible), and opportunity loss (OL, based on the time to reach the market) were key factors in the decision process. Figure 5.13 shows the development and ramp-up of this product compared to the main COVID-19 pandemic period; two quarters were required and needed to develop the new product, test the production capabilities in the facilities before the introduction to the market and ramp up the behavior of this health-related product.

Because the sales of this product were predicted and calculated during the COVID-19 pandemic, the product will have a short lifecycle with a quick return on investment. For such an initiative, the Management took advantage of the flexibility of that production system by merging this product in the production process of other family members and taking advantage of that demand reduction in other products in the same product family. After using Design for Six Sigma methodologies (DFSS), and for decades now, different companies have reported several benefits in their launched products: Reduced time to market for new or revised products, Reduced life cycle costs, an increased understanding of customers' expectations, Reduced design changes and enhanced quality and reliability among others (Antony 2002). In general, DFSS may include different solving sequences, all adapted for kinds of needs

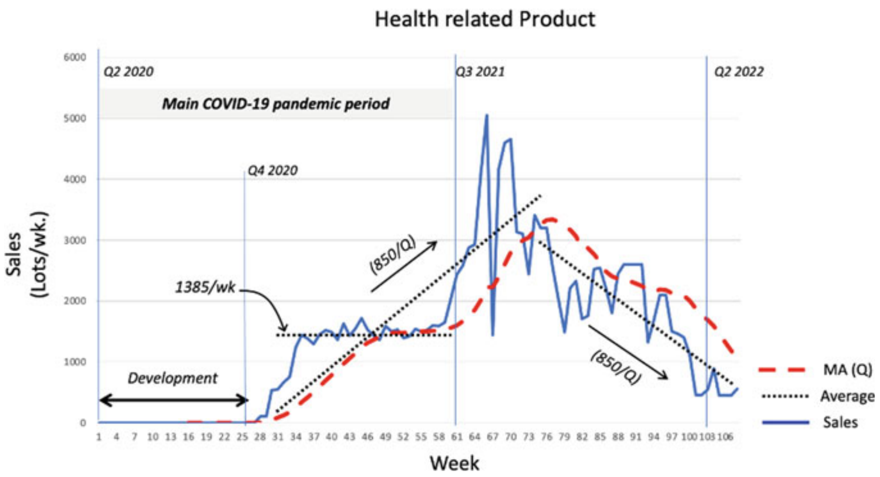


Fig. 5.13 Weekly sales chart for case 3, a health-related product

DMADV (Define, Measure, Analyze, Design, Verify), DCCDI (Define Customer and Concept, Design, Implement), IDOV (Identity, Design, Optimize, Verify and others.

All the methodologies seem to have in common that they all focus on fully understanding the customer's needs and applying this information to the product and process design, then following phases to design or redesign a product. In this case, the DMADV is the strategy used (see Fig. 5.14): In the first phase, "Define," the key goal is to organize the available resources, customer information, and market forecasting projections for defining the product design project. For this, a -Project Charter- is an efficient tool to use and organize the defined, measurable targets, such as goals for improved revenue, customer satisfaction or market share, business expectations, measurable gaps, timelines, and budgets. Also, this phase helps to prepare a -Risk Assessment Plan- to forecast the project risks, opportunity losses, and actions to take if any of the risk conditions occur. During the "Measure" phase, it is necessary to understand the customer's needs. Later translate them into design requirements (or "Must Haves" and "Would like"); for this, due to the COVID-19 pandemic restrictions, the primary source for having the required information is historical data and social media customer surveys.

The "Analyze" Phase includes efforts to convert the customer information and product requirements into measurable design performance and functional requirements. During this project, the Quality Function Deployment (QFD) tool was the main driver for the development of the product. However, assessment tools like benchmarking, brainstorming, and market and patent research were vital in successfully analyzing and providing design options. After, a Pugh Matrix was the primary decision-making tool for deciding on the final design to use. After choosing a single concept-level design during the "Design" phase, the design concept adjusts to match a similar process for the same family products by using the DFA (Design for Assembly) tool to adapt the components and fabrication process to operations and equipment in the facilities.

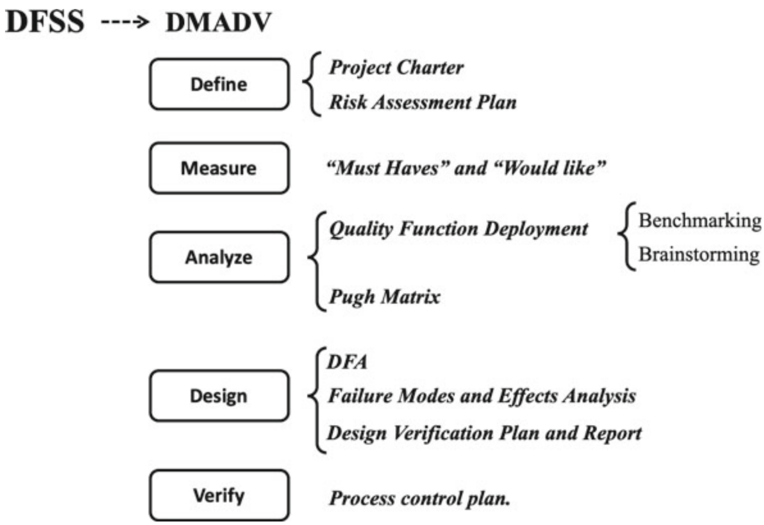


Fig. 5.14 Schematic of the use of the DFSS method DMADV

After several reviewing steps for evaluating the product through prototyping, the product adapts to the primary manufacturing process. Then, by arranging a new preparation area, annexing a molding process, and upgrading the technology used in the sanitization process. By taking advantage of the equipment and resources used in assembling a similar family health-related product (on hold because of the lack of some components and requirements), the project team adapted the manufacturing process (see Fig. 5.15). A Failure Modes and Effects Analysis (FMEA) is included as part of this step to identify the key characteristics, list of responding actions, match the potential design risks, and evaluate the main product characteristics in the quality control inspection station. Finally, a Design Verification Plan and Report (DVP&R) helps create the validation plan, including a statistical comparison through a statistical hypothesis testing process. The "Verification" phase includes running pilot trials and, with the results adjusting the product design and the manufacturing process modifications, measuring the critical aspects in productivity and quality levels. The documentation is wrapped-up with the process control plan once the expected values for this product and its process are measured and achieved.

Taking advantage of a production process for one member of the family health-related, Fig. 5.15 shows a process chart of part of the production process as it is adjusted and modified for making the new product. The first station of this section (preparation) is not eliminated or substituted in the process layout; however, aside from it being prepared, an alternative "Preparation area" is incorporated into a molding process just before the first assembly step (Assy A, as shown in Fig. 5.15). Also, the same Figure shows the position of the new sanitizing station required during and after the COVID-19 pandemic and the distribution of the five operating workers. Of these, the three workers in operations A, B, and C required a short training for

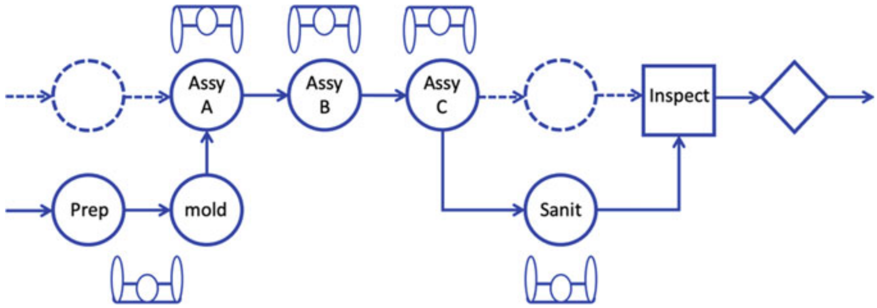


Fig. 5.15 Process chart of the production process in case 3

adapting to the new product and its characteristics. However, the two workers have the most significant adaptation challenge; a study for calculating the learning curve of these two workers is used and shown in Fig. 5.16b. A learning curve is graphed and calculated, showing a performance of around 70% attained after week 10 of continuous production.

This learning curve is also related to that growth rate; Fig. 5.16a shows the selected section of the production rates compared to the linear growth rate during the ramp-up stage of this product. Sixty-five lots per week are the ramp-up rate. Accepting that any of these two steps in the production system are the bottleneck and, without considering restrictions or later bottlenecks in other operations, the predicted equation shown in Fig. 5.16a also helps in calculating the maximum performance of this production system or up to the point of the next bottleneck operation-time restriction. Extending the Fig. 5.16a graph to observe the performance of the production rate (sales) for this product from the beginning to the time of this report, Fig. 5.17a shows the product requirements for the same period (See the criteria line). Observing that the maximum requirements were after the third quarter of 2021, followed by two-quarters of diminishing product requirements, wait for the consequent production rates reduction. Once the production system reaches its highest and the product sales reach maturity, warehouse inventory levels also pick the third quarter of 2021.

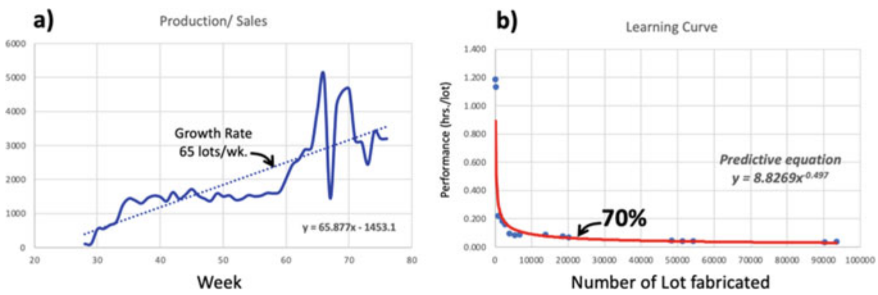


Fig. 5.16 Productivity performance graphs: **a** growth rates and **b** learning curve

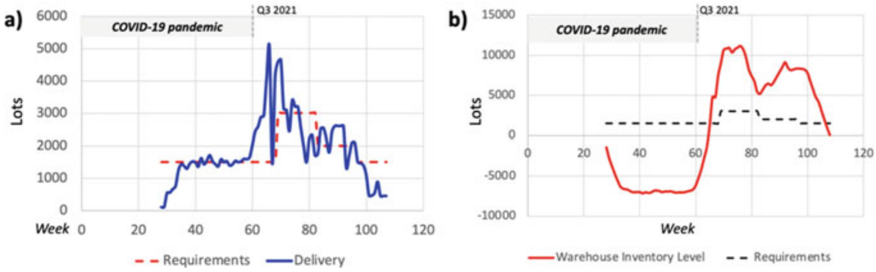


Fig. 5.17 Graphs compare **a** orders to sales and **b** orders to inventory balance

Figure 5.17b shows the inventory level's performance compared to the requirements levels. The lack of Inventory levels created pressure on the production system; however, significant inventory levels are also a problem. Warehousing final products in cargo containers was also a solution for warehousing and an investment problem simultaneously. Parking many containers in both warehouses in Mexico and the USA was a solution up to the first quarter of 2022. At the time of this report, the inventory levels were balanced, reduced to the minimum, and returned to manageable levels. After the third quarter of 2021, the requirements and sales for this product started to diminish to rate levels of 500 lots per week.

Figure 5.18 shows values of the quality performance as measured by the process capability levels of the sanitizing efficiency of the newly installed system (Technology B, see Fig. 5.18b) compared to the previously used equipment (Technology A, see Fig. 5.18a). The setting of the new lower specification limits (LSL) creates the previously mentioned need for new technology in the sanitizing process (refer to Fig. 5.15). The main goal of these changes is to reach quality levels above the LSL, and the graphical comparison shows the improvement; Cpk values make technology robust enough to assure the quality expected.

5.3 Conclusions

Global interdependence creates considerable benefits when the exchanges are free of restrictions; however, disruptions occur because of numberless factors, economic strategies, conflicts, pandemic outbreaks, and more. The frequency and severity of disasters like the COVID-19 pandemic are of interest to researchers and industrials because the trading effects and the economic impacts worsen and cause unprecedented losses. Early detection and quick responses are the keys to increasing readiness: the main priority is the Management and personnel adaptability and the use of flexible systems. Recent events have tested the World's manufacturing systems and strategies used by companies, more specifically, the ones used by the leading players in the supply chains. World-class manufacturing systems reacted to times

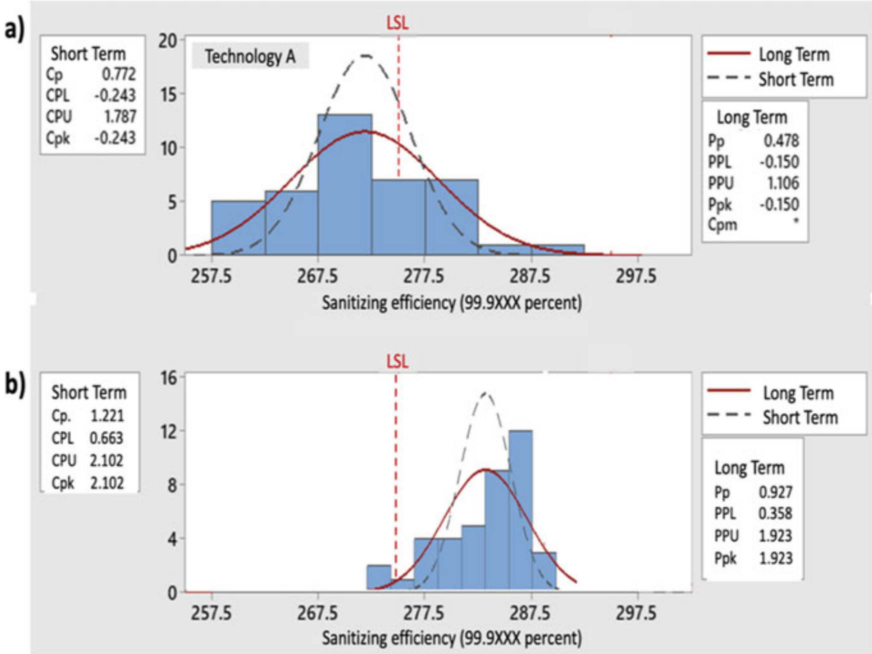


Fig. 5.18 Process capability graphs for the sanitizing operation using **a** technology A and **b** technology B

not as previously conceptualized; systems flexibility and, in general, management strategies could not surf the waves of the shocking pandemic events.

This chapter included the use of Lean Sigma and the results of testing it during the COVID-19 outbreak. Three case studies with different perspectives and conditions are described, noticing the use of a flexible set of tools and strategies under the umbrella of Lean Sigma. Each case highlights the use of different techniques and tools; the first uses the 8 Wastes of the Lean manufacturing strategy and other methods, which support the use of 5S, Kanban, and SQC to complement the logistics and quality controls. These implementations delivered the sales requirements and products to the customers. The production system advances into a more flexible configuration. In the second case, a reengineering approach was the base for adapting a dial processing system, coupled with a robotic arm integrated for manual operations in a single station, reaching a statistical Cpk value of 2.07 and an ROI of two weeks. The third case highlights a different approach, using a DFSS method (DMADV) to introduce a new product, taking advantage of the conditions generated by the COVID-19 pandemic and the available resources. The reconfiguration of the available equipment and the use of tools identified to the DMADV (Project Charter, Risk Assessment Plan, QFD, Pugh Matrix, and others) were used with DFA to succeed in a quick ROI and to take advantage of the opportunity.

The measurable results are the buffering of the outbreak's impact, resulting in customer satisfaction and, even more importantly, the trust gained from the personnel, supply chain members, and customers. These representative cases may not validate a success rate for general implementation. The success in ROI and the adaptation to increasing the usability of the on-hand resources created the resilience of the production processes in the studied cases. Moreover, the Lean Sigma strategy as a readiness alternative needs more testing and refining, and more cases are required. However, the described case scenarios have provided acceptable readiness for a manufacturing system. Increases the adaptability of the managers and their teams by using a large set of tools and provides the flexibility of managerial strategies, which are available for better readiness for future crisis scenarios.

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Chapter 6
Development of an Expert System Focused on Improving the Supply Chain by Increasing the Availability of Equipment

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Abstract The maintenance area is a transcendental link within the supply chain since it is the unit in charge of maintaining the equipment destined to carry out various organizational tasks in perfect working order. The correct maintenance management through the supply chain allows one to fulfill a primary objective, to deliver the required quantity of goods on time at the minimum cost. Within the automotive industry, the supply chain aims to be as efficient as possible, so innovation and developing new technologies are opportunities for improvement. Among the various motors, the three-phase induction motor is the most used, and, like any industrial device, it requires diagnosis and maintenance to continue operating correctly. There are various methodologies to diagnose faults in electric motors; however, their capacity is limited since they can only analyze and detect one type of fault at a time. In the present work, the development of an expert system capable of recognizing three different fault patterns in electric motors is shown; the deterioration patterns involved in the study are severe damage or fatigue in the bearings and short circuits in the winding. The architecture of this system is composed of two artificial neural

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networks capable of classifying the types of faults in the electric motor, the first artificial neural network determines whether the motor is in good condition or not, and the second artificial neural network is activated when detecting an inconvenience in the motor to give rise to the fault diagnosis. The developed expert system was implemented in an industrial process and reached an average accuracy of 99%, which is why it is validated as a reliable method to diagnose the correct operation of electric motors and, therefore, improve the availability of said motors in addition to other teams with which they relate. The scientific contribution is based on the methodological proposal to achieve a correct diagnosis of the physical state of electric motors from artificial neural networks, which brings, consequently, an increase in manufacturing productivity and greater efficiency in the supply chain of organizations based on the accurate monitoring of the equipment.

Keywords Supply chain · Expert system · Maintenance · Electric motors · Artificial neural networks

6.1 Introduction

The supply chain is a set of processes ordered sequentially to deliver a product in perfect condition to the end customer. Within the supply chain, each process adds value to the product; that is, the sale of a product or service constitutes the input of another in a continuous chain until it reaches the final consumer. The relevance of the supply chain lies in the flexibility for the exchange of information between the different processes that comprise it (Govil and Proth 2002). A supply chain structure comprises three fundamental stages that act directly with each other: supply stage, manufacturing, and distribution. The production stage in the supply chain involves all the organizations destined to execute a transformation to the raw material and add value to the product destined for the final customer (Leadley 2016).

The production stage represents a phase of the supply chain where value is added to the product, and this phase has its peculiarities and strategies that make it a competitive tool. Within the production stage, different factors are combined that uniquely characterize the processes that make up the supply chain; however, they have the same goal, to satisfy market demand. The different production techniques, and the correct administration of technical, technological, and human capital resources, make the difference between the different levels of maturity of the organizations within the supply chain (Pagano and Liotine 2019). The supply chain must be able to deal with unforeseen events effectively to avoid delays in the delivery of products. In the scenario in which the number of manufactured products is less than the customer's demand, it is considered that there is a severe problem of capacity in the supply chain. It will hurt the following organizations by not complying promptly with the client's requirements (Basu and Nevan 2008). The supply chain in its production stage faces different challenges, such as increasing the flow of materials within the production system, avoiding losses and excessive inventories during the process, and finally delivering manufactured products on time without detracting from quality in each operation. Increasing the availability of the equipment in the production system is a strategy that provides a solution to the different challenges in the supply chain. The improvement of the availability indicator in the machinery allows a positive contribution to the productivity and efficiency indicators of the manufacturing processes (Unhelkar et al. 2022).

A critical inconvenience within any industry is unexpected production stoppages. These manufacturing interruptions are generated by unforeseen equipment failures, which complicate the timely delivery of the products requested by the client. This way, it would not comply with the supply chain's primary mission. To prevent unplanned stoppages that alter the process's uniform operation and the supply chain's capacity, it is essential to establish an efficient maintenance plan to control revisions and repair equipment within the manufacturing process. In this way, maintenance is positioned as a primary activity to ensure the delivery of products on time in the hands of the final consumer and, thus, guarantee the success of the supply chain (Delic and Eyers 2020). During the production phase of the supply chain, induction motors have been widely used in various operations, mainly due to reliability, performance, and power (Cunha et al. 2015).

However, despite these favorable characteristics, three-phase induction motors can present electrical or mechanical failures caused by prolonged activity times, lack of maintenance, and overload, among other factors (Bouhoune et al. 2017). Due to the benefits of using electric motors in the manufacturing systems involved in the supply chain, their use has been exponential. They currently consume 80% of the electric energy within companies. Consequently, the maintenance of electric motors has become a highly relevant factor for any organization. Industrial assets such as electric motors are vital to guarantee production continuity, increase the performance of other equipment and reduce downtime within any production system, to meet the objectives and goals set within the supply chain (Quispe 2003).

An essential activity in the maintenance area is the detection of faults and anomalies generated in any equipment involved in a productive system that adds value to the supply chain. Efficient and timely location of any incident related to devices ensures improvement of product quality, reduces repair time, and minimizes costs. The development and issuance of a diagnosis on the state of the equipment involved in a process is an important research area in the industrial sector, where preventive and corrective maintenance is gradually complemented to guarantee the operation and reliability of the devices at the same time, the lowest possible cost to the organization. However, issuing a fault diagnosis is not an easy task for the operator since it represents a problem with multiple variables to consider and even entails the analysis of historical measurements related to the state of the equipment (Chapman 2012).

There are research works that allow identifying the advantages of integrating artificial neural networks (ANN) in diagnostic tasks on the correct operation of equipment. According to the research presented by Bazan et al. (2017), the authors mention that three-phase induction motors are considered one of the most important elements of the industrial process. However, such mechanisms are subject to electrical and mechanical failures that can cause significant financial losses. The recognition of short-circuit patterns in windings from artificial neural networks is proposed to mitigate the frequency of failures in the motors. In the work presented by Souza et al. (2016), they proposed using insulation and induction resistance as the main parameters to evaluate the condition of industrial equipment, including electric motors. The classification mechanisms were the K-means methodology and artificial neural networks. To Jafarian et al. (2018), Siano and Panza (2018), the integration between artificial neural networks and the vibration indicator generated in electric motors allows the detector of different types of faults. According to Jayachandran and Sachithanandam (2016), analyzing voltage and current from neural networks efficiently mitigates inconveniences generated by electric motors. In work done by Yang et al. (2018), the researchers presented performance prediction and optimization for motor waste heat recovery based on an artificial neural network. Hussain and Abid (2016) use a fuzzy system to verify the changes generated in the load and speed of a three-phase electric motor.

The research presented by Lashkari et al. (2015) proposed using phase current and voltage as input indicators to a multilayer artificial neural network to detect and locate short-circuit faults in electric motors. In work done by Rajeswaran et al. (2018), the researchers developed a neuro-genetic algorithm for the evaluation of failures of an induction motor from current and voltage indicators. In Karanayil and Rahman (2018), the potential of artificial neural networks to track the variation parameters generated in a flux controller of an induction motor is described. In the research conducted by Sun et al. (2016), the authors proposed the development of an artificial neural network with unsupervised learning to diagnose faults in induction motors.

Based on the literary background raised, the diagnosis related to the operation of an electric motor can be resolved by recognizing patterns generated by various readings. According to the literature review, there are efficient descriptors to identify the operating conditions in a motor. These variables are tension, voltage, insulation resistance, and vibration analysis. The proposed expert system takes the four measurements as input variables, allowing supervision and control regarding motor conditions. The system is composed of two multilayer artificial neural network structures that classify the state of the motor; the first artificial neural network determines whether the motor is in good condition. The second artificial neural network is activated when it detects that the motor is in poor condition, giving way to the recognition and classification of three types of faults related to faults generated in electric motors that are under operation, the fault diagnoses involved in the study. They are severe damage or fatigue in the bearings and short circuits in the winding. Implementing the expert system will provide the user with an automatic diagnosis based on the readings obtained from the electric motor. This will allow efficient equipment maintenance to improve availability and contribute to the manufacturing system's productivity and supply chain.

6.1.1 Electric Motors

Electric motors are rotating electrical devices that transmute electrical energy into mechanical energy and are used to drive other equipment. Its mechanism is based on the forces of attraction and repulsion stimulated by a magnet and a conductor (coil) through which an electric current pass. The action principle of alternating current motors is based on the rotating magnetic field that develops a triphasic alternating current and on the induced currents; said rotating field generated in the stator causes another magnetic field in the rotor winding, which tends to couple with the stator field and thus cause the rotating movement (Hughes 1990).

Due to their rotation speed, three-phase electric motors are classified as synchronous and asynchronous. Synchronous motors are identified because the speed of the rotating magnetic field of the stator is equal to the rotation of the field incited in the rotor. It is called synchronous because the two magnetic fields work synchronously if the load does not exceed the permitted operating limits and a desynchronization occurs. The synchronous motor has the singularity that its rotation speed is proportional to the frequency of the alternating current that supplies it. As for asynchronous motors, the speed of the rotating magnetic field produced by the stator is greater than the speed of rotation of the rotor; that is, they are not synchronized. Currently, asynchronous motors have a high level of occupation at an industrial level and are the object of study of this research (Hughes and Drury 2013).

6.1.2 Artificial Neural Networks

The human brain comprises many interconnected neurons and can think and interpret information to solve problems efficiently. Scientists have tried to computationally model some qualities related to the functioning of the human brain; the result has been artificial neural networks. Currently, artificial neural networks have a series of characteristics typical of the brain; for example, they learn from experience, they can generalize, and they abstract important characteristics from data series (Tsotsos 2015).

An artificial neural network comprises a set of units called neurons; these neurons are interconnected and organized in groups referred to as layers. An artificial neural network comprises a set of units called neurons; these neurons are interconnected and organized in groups referred to as layers. At the beginning is the input layer, where the data is entered into the network; consecutively, the intermediate layers, called hidden layers, are located and presented to the output layer. An important aspect of artificial neural networks' architecture is how neurons are interconnected. An effective method to execute the interaction between neurons is backpropagation; the technique has the objective of propagating the error backward from the output layer (a), which allows the weights (W) on the connections of the neurons located in the hidden layers (Jj) change during training. The change of the weights in the

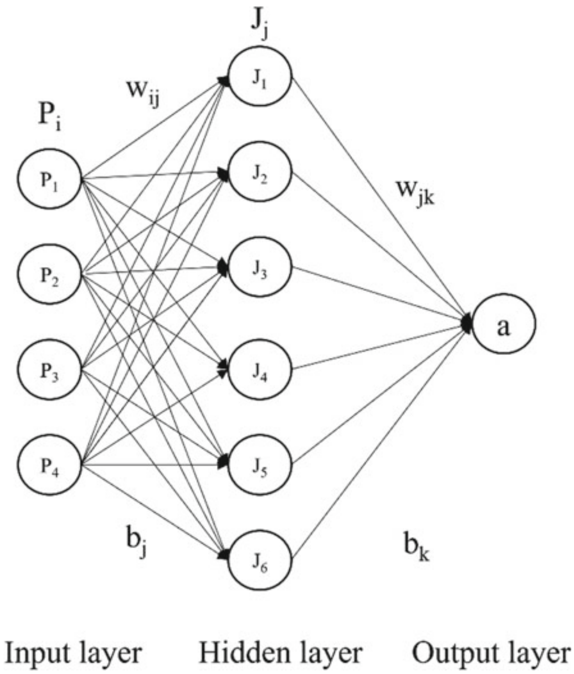

Fig. 6.1 Structure of a multilayer perceptron neural network

connections of the neurons, in addition to influencing the input (Pi), influences the output of each neuron (Alanis et al. 2019). See Fig. 6.1.

6.2 Methodology

The application case of the expert system developed was carried out within a company belonging to the supply chain of the automotive sector. A critical process within the organization is the aluminum machining and injection process to manufacture transmissions. The machining and injection operation is carried out by computer numerical control (CNC) lathes, milling machines, and injection machines. The machining and injection equipment requires constant cooling; this operation is carried out from the softened water feed supplied using electric motors. If an interruption in the water supply is caused by a malfunction in the electric motors, the manufacture of transmissions will be affected. Therefore, unnecessary costs or non-compliance in deliveries to the client will be incurred, which would negatively impact the supply chain.

The company has seen its productivity decrease due to the insufficient availability of the CNC and injection equipment, which is generated by the unscheduled stoppages incurred by the electric motors in charge of the cooling operation. The maintenance of electric motors requires an efficient diagnostic system that operates in real-time under a preventive approach. The expert system developed in the present investigation correctly solves the problem raised; in this way, a more fluid manufacturing process is achieved and with the capacity to meet the demands established in the supply chain. The expert system analyzes and interprets the signals as input variables: tension, voltage, insulation resistance, and vibration analysis. The measurements of the indicators are obtained directly from the electric motors and contribute to the generation of the training and test modules necessary for creating artificial neural networks. The objective of the expert system is to issue an interpretation of the state of the motor from the recognition of patterns in the measurements; in this way, it is possible to immediately foresee or identify an imperfection in the operation of the electric motor and correct it urgently.

The insulation resistance test is carried out to know the motor stator's state and rotor's state. The objective of the test is to carry out phase-to-phase measurements to know the internal physical conditions. The vibration analysis is carried out to identify the faults that an electric motor presents, such as: bearing defects, unbalance, and misalignment. The study on the voltage in the electric motor has the purpose of finding the voltage variations in the motor supply; with this, it is intended to avoid overheating in the windings. Finally, monitoring the electric current avoids overloads in the motor (Ben et al. 2015).

The operation of the expert system proposed in the research is shown in the scheme of Fig. 6.2. The architecture of the system is divided into two phases; the first phase contains a multilayer perceptron artificial neural network (ANN) that determines the adequate or inadequate state of the motor, while the second phase is made up of another multilayer ANN that classifies any of the three types of faults used that the electric motor could present. The fault diagnosis will prevent inconveniences on the state of the engine, and in case of a fault, to be able to focus efforts to correct the fault immediately. It is worth mentioning that within the production systems that make up the supply chain, it is important to have the capacity to respond to breakdowns that may arise in the equipment; the designed expert system provides an improvement strategy in the face of this area of opportunity that afflicts the manufacturing processes belonging to the supply chain.

6.2.1 Training and Testing of Artificial Neural Networks

Artificial neural networks have gained interest in pattern recognition and predictive response modeling due to their ability to learn from experiments without requiring a physical sense of a system and process. The multilayer perceptron artificial neural network is a tool used to classify and model nonlinear behaviors such as those that occur with the operating variables of an electric motor within the industrial sector (Jamadar and Vakharia 2016).

The architecture of the multilayer perceptron ANN consists of an input layer, an arbitrary number of hidden layers, and an output layer. Each hidden or output neuron receives input from neurons in the previous layer, but there are no lateral connections between neurons within each layer. The input layer contains as many

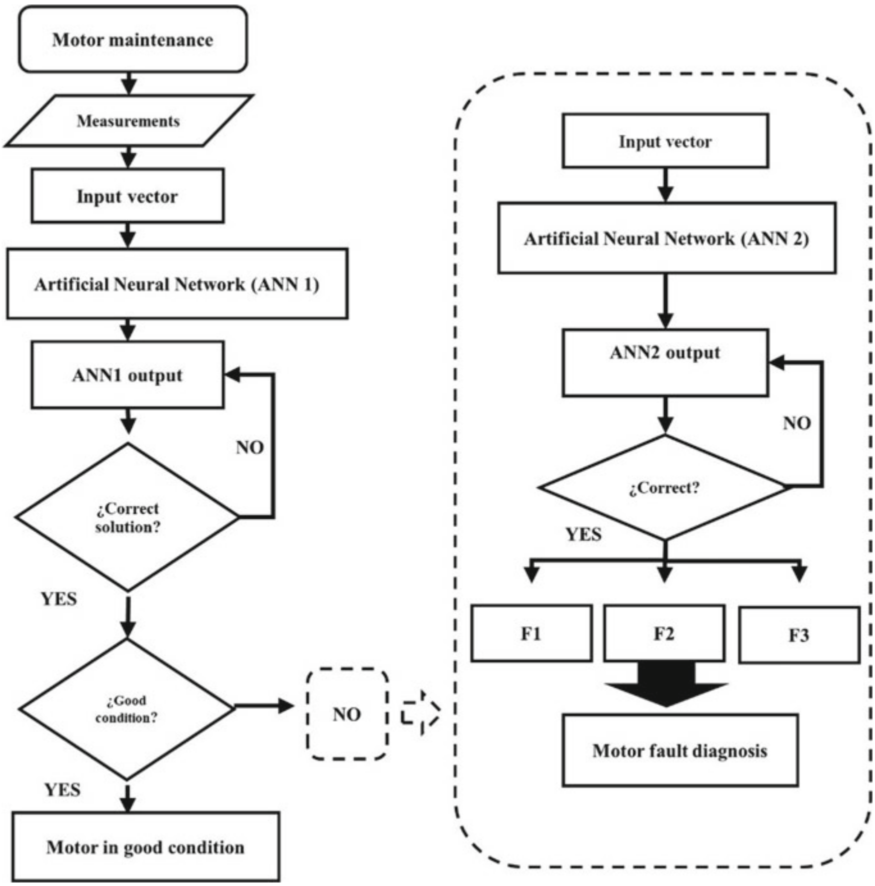

Fig. 6.2 Functional scheme of the expert system

neurons as categories correspond to the independent variables to be represented, and the output layer corresponds to the response variable. The operation of the ANN consists of two important tasks: training and testing. Training an ANN is a process that modifies the value of the weights and biases associated with each neuron so that the ANN can generate an output based on data presented in the input layer. The test task measures the error level generated by the ANN when emitting an output with problem data that were not included in the training task (Moreno et al. 2013).

The training set introduced to the artificial neural network comprises a matrix containing the different states of the motor previously prequalified based on the values the selected activation function can take. The test matrix is cases not involved in the training matrix, and the artificial neural network must recognize them efficiently. Table 6.1 shows the training and test matrices used for the two neural networks that comprise the expert system. The activation function used for both artificial neural networks is the tangent-hyperbolic function, whose values range from −1 to 1. One reading corresponds to the recording of 12 data since four variables are measured in each phase of the three-phase motor.

The artificial neural network topologies that efficiently solve the classification and pattern recognition tasks are shown in Table 6.2.

Subsequently, the mathematical methodology that follows the expert system to issue a fault diagnosis in the electric motor is developed. Table 6.3 shows the data obtained to generate an input vector to the artificial neural network. It should be noted that the measurements correspond to a motor diagnosed with severe bearing damage.

Table 6.1 Training and test sets for the expert system

Artificial neural network 1			Artificial neural network 2		
Training [160 × 12]			Training [180 × 12]		
Behavior pattern	Number of samples	Target	Behavior pattern	Number of samples	Target
Damaged motor	80	0	Short circuit in the winding	60	−1
The motor is in good condition	80	1	Severe bearing damage	60	0
			Bearing fatigue	60	1
Testing [100 × 12]			Testing [120 × 12]		
Behavior pattern	Number of samples		Behavior pattern	Number of samples	
Damaged motor	50		Short circuit in the winding	40	
The motor is in good condition	50		Severe bearing damage	40	
			Bearing fatigue	40	

Table 6.2 Topologies of artificial neural networks

Parameters	ANN 1	ANN 2
Number of hidden layers	1	1
Number of neurons in the hidden layer	9	9
Activation function	Tangent-hyperbolic	Tangent-hyperbolic
Learning rate	0.01	0.01
Allowed error	1e-04	1e-03
Iterations	532	947
Training algorithm	Conjugate gradient	Conjugate gradient
Root mean square error	0.999995681	0.99992618

Table 6.3 Measurements made to the motor

Measurements	Motor phases		
	1	2	3
Tension	26	26	28
Voltage	441	442	443
Insulation resistance	550	550	550
Vibrations	0.6	0.05	0.6

The processing unit of an artificial neural network is a mathematical model through which it is possible to calculate a value that will be classified from the activation function. The function of the artificial neural network is shown in Eq. (6.1), and the tangent-hyperbolic activation function is defined in Eq. (6.2).

$$K = [W * p] + b \tag{6.1}$$

$$J = \frac{e^k - e^{-k}}{e^k + e^{-k}} \tag{6.2}$$

where: W = weights, p = inputs, b = bias, J = output of the activation function.

Using the conjugate gradient algorithm, the training phase is carried out to generate the synaptic weights and bias for each layer belonging to the expert system's artificial neural networks. The final weights and biases of the artificial neural network number 1 are shown in Eqs. (6.3), (6.4), (6.5), and (6.6). The matrix W corresponds to the weights in the first layer [9 × 12]. The vector b is the bias of the first layer [9 × 1]. LW is the weights matrix of the hidden layer [1 × 9]. The variable Lb refers to the bias of the hidden layer [1 × 1].

$$\text{WANN1} = \begin{bmatrix} 0.0861 & 0.1265 & \cdots & -0.1909 \\ 0.1086 & -0.0929 & \cdots & -0.3882 \\ -0.0883 & 0.1112 & \cdots & 0.2972 \\ 0.0889 & 0.1016 & \cdots & -0.2039 \\ 0.2754 & 0.2141 & \cdots & 0.1022 \\ -0.1098 & 0.0767 & \cdots & -0.3776 \\ -0.0733 & -0.1174 & \cdots & 0.1430 \\ 0.0173 & -0.0283 & \cdots & -0.3686 \\ 0.1233 & 0.1111 & \cdots & 0.1759 \end{bmatrix} \tag{6.3}$$

$$\text{bANN1} = [-17.737010.5496 \ldots 55.9801]' \tag{6.4}$$

$$\text{LWANN1} = [0.23570.3312 \ldots 0.1329]' \tag{6.5}$$

$$\text{LbANN1} = [0.0710] \tag{6.6}$$

As for the weights and bias calculated to complete the task of the artificial neural network number 2, they are observed in Eqs. (6.7), (6.8), (6.9), and (6.10).

$$\text{WANN2} == \begin{bmatrix} 0.1295 & -0.1035 & \cdots & -0.3003 \\ -0.1167 & -0.0279 & \cdots & -0.3851 \\ 0.0277 & -0.5050 & \cdots & 0.3789 \\ -0.1137 & 0.0855 & \cdots & -0.0788 \\ 0.1228 & -0.0187 & \cdots & -0.2143 \\ -0.1348 & 0.1046 & \cdots & 0.4760 \\ 0.1022 & -0.1202 & \cdots & -0.1114 \\ 0.0856 & -0.0628 & \cdots & -0.3606 \\ 0.1051 & -0.0999 & \cdots & 0.4897 \end{bmatrix} \tag{6.7}$$

$$\text{ANN2} = [-2.694581.9530 \ldots 6.2855]' \tag{6.8}$$

$$\text{LWANN2} = [1.1172 - 0.2329 \ldots 0.2719]' \tag{6.9}$$

$$\text{LbANN2} = [-0.1189] \tag{6.10}$$

The replacement of neuronal function and activation are shown in Eqs. (6.11) and (6.12), respectively.

$$\text{K} = \left(\begin{bmatrix} 0.0861 & 0.1265 & \cdots & -0.1909 \\ 0.1086 & -0.0929 & \cdots & -0.3882 \\ -0.0883 & 0.1112 & \cdots & 0.2972 \\ 0.0889 & 0.1016 & \cdots & -0.2039 \\ 0.2754 & 0.2141 & \cdots & 0.1022 \\ -0.1098 & 0.0767 & \cdots & -0.3776 \\ -0.0733 & -0.1174 & \cdots & 0.1430 \\ 0.0173 & -0.0283 & \cdots & -0.3686 \\ 0.1233 & 0.1111 & \cdots & 0.1759 \end{bmatrix} * \begin{bmatrix} 26 \\ 26 \\ 28 \\ 441 \\ 442 \\ 443 \\ 550 \\ 550 \\ 550 \\ 0,6 \\ 0,05 \\ 0,6 \end{bmatrix} \right)' + \begin{bmatrix} -17.7370 \\ 10.5496 \\ -40.9600 \\ -3.2393 \\ 31.2056 \\ 87.9092 \\ -5.9625 \\ -16.4195 \\ 55.9801 \end{bmatrix}' \tag{6.11}$$

$$\text{K} = [-35.635 - 46.576.203 - 433.745 \ldots 50.494]$$

$$J = [-1 - 11 - 11 - 1 - 111] \tag{6.12}$$

Substituting in Eq. (6.13), the output of ANN number 1 is generated; see Eq. (6.14).

$$a = \left[J * LW'\right] + Lb \tag{6.13}$$

$$a = \left([-1 \cdots -111] * \begin{bmatrix} 0.2357 \\ 0.3312 \\ -0.0070 \\ -0.7451 \\ -1.0299 \\ 0.5988 \\ -0.6345 \\ 0.5992 \\ 0.1329 \end{bmatrix} \right) + [0.0710] = -0.019987 \approx 0 \tag{6.14}$$

The output value of the expert system is close to the value of (0); therefore, the diagnosis of the motor failure is severe damage to the bearing, as had already been assessed from the beginning. In this way, the application of the mathematical methodology and the operation of the developed expert system are demonstrated.

The expert system enables the continuous analysis of the input signals, so it is possible to determine the operating status of the motor immediately. Due to the generalization capacity of artificial neural networks, the expert system can anticipate possible failures in electric motors. The start-up of the expert system allows closer monitoring of the state of the electric motors; therefore, interruptions due to unforeseen failures in the company's machining and injection processes are avoided. Monitoring the status of the equipment enables customer satisfaction with the delivery of the product demanded within the agreed time; for this reason, the use of expert systems applied to diagnostic tasks contributes to improving the efficiency of the supply chain.

6.3 Results

The impact of the expert system on productivity in machining and injection operations will be directly linked to the production capacity of automotive transmissions that the organization has and, consequently, the capacity of the supply chain to comply with the end customer demand. The main activity of the expert system is to identify the physical state of the electric motors efficiently and, in the event of any damage, classify the generated fault and issue a diagnosis in real-time.

To verify the performance of the ANN in the classification-recognition task of the failure patterns involved in the investigation, a validation phase was developed in which failure cases not included in the training stage are introduced, see Table 6.1. According to Radhakrishnan and Kuttiannan (2012), it is possible to validate a correct classification through the indicators: sensitivity Eq. (6.15), specificity Eq. (6.16), and accuracy Eq. (6.17). See Table 6.4.

Table 6.4 Validation of the expert system in the classification task

		Artificial neural network 1	
Behavior pattern	Sensitivity	Specificity	Accuracy
Damaged motor	1	1	1
The motor is in good condition	1	1	1
		Artificial neural network 2	
Behavior pattern	Sensitivity	Specificity	Accuracy
Short circuit in the winding	0.9902	0.9814	0.9872
Severe bearing damage	0.9894	0.9924	0.9931
Bearing fatigue	0.9958	0.9941	0.9975

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{6.15}$$

$$\text{Specificity} = \frac{\text{TN}}{\text{VN} + \text{FP}} \tag{6.16}$$

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{FN} + \text{FP} + \text{TN} + \text{TP}} \tag{6.17}$$

where: TP: True-positive, FN: False-Negative, VN: True-Negative, FP: False positive.

Referring to the data obtained from Table 6.4, the artificial neural network number 1 has an accuracy of one hundred percent; this is because it only classifies the correct or incorrect operation of the electric motor. On the other hand, artificial neural network number 2 recognizes and classifies three potential faults the electric motor can incur (short circuit in the winding, severe bearing damage, and bearing fatigue). The average accuracy of the fault diagnosis issued by the artificial neural network number 2 is ninety-nine percent, see Fig. 6.3.

It is important to point out that the main objective of the proposed expert system is to maximize the operating efficiency of electric motors by recognizing fault patterns. With the implementation of the expert system, it is necessary to monitor indicators that allow visualizing the relevance and advantages of implementing systems focused on improving equipment performance within a production process.

Based on the work developed by McCarthy and Rich (2015), the authors state that the mean time between failures (MTBF) and the mean time to repair (MTTR) are adequate indicators to monitor the availability of equipment in processes (AOE) Eq. (6.18). With the start-up of the expert system for six months, data related to the performance of the engines were obtained, and it was possible to make a quantitative

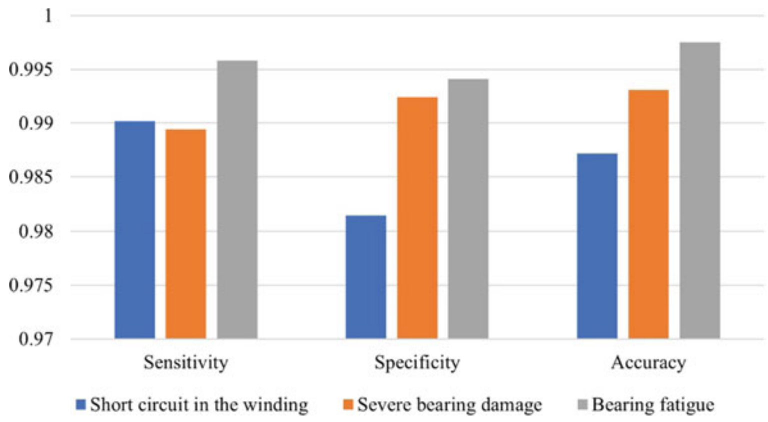

Fig. 6.3 Efficiency indicators in fault diagnosis

comparison of the indicators before and after the implementation of the proposed expert system, see Table 6.5

$$AOE\% = \left(\frac{MTBF}{MTBF + MTTR}\right) * 100 \tag{6.18}$$

The implementation of the expert system has the purpose of measuring the benefits of monitoring the physical state of electric motors in the machining and injection process that the organization has. After a trial period, it was possible to considerably reduce the downtime in the devices due to faults generated in the electric motors used

Table 6.5 Performance indicators of the expert system

	System implementation	
Indicators	Before	After
Planned hours of operation	3120 h	3120 h
Number of faults	24	3
Hours with equipment in failure	108	5.4
Mean time between failures (MTBF)	125.5 h/failure	1,038.2 h/failure
Mean time to repair (MTTR)	4.5 h	1.8 h
Availability of equipment (%)	96.53	99.82

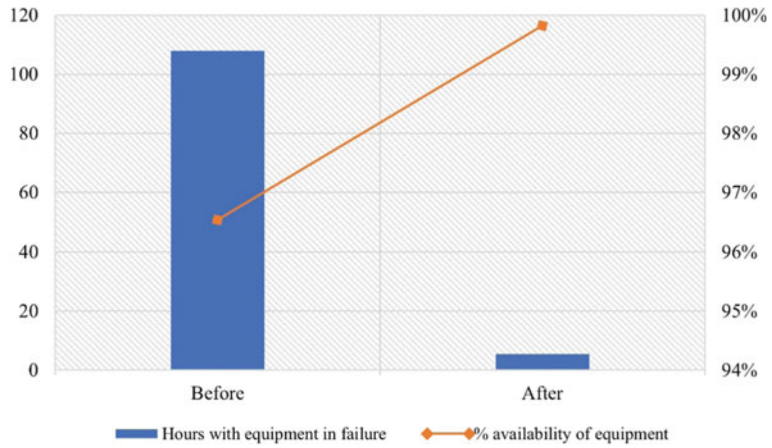

Fig. 6.4 Implementation of the expert system

for the cooling system. Consequently, the availability of the equipment is increased, and the productivity of the manufacturing system benefits, see Fig. 6.4.

Mitigating failure times and increasing the availability of the mechanisms used within a production process directly benefits the supply chain's ability to comply promptly with any demand established by the customer.

6.4 Conclusions

Technology increases profitability within organizations, and the modernization of procedures by taking advantage of information analysis and automation will be essential to support supply chains to provide more detailed monitoring of processes and assets. The correct maintenance management within the different phases of the supply chain positively impacts the quality and quantity of the products manufactured in each supply chain link, which translates into a benefit for the clients and the organizations that comprise it.

The expert system presented in the research demonstrates its viability as a tool for supporting and diagnosing faults in electric motors within a production process. The implementation of the expert system allowed for improving the availability of the equipment (3.29%), reducing the repair time of a motor (2.7 h), reducing the number of faults generated in the electric motor (21 faults) and, therefore, a positive impact is achieved in terms of the productivity of the company and the capacity of the supply chain. The architecture developed for the expert system can efficiently diagnose the physical state of a motor; specifically, three types of faults were addressed: short circuits in the winding, severe bearing damage, and bearing fatigue. The diagnosis issued by the expert system allows the maintenance team to immediately focus its efforts on repairing a previously identified fault, thus providing more efficient maintenance to electric motors.

The average accuracy of the system when classifying the damage and subsequently issuing a diagnosis is 99%. The tangent-hyperbolic activation function is efficient for the cited context since it is a non-linearly separable problem, despite interpreting only two motor states in the first artificial neural network. In future research, it is recommended to expand the use of indicators related to the state of the engine to obtain more detailed information on the operation of the equipment. Therefore, the capacity of the expert system could be extended when it comes to recognizing and diagnosing types of faults present in an electric motor.

The scientific contribution of this research focuses on generating a methodology capable of recognizing and classifying three anomalous states in electric motors from artificial intelligence. In the literary review, works were identified that analyze the physical state of the motors from artificial neural networks; however, they focus on recognizing a single fault present in electric motors. Regarding the technological contribution, a graphical interface was developed so that the user enters measurements and is provided with a reliable diagnosis of the physical state of the engine without the condition that the user has any knowledge of intelligent systems. It is important to point out that developing expert systems focused on data interpretation and decision-making in the maintenance area is a guideline to broaden organizations' vision and improve their operations, contributing to the supply chain of which they are a part.

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Chapter 7
Leadership as a Strategy for Flexibility and Resilience in the Supply Chain

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Abstract This study examines the transactional and transformational leadership of manufacturing managers in Ciudad Juarez (Mexico) and its impact on supply chain flexibility and resilience, which contributes to quantifying the relationship between the variables to provide knowledge on the importance of leadership style in supply chain resilience. The dimensions and items of each latent variable were integrated into a questionnaire administered to Mexican Maquiladora. Two hundred thirty-one valid questionnaires were obtained and analyzed using a structural equation model (SEM) based on partial least squares (PLS) for validating the five hypotheses or relationships between variables. The results indicate that both leadership styles influence supply chain resilience; however, transformational leadership has a greater direct impact than transactional leadership. However, transactional leadership yielded better results when the mediating variable of flexibility was used. These results create a frame of reference to determine which leadership style can benefit the company, depending on the situation in which it finds itself.

Keywords Transformational leadership · Transactional leadership · Resilience supply chain · Structural equation modeling · Maquiladora industry

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7.1 Introduction

To get closer to their customers, obtain lower production costs, access raw materials and provide better service to their customers, in recent decades, companies have left their home territory and have strategically established subsidiaries in other countries so that international trade has increased significantly. This has led to companies not competing among their production processes but their supply chains (SC) (Gong et al. 2018); hence, it is important to efficiently manage supply networks and develop strategies to compete in globalized markets (Mokhtar et al. 2019). These competitiveness strategies depend on the managers' leadership and the company's line of business.

Leadership has been studied in different areas, such as hospitals (Baysak and Yener 2015), academic universities (Cetin and Kinik 2015), business (Chiu and Walls 2019), military (Martínez-Córcoles and Stephanou 2017). However, there is a need to analyze its impact on performance management in interconnected firms, i.e., supply chains. For Mokhtar et al. (2019), SC leadership seeks the collaborative integration of members for outsourcing, production, and distribution of finished products. This involves putting aside the individual interests of the companies that make up the network and focusing on strengthening the SC to reach new levels of competition that they cannot reach alone.

However, Sharif and Irani (2012) mention that supply chain leadership (SCL) is a function of responsibility in supply chain management (SCM). In addition, Akhtar et al. (2017) declared that SCL is the ability of one or more companies to influence decisions and performance among channel members. According to this, leadership should be considered an equally important resource for the company and, in this case, applied to the SC (AlNuaimi et al. 2021) and, in this case, the SC.

In SC, the company can lead from two angles, either in the two channels (sourcing and distribution) or as (buyer and supplier), so it must show a specific leadership style that marks the influence towards better performance in the whole network. To improve SC performance, leadership must contribute to sustainability strategies (Meinlschmidt et al. 2018), collaborative learning (Hult et al. 2000a), and resilience (Shin and Park 2021).

7.1.1 The Maquiladora Industry in Mexico

A maquiladora can be defined as a foreign-owned subsidiary located in Mexico because of its strategic location, skilled labor, and advantages in trade agreements with countries such as the United States of America and Canada, which implies proximity to customers. By nature, they perform activities with high labor demand, import raw materials, and export finished products to other countries. Many world-class companies follow this production strategy.

According to García-Alcaraz et al. (2015), the maquiladora industry in Mexico competes in global and changing markets. Hence, its resilience is critical for survival in adverse situations, such as changes in demand, technological innovations, economic crises, and environmental and health crises. The adaptability of the maquiladora in Mexico is due primarily to its leaders' effectiveness and impact on supply chain performance, as well as its flexibility (García-Alcaraz et al. 2020).

The maquiladora industry (IM) in Mexico began in the 1960s and is currently highly recognized internationally for its skilled labor, employing 2,702,116 nationwide IMMEX (2021). Specifically, according to data from IMMEX (2021), Ciudad Juarez has 24 industrial parks in which 328 maquiladoras operate and directly employ 322,787 people, and 19,107 occupy administrative and leadership positions, indicating the high importance of the industrial sector, socially, economically, and environmentally.

For example, to illustrate the economic importance, from January to September 2021, 184,868 million dollars in raw materials were imported, and 188,645 million dollars in finished products were exported nationwide, of which 16,638 (imports) and 16,978 (exports) million dollars belong to Ciudad Juarez. These goods (raw materials or finished products) enter through one of the city's international bridges. In 2021, there were 581,548 full container crossings through three of them, indicating the intensity of the supply chain associated with sourcing and distribution and the role played by the leaders of the departments involved.

This chapter aims to identify the SCL style applied to the Mexican maquiladora industry and its impact on SC resilience, having as mediating variables the SC flexibility and transformational leadership style (TFL) and transactional (TSL) as response variables. These leadership styles are selected because they are parts of the theory of relationships which has been widely accepted in the academic and business world.

This chapter is organized into six sections: the first includes an introduction to the SCL research; the second provides a literature review and hypotheses of the variables of TSL, TFL, flexibility, and resilience in SC and the relationship between them; the third illustrates the methodology applied and includes the design, implementation, data collection, and validation as well as the structural equation model; the fourth section presents the results obtained through structural equation analysis; and the fifth section presents the conclusions.

7.2 Literature Review and Hypotheses

Throughout history, there have been different theories about leadership styles and their effectiveness; however, Baysak and Yener (2015) established that its understanding is complex because it is analyzed from a scientific scope and should be considered as a social phenomenon. The leadership in the SC is visualized in companies because it stands out among the members of the network and sets the tone to establish agreements, commitments, collaboration, strategies, vision, and influence on others. However, this influence or leadership of the network can be analyzed in two styles using the theory of relationships (Sarachek 1968; Bass 1985; Burns 1978), where transactional and transformational leadership are presented. Therefore, this study analyzes these styles from an SC perspective.

7.2.1 Transactional Leadership in the Supply Chain (TSLSC)

TSL in SC is based on a system of rewards and punishments. The leading company benefits or penalizes other companies depending on the level of performance it obtains in a given time. According to Dubey et al. (2015), rewards can be tangible or intangible; in the former, the company can give a reward to the other, and in the intangible form, it could be respect and loyalty in alliances, so the leading company influences the others.

Birasnav et al. (2015) argue that TSL is applied by the company when one company supervises or audits another in its operations. Those supervisions may occur in the quality, manufacturing, and materials, among others, where it seeks to determine needs and performance to ensure the SC's satisfaction and expected objectives (Hult et al. 2000b).

The TSLSC has three dimensions: Contingent Reward, Management by Active Exception, and Management by Passive Exception.

Contingent Reward (CR): In this dimension, members' goals, tasks, and roles are set (Martin 2017; Arokiasamy et al. 2015). The main focus is the exchange applied according to the performance obtained in achieving the set metrics (Aga, 2016). Here the leading company motivates suppliers by assigning them goals in performance levels and rewarding the effort if they comply with what is established, as stated by Birasnav et al. (2015).

Management by Active Exception (MBE Active): In this dimension, monitoring is constant (Aga 2016), which is aimed at avoiding and correcting deficiencies in the system and, at the same time (Arokiasamy et al. 2015), promoting changes to avoid potential severe problems or to deviate from the standards (Birasnav et al. 2015), and thus ensure that the system ensures that the agreed performance is met (Gençer and Samur 2016).

Management by Passive Exception (MBE Passive): This dimension presents carelessness in leading because the leader-member only acts if necessary (Aga 2016). Therefore, it exhibits passive and reactive behaviors (Mokhtar et al. 2019). It can be said that it does not contribute positively to achieving these objectives (Birasnav and Bienstock 2019).

The TSLSC shows control and coordination behaviors towards follower companies, both in everyday operations and when a disruptive event occurs; in both cases, the flexibility that the company manages could help to obtain the expected returns, stay in the event, and show resilience in the SC.

7.2.2 Supply Chain Flexibility (SCF)

For Jüttner and Maklan (2011), supply chain flexibility is “the ease of modifying the number and range of possible alternatives in the SC or the number of possible alternatives and the degree of differences between them to cope with a variety of changes and developments in the market while still providing acceptable performance”. According to Shin and Park (2021), SC flexibility can vary in effectiveness in mitigating risks that may arise in transportation, inventories, manufacturing processes, and distribution.

Ali et al. (2017) stress that flexibility should be part of a company’s management strategy in which alternatives are sought to solve problems associated with SC. Kumar et al. (2017) indicate that they are vital factors together with leadership in the performance of the same. This flexibility must be written in contracts and agreements inside and outside the company and between departments, suppliers, and clients (Liu and Çetinkaya 2009). Given that flexibility in SC is considered an adaptation strategy in changing environments, mediated by agreements and contracts of responsibility between both parties, we propose the following:

$\boldsymbol{H_1}$. The TSLSC has a positive and significant impact on the SCF of Mexican IM.

7.2.3 Transformational Leadership in the Supply Chain (TFLSC)

TFL fosters relationships based on empathy, charisma, and loyalty, which can be considered as emotional leadership (Luo et al. 2019). TFLSC determines how one company influences another by modeling its actions and behaviors in the SC (Mokhtar et al. 2019). Here, the company inspires others, driving its business partners to reach new levels in their areas, such as technological innovation (Wamba and Chatfield 2009) or social responsibility (Müller-Seitz and Sydow 2012).

This leadership facilitates renewal while promoting change (McKean and Snyderman 2019), establishes long-term relationships with partners, empowers (Birasnav and Bienstock 2019), empowers, develops and coaches them (Yue et al. 2019), and establishes trusting relationships. Through this approach, empirical evidence affirms that leadership is the most effective leadership style for organizations (Park and Pierce 2020).

The TFLSC has four dimensions: idealized influence, motivational inspiration, intellectual stimulation, and individualized consideration. These are defined as follows.

Idealized Influence (II): A relationship is established based on values and respect. The leader shares the vision, mission, and strategies with the follower (Shao et al. 2017). The leader shares the vision, mission, and strategies with the follower member; the behavior is ethical and integral, so it is considered a role model (Sandstrom and

Reynolds 2020). Thus, the company provokes the admiration and loyalty of SC members (Birasnav and Bienstock 2019; Mokhtar et al. 2019).

Motivational Inspiration (MI): expectations and motivationally communicated goals are set, and teamwork is encouraged to achieve them (Birasnav and Bienstock 2019). The approach requires maximizing effort (Shao et al. 2017), encouraging spirit, and fostering optimism (Sandstrom and Reynolds 2020). This approach requires maximizing efforts, encouraging spirit, and fostering optimism, whereby the company can influence its business partners enthusiastically and collaboratively (Birasnav and Bienstock 2019; Mokhtar et al. 2019).

Intellectual stimulation (IS) promotes creative problem-solving, brainstorming (Shao et al. 2017), and innovation (Birasnav and Bienstock 2019). Here, the company stimulates intellectual ability in the members of the SC (Mokhtar et al. 2019) and sets the tone to question, rethink, and redefine systems and procedures.

Individualized Consideration (IC): The leading firm focuses on recognizing the individual needs of members in the SC (Mokhtar et al. 2019), encourages personalized attention (Birasnav and Bienstock 2019), and develops potential coaches and mentors (Shao et al. 2017; Sandstrom and Reynolds 2020).

The TFLSC shows mentoring behaviors, where, through motivation and stimulation, the influence on the other companies is achieved and positioning itself as the leader in SC, which contributes to developing them, certifying them in the required areas, and establishing strategies for sustainability and resilience to stay in the market. Thus, SC flexibility is the organization's ability to respond quickly to market changes, establish management strategies, maintain acceptable yields, and maintain the ability of the organization to respond quickly to market changes (Ali et al. 2017), maintain acceptable returns (Jüttner and Maklan 2011) and show resilient behaviors (Shin and Park 2021).

However, this ability may be determined by the level of leadership of the company. The following hypothesis is proposed as TFL has a transformative and adaptive style.

$\boldsymbol{H_2}$. The TFLSC has a direct and positive effect on the flexibility of Mexican IM SC.

7.2.4 *Supply Chain Resilience (SCR)*

The number of studies on resilience in SC has increased as firms have become more vulnerable to shocks in globalized markets (Alfarsi et al. 2019). Ponomarov and Holcomb (2009) define supply chain resilience (SCR) as "the adaptive capacity of the SC to prepare for, respond to, and recover from unexpected events while maintaining continuity of operations at the desired level of connectivity and control of structure and function".

Queiroz et al. (2022) mention resilience as an ability to recover, adapt and transform. Several studies have investigated the role of leadership in SCR. For example, Shin and Park (2021) conducted a study using leader-member (LMX) leadership in SC and its impact on resilience; the results showed that firm-focal leadership enhances resilience capacity in the network. Therefore, we propose the following hypothesis:

H_3. The TSLSC has a direct and positive effect on resilience in Mexican IM SC.

On the other hand, Shin and Park (2021) mention that the focal company's leadership impacts resilience in SC through mediating variables such as flexibility, agility, efficiency, and alertness. Pereira et al. (2014) mention that SCR can bring opportunities to create sustainable competitive advantages and enhance a company's reputation. Since TFL presents characteristics of renewal, it is based on values and ethics, which help a company in its reputation in the market and be more competitive in decision-making in disruptive events (Pereira et al. 2014), which are required characteristics in SCR, then the following hypothesis is proposed:

H_4. The TFLSC has a direct and positive effect on resilience in Mexican IM SC.

Flexibility in SC has been understudied, so the area of opportunity for further research is extensive. On the contrary, there are a diverse variety of studies on flexibility in manufacturing systems (Merschmann and Thonemann 2011); however, flexibility has recently been used to measure the resilience level.

Azevedo et al. (2013) consider SCF as the basis of provisioning and contributes to improving resilience; however, Pujawan (2004) suggests that flexibility is costly and should be evaluated whether the firm needs it to improve performance and offer diverse alternatives to customers. Thus, companies that wish to have flexibility must invest in infrastructure and resources in advance and anticipate disruptive events to which they can quickly adapt and make operational decisions as part of SCF resilience management strategies (Ali et al. 2017). Therefore, the following hypothesis is proposed:

H_5. Flexibility has a direct and positive effect on resilience in Mexican MI SC.

Figure 7.1 graphically illustrates the relationships between the hypothesized variables.

7.3 Materials and Methods

We require information from the Mexican MI to validate the model in Fig. 7.1, so the following methodology was executed.

7.3.1 Questionnaire Design

A literature review of more than 80 articles was conducted using keywords such as transformational leadership, transactional leadership, supply chain leadership, supply chain flexibility, and supply chain resilience. The search was limited to papers published between 2015 and 2022, which allowed for rational validity.

Two questionnaires were identified in the literature; the first measured transformational (10 items) and transactional (13 items) leadership in SC (Mokhtar et al.

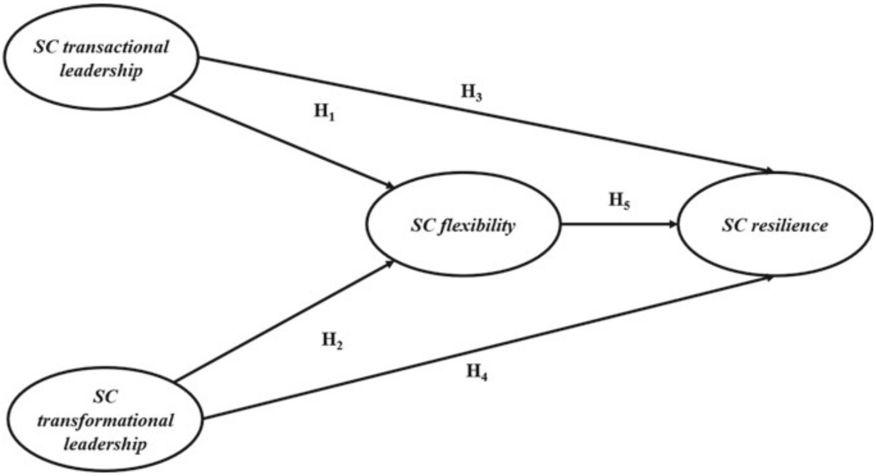

Fig. 7.1 Proposed model

2019), and the second measured flexibility in SC (3 items) and resilience (4 items) in SC (Shin and Park 2021), which were unified to generate a single questionnaire. An introductory section is added to the questionnaire, which seeks to obtain demographic information associated with the respondent, such as the position, seniority, gender, industrial sector, and company size. This information helps characterize the sample and make comparisons with other sectors and regions in the future.

The preliminary questionnaire was reviewed by a group of six academic experts in leadership and SC and four managers active in Mexican MI to adapt it to the regional context. The questionnaire should be answered on a five-point Likert scale, where one indicates that the activity does not occur and five indicates that it always takes place. The scale indicates that the activity is not done, and intermediate values rarely indicate regular and almost always.

The Google Forms platform was used for the questionnaire application because of health restrictions caused by the COVID-19 pandemic. The questionnaire focuses on managers, engineers, and supervisors of the SC since they serve as leaders within the Mexican MI, so the sampling was stratified.

7.3.2 Application of the Questionnaire

With the help of the Mexican Maquiladora Export Industry (IMMEX), potential respondents were identified and sent a link to the questionnaire by email, inviting them to participate in the study. Data will be collected from January 3 to June 8, 2022. Respondents must be responsible for a work team and belong to a materials department such as purchasing, logistics, warehouse, and materials planning. They must have at least one year in the position to ensure they have sufficient knowledge to answer the survey.

7.3.3 Recording and Debugging of Information

After its closure, a database in XLSX (Excel extension) was downloaded from the Google Forms platform. Then the information was analyzed using SPSS v.25® software because of the easy handling of variables. The debugging of information was carried out in three phases.

Identification of missing values. If the percentage of missing values was greater than 10%, the case was eliminated; if it was less, it was replaced by the median of the item (Hair et al. 2010).

Identification of extreme values. They are replaced by the median to avoid biases in the study and identified when standardizing the items, where values greater than four in absolute value are considered extreme values.

Identification of non-committed respondents. The standard deviation of each row or case was estimated. If it was less than 0.5, it was eliminated from the analysis because it was assumed that the respondent was not committed to answering each question seriously and responded with the same or similar values (Hair et al. 2010).

7.3.4 Descriptive Analysis of the Sample and Items

Demographic information was analyzed using crosstabs to summarize it. Given that the items were obtained on an ordinal scale, the median was obtained as a measure of central tendency and the interquartile range (IQR) as a measure of dispersion (difference between the third and first quartiles) (García-Alcaraz et al. 2017; Tastle and Wierman 2007).

High median values indicate that respondents attach high importance to that activity, whereas low values represent low importance. High IQR values indicate a low consensus among respondents regarding the mean value of the item, and low values represent high consensus.

7.3.5 Validation of Variables

We use the validation indices proposed by Kock (2015) to validate the latent variables individually, and some are obtained iteratively because eliminating some of the items that compose them improves validity. The indices are:

- Cronbach's alpha and composite validity index for internal validity and values greater than 0.7 are accepted.
- R-squared and adjusted R-squared to measure parametric predictive validity on dependent variables, and values greater than 0.02 are desired.
- Q-squared values for non-parametric predictive validity and values greater than zero, similar to R-squared, are also desired.
- The average variance extracted (AVE) to measure convergent validity and values greater than 0.5 are required.
- Variance inflation factor (VIF) to measure multicollinearity between items within variables and values less than five are required, preferably less than 3.3.

7.3.6 Validation of Hypotheses—Structural Equation Modeling

Structural equation modeling (SEM) was used to validate the hypotheses proposed in Fig. 7.1, as reported in social sciences and engineering studies (Doral Fábregas et al. 2018; Chan et al. 2007) and helps validate the relationships between variables (Nitzl 2016). This technique has been used in similar research by Ebrahimi et al. (2016) to evaluate the relationship between leadership styles and organizational performance in manufacturing companies.

WarpPLS v.7® software was used to validate the relationships between variables based on partial least squares (PLS) algorithms. Kock (2019) recommends it for small samples without normal data distribution or obtained on a Likert scale.

Once the particular variables have been validated, they are integrated into the SEM for evaluation and validation as a whole with 95% confidence, and Kock (2013) suggests estimating six model efficiency indices:

- The average path coefficient (APC) to measure the dependence between variables and the associated p-value should be less than 0.05.
- The average R-squared (ARS) and average adjusted R-squared (AARS) were used to measure the predictive validity of the dependent variables, and the associated p-value should be less than 0.05.
- The average block VIF (AVIF) and average full collinearity VIF (AFVIF) to measure collinearity should ideally be less than 3.3, although values less than 5 are acceptable.
- The Tenenhaus GoF (GoF) to measure the data fit to the model should preferably be greater than 0.36.

Three types of effects were estimated between the constructs in the SEM. The first is direct effects, which are used to validate the hypotheses stated in Fig. 7.1 and are visualized in the arrows that connect the constructs in the model, presented by a standardized β value as a measure of dependence. The second is the indirect effect, which occurs through a mediating variable and requires two or more segments. Their interpretation is important when there is no direct relationship between the variables or when it is not statistically significant. Finally, the total effect represents the sum of the direct and indirect effects.

To accept or reject an effect between variables (relationship between variables), we test the null hypothesis H_0: $\beta = 0$ versus the alternative hypothesis H_1: $\beta \neq 0$, with a confidence level of 95%. If the p-value associated with β is less than 0.05, it is concluded that there is a relationship between the constructs, and the hypothesis is accepted; otherwise, it is rejected. In addition, the effect size (ES) is given as a measure of the variance explained by the dependent variable's independent variable for each effect. The sum of all ES for a dependent variable equals the R-squared value.

7.3.6.1 Sensitivity Analysis

In general, the relationship between latent variables cannot be fully explained by the standardized value of β. Therefore, in this study, for each relationship or hypothesis in Fig. 7.1, we estimate the probability of occurrence of low $P(Z < -1)$ and high $P(Z > 1)$ occurrence scenarios for the variables independently, simultaneously, or jointly, and the conditional probability of occurrence of the dependent variable in a scenario, given that the independent variable has occurred in a scenario. High scenarios are represented by the symbol (+), and low scenarios by (−). The probability of simultaneous occurrence between two variables is represented by (&), and finally, the conditional probability is represented by "If". Conditional probability is vital for identifying variables and scenarios that favor others and risk-low scenarios.

7.4 Results

7.4.1 Descriptive Analysis of the Sample

A total of 328 surveys were submitted online, of which 240 questionnaires were received before June 8, 2022 (the cutoff date). However, nine were eliminated because they did not comply with the inclusion process in the filtering process, leaving 231 surveys to be analyzed, where men and 61.5% of women answered 38.5%. Table 7.1 reports the position of the respondents and the number of years they held the position. It is observed that the categories of manager/coordinator and technician responded to 107 and 77, respectively, so these two positions represent 79.65% of the surveys analyzed. Likewise, it was observed that most respondents (90.90%) had one to five years of experience in their position.

Table 7.2 illustrates the number of employees and the industrial sector to which they belong. Most respondents worked in companies classified as large, 130 had more than 501 employees (56.26%), and the representative industrial sectors were medical and automotive, with 63 and 56 cases, respectively.

Table 7.1 Position and years in the same position

Position	Year			Frequency
	1–5 years	5–10 years	+10 years	
Manager/coordinator	107	7	2	116
Engineer	13	2	0	15
Supervisor	13	0	1	14
Technician	77	7	2	86
Total	210	16	5	231

Table 7.2 Industry sector and company size

Employees	Industrial sector								
	A	L	P	M	E	D	C	S	
0–50	1	2	2	1	3	10	2	15	36
51–100	2	2	0	1	3	3	1	8	20
101–200	6	0	0	1	4	0	0	5	16
201–500	5	5	0	0	2	10	0	7	29
501 or more	42	23	4	3	3	40	5	10	130
Total	56	32	6	6	15	63	8	45	231

A-Automotive, L-Electrical/electronics, P-Plastics, M-Metals, E-Packaging, D-Medical, C-Communications, S-Services

7.4.2 Descriptive Analysis of the Items

Table 7.3 presents the descriptive analysis of each item that comprises the validated constructs and is integrated into the SEM analysis. It can be observed that almost all the items of the latent variables have medians greater than 3.0, which indicates that they are performed regularly. Concerning the interquartile range (IQR), low values indicated adequate consensus among the respondents.

It should be noted that the management by passive exception dimension was removed from the analysis due to the literature's view that it is not conducive to TSL or firm performance (Birasnav and Bienstock 2019; Asrar-ul-Haq and Kuchinke 2016; Flatau-Harrison et al. 2020).

7.4.3 Validation of Latent Variables

Table 7.4 presents the validation indices for each construct, and it can be observed that all of them are fulfilled according to the established criteria. For example, R-squared and adjusted R-squared indices are presented for parametric validity, which is greater than 0.02. In addition, for internal validity, Cronbach's alpha index and

Table 7.3 The median and interquartile range of model items

Latent variable/item	Median	IQR
TFLSC-transformational leadership in supply chain		
A leading firm goes beyond its self-interest for the good of the supply chain (II)	3.48	1.67
Leading firm talks enthusiastically about what needs to be accomplished in the supply chain (II)	3.61	1.81
Leading firm clarifies the central purpose underlying their supply chain actions. (II)	3.68	1.65
A leading firm displays power and confidence. (II)	3.91	1.55
The leading firm seeks different views when solving supply chain issues. (IS)	3.76	1.69
The leading firm suggests new ways to solve supply chain issues. (IS)	3.74	1.67
Our company is encouraged to express ideas. (IS)	3.72	1.79
The leading firm spends time teaching and coaching us. (IC/IM)	3.71	1.80
Our company gets individual consideration (IC)	3.45	1.86
The leading firm encourages us to improve our strengths (IC/IM)	3.62	1.90
TSLSC—Transactional leadership in supply chain		
A leading firm lets us know what is expected of us in the supply chain process. (CR)	3.84	1.68
The leading firm encourages using uniform procedures in the supply chain process. (CR)	3.80	1.69
A leading firm decides what shall be done and how it will be done in the supply chain process. (CR)	3.82	1.67
The leading firm maintains definite standards of performance in the supply chain process. (CR)	4.03	1.64
The leading firm asks that we follow established purchasing rules and procedures. (CR)	3.54	1.99
Leading firm rewards our company for achievement. (CR)	3.64	2.05
Our company is punished for fault and misconduct such as late delivery. (CR)	3.88	1.67
Leading firm tracks our company mistakes (MBE Active)	3.57	1.80
The leading firm concentrates its full attention on dealing with our mistakes (MBE Active)	3.47	1.88
The leading firm concentrates on our failures (MBE Active)	2.89	2.41
SCF—Supply chain flexibility		
Adjust the delivery time of the supplier's order to mitigate disruptions	3.48	1.74
Adjust production volume capacity in response to a disruption	3.61	1.75
Adjust delivery schedules to cope with disruptions	3.65	1.88
SCR—Supply chain resilience		
How well is your firm prepared for a disruptive event recovery?	3.77	1.76
How well can your firm's material flow quickly be restored after a disruptive event?	3.84	1.65

(continued)

Table 7.3 (continued)

Latent variable/item	Median	IQR
How quickly can your firm deal with a disruptive event?	3.88	1.59
How easily can your firm recover its average operating performance after a disruptive event?	3.76	1.60

Table 7.4 Validation of latent variables

Index	TFLSC	TSLSC	SCF	SCR
R-squared			0.267	0.380
Adj. R-squared			0.261	0.71
Composite reliability	0.932	0.916	0.902	0.920
Cronbach's alpha	0.918	0.895	0.837	0.884
Average variance extracted	0.579	0.578	0.754	0.741
Full collinearity VIF	2.155	2.303	1.380	1.566
Q-squared			0.271	0.384

composite reliability present value greater than 0.7 in all constructs. No collinearity problems are observed since the VIF reports values less than 3.3, and there is sufficient convergent validity since the AVE is greater than 0.5 in all the variables analyzed, so we proceed to the integration of the variables in the model.

7.4.4 *Structural Equation Modeling*

Table 7.5 illustrates the efficiency indices of the model, where APC, ARS, and AARS indicate acceptable predictive validity because all associated *P-values* are less than 0.05. The VIF and AFVIF values were less than 3.3, indicating that the model had no collinearity problem. Finally, it is observed that the Tenenhaus GoF is greater than 0.36; therefore, it is concluded that the model is valid and can be interpreted.

Table 7.5 Model efficiency indexes

Index	Value
Average path coefficient (APC)	0.253, $P < 0.001$
Average R-squared (ARS)	0.323, $P = 0.001$
Average adjusted R-squared (AARS)	0.316, $P = 0.001$
Average block VIF (AVIF), ideally ≤ 3.3	1.873
Average full collinearity VIF (AFVIF), ideally ≤ 3.3	1.851
Tenenhaus GoF (GoF), ideally ≥ 0.36	0.463

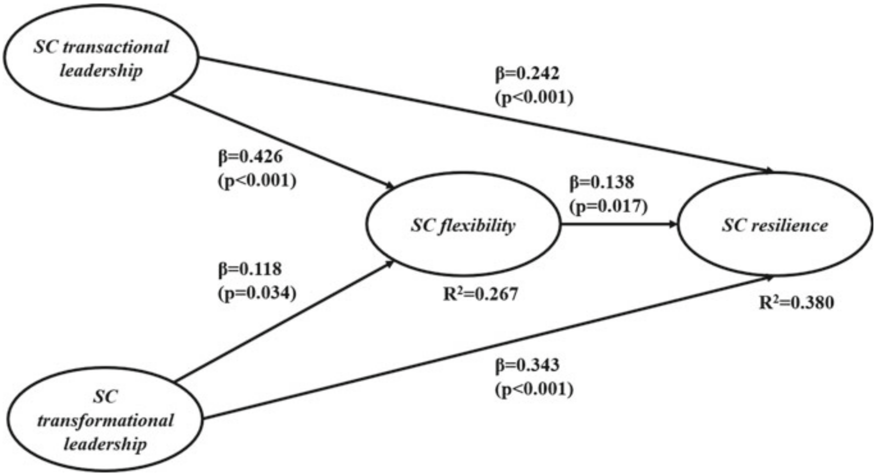

Fig. 7.2 Evaluation of the proposed model

Figure 7.2 presents the model analyzed, where the standardized values of β and the associated *P-value* for the hypothesis test are shown. In each dependent construct, the R-squared value is indicated as a measure of the variance explained by the independent variables that affect it.

7.4.4.1 Validation of Hypotheses, Indirect and Total Effects

Table 7.6 shows the direct effects of the latent variables in the model, represented by arrows in Figs. 7.1 and 7.2. The β index represents the dependence value, which is associated with a p-value that measures the statistical significance of the relationships. For example, the relationship between TSLSC and SCF presents values of $\beta = 0.426$ and $P < 0.001$, which indicates that when TSLSC increases its standard deviation by one unit, SCF increases by 0.426 units; therefore, it can be said that the relationship between both variables is very strong. Based on the p-value associated with each of the β parameters, it is concluded that all the relationships are statistically significant, and therefore, all the proposed hypotheses are accepted.

Table 7.6 Hypotheses validation

H_i	Relationship	β (p-value)	ES	Decision
H_1	TSLSC → SCF	0.426 (<0.001)	0.217	Accepted
H_2	TFLSC → SCF	0.118 (=0.034)	0.050	Accepted
H_3	TSLSC → SCR	0.242 (<0.001)	0.132	Accepted
H_4	TFLSC → SCR	0.343 (<0.001)	0.194	Accepted
H_5	SCF → SCR	0.138 (<0.001)	0.054	Accepted

Table 7.7 Total effects

To	From		
	TFLSC	TSLSC	SCF
SCF	0.118 ($p = 0.034$) ES = 0.050	0.426 ($p < 0.001$) ES = 0.217	
SCR	0.359 ($p < 0.001$) ES = 0.203	0.301 ($p < 0.001$) ES = 0.164	0.138 ($p = 0.017$) ES = 0.054

The model in Fig. 7.1 shows that TFLSC and RSLSC may affect SCR through Flexibility, which is an indirect effect. In this case, for the relationship TFLSC → SCR, the effect is $\beta = 0.016$ ($p = 0.363$) and for the relationship TSLSC → SCR the effect is $\beta = 0.059$ ($p = 0.102$), which are not statistically significant. However, Table 7.7 indicates that the total effects (sum of the indirect effects) are statistically significant, as the p-values associated with β are less than 0.05.

7.4.4.2 Sensitivity Analysis

Table 7.8 illustrates the sensitivity analysis results for the direct relationships between the variables. Recall that low levels are represented by the sign "–" and refer to $P(Z < -1)$, while high levels are represented by the sign "+" and refer to $P(Z > 1)$. For example, the probability of TFLSC occurring at a high level (TFLSC+) in isolation or independently is 0.173, whereas the probability of it occurring at its low level (TFLSC+) in isolation and independently is 0.182.

Table 7.8 Sensitivity analysis

Dependent variable			Independent variable					
			TFLSC		TSLSC		SCF	
	Scenario		+	–	+	–	+	–
		Probability	0.173	0.182	0.177	0.16	0.169	0.156
SCF	+	0.169	& = 0.061	& = 0.017	& = 0.082	& = 0.004		
			If = 0.350	If = 0.095	If = 0.463	If = 0.027		
	–	0.156	& = 0.013	& = 0.061	& = 0.013	& = 0.061		
			If = 0.075	If = 0.333	If = 0.073	If = 0.378		
SCR	+	0.199	& = 0.100	& = 0.013	& = 0.087	& = 0.009	& = 0.078	& = 0.083
			If = 0.575	If = 0.071	If = 0.488	If = 0.054	If = 0.462	If = 0.083
	–	0.173	& = 0.004	& = 0.078	& = 0.009	& = 0.074	& = 0.017	& = 0.061
			If = 0.025	If = 0.429	If = 0.049	If = 0.459	If = 0.103	If = 0.389

Similarly, the probability of TFLSC+ co-occurring with SCF+ is only 0.061, but the conditional probability of SCF+ occurring, given that TFLSC+ has occurred, is 0.350. However, if TFLSC− occurs, there is a 0.333 probability of SCF− occurring, representing risks to managers and decision-makers. Overall, sensitivity analysis helps identify vital or risky variables to achieve SC performance and complements the β indices traditionally reported in SEM.

7.5 Conclusion

7.5.1 Structural Equation Modeling Findings

In the initial model shown in Fig. 7.1, five hypotheses were established. The following conclusions can be drawn based on the results obtained and illustrated in Fig. 7.2.

$\boldsymbol{H_1}$. There is sufficient statistical evidence to state that *TSLSC* has a direct and positive effect on *SCF* in Mexican MI since when the first variable increases its standard deviation by one unit, the second latent variable increases by 0.426 units and can explain 21.7% of its variability. This finding sets the tone for managers in Mexican IM, who aim to increase flexibility in SC to manage a transactional leadership style with members in SC, which implies the creation of accountability contracts on both sides, which benefits SC performance under normal and disruptive conditions.

These findings differ from those of a study conducted on leadership styles and flexibility in strategic decision-making to obtain better organizational effectiveness, which was applied to SMEs in Chile. The results determined that the style of TSL is not significant for obtaining flexibility and, in turn, is not significant for strategic decision-making or the effectiveness of the company (Rodríguez-Ponce 2007). In this study, the results indicate that the TSL in the SC significantly impacts flexibility. This difference may be due to demographic and cultural characteristics in which the studies are conducted; the industrial sector and large companies with a high technological level represent the size of the companies in the Mexican MI.

$\boldsymbol{H_2}$. There is sufficient statistical evidence to state that *TFLSC* has a direct and positive effect on *SCF* in Mexican MI since when the first variable increases its standard deviation by one unit, the second latent variable increases by 0.118 and can explain 5.0% of its variability. This finding may imply that managers in Mexican MI do not manage a transformational style when they want to increase flexibility in SC because of the ambiguity of commitments, investments, and responsibilities in SC. Although the TFLSC has a positive impact, it has a greater impact and ensures the management of responsibilities through its dimensions.

This study shows a degree of relationship with Rodríguez-Ponce (2007), who finds that TFL positively impacts flexibility in strategic decision-making and firm effectiveness. Although not in the area of SC, its impact on the firm may impact SC.

H_3. There is sufficient statistical evidence to state that *TSLSC* has a direct and positive effect on *SCR* in Mexican IM, given that when the first variable increases its standard deviation by one unit, the second latent variable increases by 0.242 units. In addition, it has an indirect effect through an SCF of 0.059, which is not statistically significant but generates a total effect of 0.426 units, which provides managers in Mexican MI with the insight to manage a TSLSC if they need to increase SCR.

According to the results of this study, it is advisable to manage this leadership style when preparing for unexpected events to ensure the continuity of operations among chain members. Shaaban and Shehata (2019) conducted a study that obtained similar results, although not in SC; however, they determined that TSL impacts resilience, which, in turn, on the company's overall performance.

H_4. There is sufficient statistical evidence to state that *TFLSC* has a direct and positive effect on *SCR* in Mexican IM, given that when the first variable increases its standard deviation by one unit, the second latent variable increases by 0.343 units. In addition, it has an indirect effect through an SCF of 0.016, which is not statistically significant but generates a total effect of 0.359 units, which is significant.

This finding provides information to managers in Mexican MI to act on disruptive events because it was found to have a greater impact on SCR when needing to respond and recover quickly from unplanned events in SC and maintain operations among channel members. This result is similar to that of Shaaban and Shehata (2019), where TFL was found to impact resilience, which, in turn, has an impact on performance.

H_5. There is sufficient statistical evidence to state that *SCF* has a direct and positive effect on *SCR* in Mexican MI, as when the first variable increases its standard deviation by one unit, the second latent variable increases it by 0.138 units. The results of this study are consistent with the literature review, which found that SCF is one of the six elements that have the greatest impact on SCR and is a risk management strategy among SC members (Shin and Park 2019; Hohenstein et al. 2015). For this reason, managers in the Mexican IM who wish to obtain benefits by strengthening resilience in the SC must invest in the flexibility of this as a predecessor variable, which leads to decisions about infrastructure, furniture, and operating equipment in their facilities, as well as their supply and distribution channels.

7.5.2 Conclusions from the Sensitivity Analysis

From the sensitivity analysis, interesting conclusions were obtained that have great applicability for managers and decision-makers because they indicate the probabilities of extreme scenarios (high and low) for the variables and allow identifying the variables that favor the occurrence of others or the variables and scenarios that represent a danger. For example, TFLSC+ is vital for companies because the conditional probabilities of SCF+ and SCR+ are 0.350 and 0.575, respectively. However, if TFLSC- occurs, they have probabilities of SCF− and SCR− occurring at 0.333 and 0.429, respectively, representing a risk for them. It is also observed that TFLSC+ is only weakly associated with SCF− and SCR−, as the conditional probabilities are low, indicating that efforts made in TFL always give benefits in flexibility and resilience.

Similarly, TSLSC+ favors the occurrence of SCF+ and SCR+, with probabilities of 0.463 and 0.488, respectively. However, if TSLSC− occurs, there is a conditional probability of SCF− and SCR− occurrence of 0.378 and 0.459, respectively, representing risks. In addition, efforts to achieve TSLSC+ are always rewarded, as there is little association between SCF− and SCR−, as the probabilities are low. Similarly, scenarios in which TSLSC− is present do not guarantee the occurrence of SCF+ and SCR+, as the probabilities are also low.

The analysis of the impact of leadership styles is essential since it is observed that TFLSC favors the occurrence of SCR in the Mexican IM sector. In contrast, TSLSC favors more SCF, allowing managers to focus on a specific style to achieve the desired goals. This conclusion can also be obtained by observing the β indices that relate them because TSLSC impacts SCF by 0.426 units, while TFLSC impacts so by only 0.118 units; for its part, TSLSC impacts SCR by 0.242 units, while TFLSC impacts so by only 0.343 units.

Finally, the sensitivity analysis also shows that SCF is important for SCR because if SCF+, there is a conditional probability of 0.462 for SCR+ to occur and 0.103 for SCR− to occur. However, if SCF− occurs, there is a 0.389 probability of SCR− occurring, representing the risk and difficulty in achieving normal working conditions in SC.

7.5.3 Limitations and Future Lines of Research

Mexican IM is generally distributed in the northern part of the country; however, this study analyzes and reports only the companies established in Ciudad Juarez, which is a limitation that does not reflect the national trend. Future research should conduct this study in cities with similar broad industrial cultures, such as Monterrey, Tijuana, and Apodaca. In addition, it analyzes leadership styles as a global variable; therefore, in future research, we intend to analyze each dimension of leadership styles separately and report it as a model of second-order equations.

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Part III
The Supply Chain in the Distribution Process

Chapter 8
Demand and Inventory Management for the Creation of an Automated Information Management System: A Case Study Applied to an Ecuadorian Supermarket

Paula Lizbeth Cárdenas-García, Denisse Mishel Ichau-Tabango, Patricia Johanna Pando-Sigua, and Sonia Valeria Avilés-Sacoto

Abstract In 2020, due to the COVID-19 pandemic, supermarkets took over as distributors of essential products. Due to this same situation, even the behavior of consumers changed radically since food, cleaning products, and personal hygiene products increased their presence at historical levels. This situation forced several commercial sectors to evaluate their data to respond immediately to the requirements of consumers. Therefore, the need arises for efficient and optimal planning of the products on the rack that are offered, focusing on those of greatest demand and sale to consumers. The present research study was carried out in an Ecuadorian supermarket, in which methodologies for the treatment of forecasts and inventories were applied through the historical sales data provided by the company for the years 2018, 2019, and 2020. Forecast models were applied to reduce uncertainty regarding planning the supply of the different products offered in the supermarket. The models were ARIMA, Holt, Holt-Winters, Seasonal Simple, and Winters Additive, while for the treatment and efficiency planning of the existing stock within the company; that is, having enough products to satisfy the demand, different inventory models and respective EOQs (economic order quantities) were applied according to the case. The information on sales management has been compiled and standardized in a

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Microsoft Excel template for the optimal flow of information and the recording of internal operations, achieving efficient product planning to avoid shortages in the supply chain.

Keywords Forecasts · Inventories · Supermarkets · BPM · Information system

8.1 Introduction

Supermarkets are spaces of commercial exchange between the customer and the business owner. Cristóbal Fransi and Marimon Viaidu (2011) state that a store or supermarket meets the following conditions: (a) inform and sell; (b) allow orders; (c) charge; (d) deliver the product; and (e) deliver an after-sales service. On the other hand, it is established that the goods sold in a store of this category are plural. This range of products is established in different relationships according to the type of supplier since, when it comes to agricultural or perishable goods, we work with a different level of supplies and collection than that of mechanical goods, groceries, clothes, tools, pharmacy, beauty, paintings, home, etc., (González 2020). Espinel et al. (2019) affirm that supermarkets or stores are "a microenterprise business, usually developed by a family group on a very small scale, in which necessities such as food, beverages, liquors, miscellaneous, and toiletries are sold". With this type of exchange, the local economies of the different sectors grow considerably as job opportunities arise for the retail sector (Flexor 2014). Considering the number of products offered on the premises, it is important to conduct a thorough analysis of the treatment and management to avoid losses due to expired, missing or excess products in inventories because of the need to maintain high quality while also being concerned about fluctuations in demand (Van der Vorst et al. 1998).

Thus, strategic planning must begin with demand estimation, better known as demand forecast analysis. For this reason, factors such as the time to plan forecasts, future periods, and the prediction interval (calculation period for new predictions) must also be integrated into this type of analysis (Cacatto et al. 2012). On the other hand, Corres et al. (2009) suggest that supermarket-type companies forecast their sales to estimate and analyze future demand, representing the central axis of the planning and control of budgets related to logistics and supply chain activities.

Within Ecuador, revenues from the economic activity carried out by supermarkets represent the third sector with the highest turnover, according to information obtained from the Internal Revenue Service of Ecuador (SRI) in 2019. According to Ortega (2013), the growth of income, and therefore the phenomenon of the increase in hypermarkets within Ecuador, began after the banking crisis that the country went through in 1999. In 2019, the number of supermarkets nationwide increased by around 7%, going from 460 self-service stores in 2018 to 492 in December 2019 (Mondragón 2019).

The data makes Ecuador the fourth country in supermarkets per capita, referring to how many people have a supermarket on average (Mondragón 2019). It was found that

33,000 people exist per supermarket, which is close to what is handled in countries such as Chile or Argentina, with 25,200 and 30,000 people, respectively (Mondragón 2019). Likewise, Ecuador presents a trend of greater growth in annual openings within the region, surpassing countries such as Colombia and Peru (5.5 and 5%) (Mondragón 2019).

The effects of the COVID-19 health crisis were palpable in many sectors of society in 2020, as supermarkets became important distributors of necessities (Ministry of Labor and Social Security Honduras 2020). Within this context, the Ecuadorian supermarket, as the object of this study, suffered in 2020 a series of eventualities because of the pandemic, one of which was the deficient management of the management of inventories itself, as evidenced by the poor distribution of hangers, missing products, obsolete products, delays by suppliers, among others. The Ecuadorian markets were not unscathed by these abrupt changes generated by the pandemic. Large supermarket chains such as Almacenes Tía presented peak stages during the quarantine in the number of products per invoice. However, they have begun to stabilize because, during the confinement, customers carried, on average, 13.64 products per invoice and currently only 9.50 (El Universo 2020a, b). Therefore, it is relevant to carry out an analysis in supermarkets focused on the treatment of forecasts and inventories based on historical data of sales and demand, which provides valuable information for decision-making regarding the management of the supply of products that allows a prompt and effective response to the needs of the consumer. For confidentiality reasons, the supermarket located in the province of Azuay will be called "Ecuadorian supermarket."

This Ecuadorian company was founded on May 15, 2017, and began its activities as a family company located in the canton of Santa Isabel and later two branches located in the parish of La Unión and the canton of Gualaceo, all in the province of Azuay. Its primary economic activity is the commercialization and distribution of necessities.

Currently, the matrix presents problems in the purchasing area; orders are made without any reference, which causes an overage of inventory, expired products, and a lack of high turnover. For these reasons, the current study aims to develop an information management system to improve forecasting and inventory management.

Given its accelerated expansion to other cantons, it is necessary to have greater control over the supply and demand of products and the management of inventories since certain products are distributed to the two branches of the matrix. For this reason, the present study was carried out in the matrix with historical data for 2018, 2019 and 2020.

From November 2019-September 2020, 48 complaints were received for non-existent product billing and 23 complaints for expired products and not available on hangers; of these, 23 complaints and 9 complaints were resolved, obtaining only 45.07% of the claims and complaints resolved. As noted, most complaints cannot be resolved, which affects the level of service, which means lost sales for the company. Concerning claims for non-existent product invoicing, the product is invoiced, but in the warehouse, the specified amount does not exist; therefore, incomplete deliveries are presented.

Figure 8.1 records the main complaints arising in the Ecuadorian supermarket, where 80% of complaints are represented by 20% of problems such as "expired products" and "lack of stock". On the other hand, in Fig. 8.2, it was obtained that 80% of the claims correspond to 20% between "billing for non-existent product" and "long payment lines". Emphasis was placed on complaints since they are the factor that causes more unresolved problems were obtained.

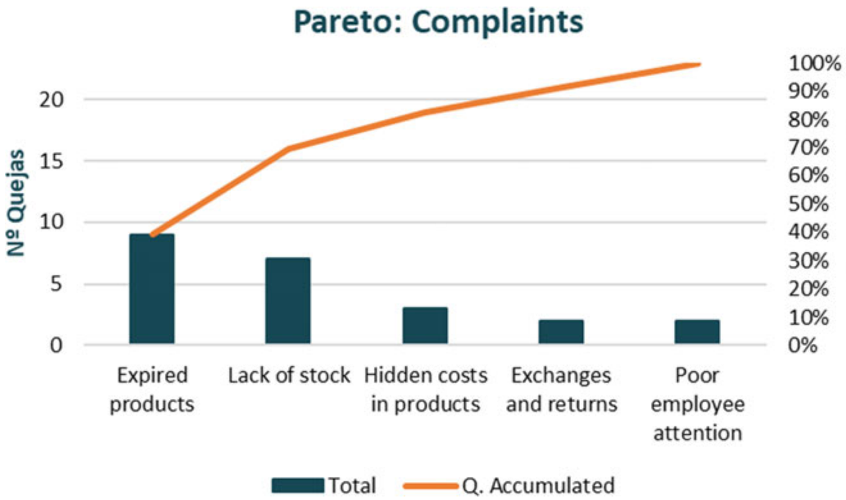

Fig. 8.1 Pareto: complaints

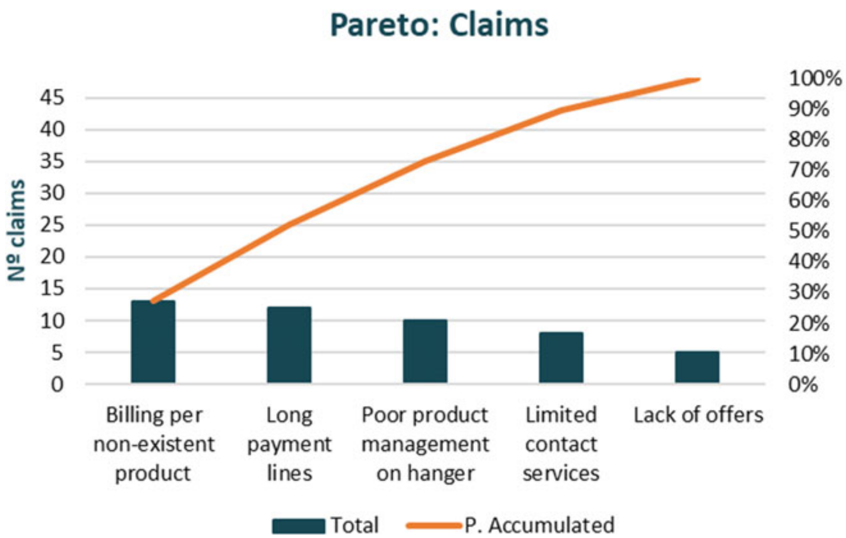

Fig. 8.2 Pareto: claims

Other information and available data are included in the Appendix Section. To view all the appendices, please go to the following link: https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing.

8.2 Methodology

8.2.1 Description of Methodology

This project is based on the methodology proposed by Córdoba (2016), which was developed for a company dedicated to the market of perishable products (AEX Alimentos Exquisitos). In addition, the methodology proposed by Méndez and López (2013) is aggregated, in which more specific steps are proposed for processing data, classification criteria, and use of forecasts and inventories. According to Córdoba (2016), the first step consists of:1.

8.2.2 Collection of Historical Data of the Company

For the treatment of these data, human intervention is established as an important factor, that is, the experience with which the analyst has and the knowledge of data and the different trends so that they can detect changes in the structure of the data, abnormal data, and seasonal characteristics (Prusa and Chocholac 2015).

According to Toscano (2017), it is very common for databases to contain 40–90% of quality problems within the information they contain. Therefore, data cleansing must be performed (Shmueli and Koppius 2011). This stage begins with the following:

- Data analysis to identify errors or inconsistencies to work on during this phase.
- Define the transformation of the data and the mapping rules, that is, establish the type of data with which they work and the level of affectation. Mapping rules consist of the series of standards that analysts follow to treat data.
- An evaluation of the level of adequacy and effectiveness obtained by the corrective actions carried out through an evaluation of the data.
- Data transformation occurs when quality errors have been detected within the dataset; the transformation to the original data must be established to be used in the following analysis points.

8.2.3 ABC Rating

The demand/sales factor is relevant because it reflects a clear vision of the number of physical units that generate higher percentages of profit for the company (Castro et al. 2011). On the other hand, the criterion of movements refers to the handling and different movements made to the products within inventories to maintain a certain amount of each product, considering the time and frequency of consumption (Múzquiz 2013).

8.2.4 Forecasts

8.2.4.1 Determine the Forecasting System that Best Suits the Behavior of Demand

This phase is complemented by what is mentioned in the methodology of Méndez and López. (Appendix 2 contains relevant information. Please visit the following link https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

8.2.4.2 Inventory Management

Within the inventory management system, Córdoba (2016) establishes that it must be established that the method must be implemented according to the requirements presented by the company. The needs must be analyzed and used accordingly to plan and control products within the company. Through the application of inventories, you can know the number of items and estimate replenishment times, in addition to having the advantages of reducing storage costs, optimization and cash flow planning (Durán 2012). Please see Appendix 3 at https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing.

8.3 Research Methodology and Design

The methodology proposed by Córdoba (2016) within the case study will be used. In addition, the methodology of Méndez and López (2013) is incorporated, based on the number of products and similarity of conditions concerning the "Ecuadorian Supermarket" that will be treated throughout this research. Specific difficulties in inventory management are established since the number of articles is usually very high, and, in addition, the nature of these is diverse, either by the raw material or the final product. As such, for the above reason, the authors advise differentiating classification into different criteria (Flores and Whybark 1986).

8.3.1 Gathering Historical Data

The company delivered the data in excel files separated by months of 2018, 2019, and 2020. The fields in excel files are SKU, sales, cost, and utility.

8.3.2 Data Purification

In the application case, only the data for 2018, 2019, and 2020 are counted because, as mentioned, the company was founded in mid-2017. In addition, the year 2020, due to the health emergency, should be considered an atypical year because products that are part of the basic basket of Ecuadorian families, such as rice, milk, cheese, and canned goods, among others, were disproportionately acquired by customers in the most critical months of the pandemic.

However, not all products are framed as atypical data because there are some whose demand has continued with the same behavior as in the years 2018 and 2019. Atypical data within forecasts constitute those whose value is numerically different from the rest (Prusa and Chocholac 2015).

For the treatment of these data, human intervention is established as an important factor, that is, the experience with which the analyst and the knowledge of data and different trends so that they can detect changes in the data structure, abnormal data, and seasonal characteristics (Prusa and Chocholac 2015). Within the files delivered by the company, data cleaning was carried out. According to Toscano (2017), it is very common for databases to contain 40–90% of quality problems within the information they contain. Data cleansing consists of (Shmueli and Koppius 2011).

8.3.2.1 Data Analysis

From the data, there are errors or inconsistencies to be dealt with. Among the datasets provided by the company are:

- The number of times the customer buys a specific product.
- The cost.
- Sales.
- Usefulness.
- SKU.

The number of records that the company had can be seen in Appendix 4, where they are detailed by month of the years analyzed prior to the cleaning of the data.

(See Appendix 4, please visit the following link: https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

8.3.2.2 Define Data Transformation and Mapping Rules

That is, establish the type of data with which they work and the level of affectation. Mapping rules consist of the series of standards that analysts follow to treat data. Taking some of these rules into consideration, certain criteria were defined under which some data were eliminated from the analysis due to inconsistent data, two of which stand out: zero cost values and negative utility. In an interview with the company, they indicated that the presence of zero-cost values is because, in certain products, the suppliers send them as promotions. However, since inventory issues must enter them, the income is declared with zero value at cost.

Regarding negative profit, the company indicated that there are occasions to buy products in large volume from other suppliers due to promotions; however, the cost price is not changed. The product purchased under this policy has a lower selling price, but the price remains high, and this causes a lag with negative utility.

8.3.2.3 Data Evaluation

An evaluation of the level of adequacy and effectiveness obtained by the corrective actions carried out through an evaluation of the data.

8.3.2.4 Data Transformation

When quality errors have been detected within the dataset, the transformation to the original data must be established to be used in the following analysis points.

By completing this series of steps, the data is appropriate for the following points of the described methodology. Appendix 5 includes the number of records used for this study after the data cleansing (See Appendix 5 at https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

8.3.3 ABC Rating

It was worked considering the application of the ABC multicriteria methodology. This is based on the curve 80–20, or Pareto Law, which states, "There are a few critical values and many insignificant." Therefore, resources must be concentrated on critical values (Parada Gutiérrez 2009). The author assures that, based on the effectiveness, the need to classify the inventory and carry out selective control. After having cleaned the data on average, 1642 products from all the years considered in the study, it is necessary to make a classification by which products that are considered relevant to the Ecuadorian supermarket are prioritized.

It begins with the ABC classification of the complete database. Table 8.1 includes the results. For this classification, the utility criterion was considered since the company is interested in those products from which it receives the highest income. According to Nahmias (2007), not all products require inventory control, and the greatest attention should be focused on those that generate a greater share of the company's profits. This author proposes an ABC classification by sales volume and indicates that more attention should be directed to product A concerning others. Products B and C do not require scrutiny, and products D and E are generally not ordered in large volumes. Therefore, it is not recommended to focus too much on these.

The products with high utility that generate 80% of income are made up of 20%, that is, 234 products. In this classification, there are products of different natures, such as canned, frozen, grains, balanced, cleaning, and personal hygiene products, among others. The present study only concentrates on the 234 products that generate the greatest utility. From these, a sub-classification is created that is presented below.

As mentioned in the data cleansing section, there are certain products for which the demand for the year 2020 was not considered since, when graphing the data, high variability was observed concerning the data corresponding to the years 2018 and 2019, resulting in a total of 114 products forecast only with data from the years 2018 and 2019. The nature of these products was mostly made up of grains (beans, peas, chickpeas, popcorn, etc.), rice, personal cleaning products, eggs, bread, and

Table 8.1 ABC classification of products with greater utility

Code	Utility	Kind for utility
28,580	$1.893.0	A
12,449	$579,0	A
9394	$423.5	A
27,837	$265.9	A
9382	$252.0	A
17,720	$245.8	A
17,830	$241.1	A
.	.	.
.	.	.
15,580	$6.4	B
16,852	$6.4	B
25,593	$6.3	B
25,129	$6.3	B
.	.	.
.	.	.
27,898	$1.893.0	C
18,430	$1.893.0	C

milk, among others. For the remaining 120 products, sales for the years 2018, 2019, and 2020 were included since, comparing the demand for the year 2019 with the year 2020; there was no great variation. These products include, among other things, beverages, coffee, meat, snacks, and balanced diets.

Due to the limitation of the time counted to carry out the present project, Hamerly and Elkan (2004) recommends aggregate planning because it establishes that an individual analysis of all the products a company manages is irrelevant. Under the concept, it was decided to implement machine learning tools, in this case, K-Means Grouping (Bradley et al. 2000).

8.3.3.1 K-Means Clustering

The use of K-Means is recommended because it has excellent scalability due to the amount of data (Bradley et al. 2000). It is necessary to use this algorithm, and you must specify the number of clusters to be found. Clustering consists of the grouping of data automatically. However, as it is unsupervised learning, it is not perfect, and there is no correct answer. It is then suggested to establish K (cluster number) and use the Jambu Elbow test (Hamerly and Elkan 2004). It is a good choice because it helps determine the number of clusters that must be applied to form an optimal number of data sets. The elbow name is due to the shape of the graph that is generated and compared to the onset of its stability; these changes indicate where the appropriate K for the data is located (Hamerly and Elkan 2004).

Figure 8.3 indicates that 7 is the number of clusters that will be formed. This is because, at that point, the last inflection point in the graph is presented. In addition to this test, a qualitative method was used in which the researcher's judgment was used.

Specific clusters were identified that did not follow the same pattern, so the decision was made to separate them from having better results when making aggregate sales of them. After this analysis, 20 clusters were applied to the 234 products, maintaining the initial separation of those products considering the three years of historical

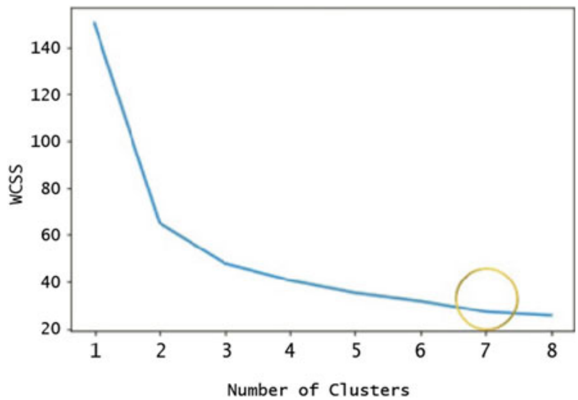

Fig. 8.3 Jambu's Elbow—Optimal number of K

data. In contrast, in others, the year 2020 is excluded for the reasons mentioned above. The summary of the clusters created can be reviewed in Appendix 6. (See Appendix 6 at https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

8.3.4 Forecasts

In this section, sales of historical data for the years 2018 and 2019 and 2020 were analyzed for each case mentioned in the previous section. In the case where the year 2020 is excluded, the lawsuits presented a high variability concerning the previous years in March-August. In September and December, the demand is affected by a large decrease. This is because most people bought a high amount of food in the previous months, so they kept it at home; therefore, they no longer acquired it from the supermarket.

In the case of Ecuador, it was discovered that the average expenditure of each purchase per consumer was $45 in February 2020, $105 in April 2020, and $58 in June 2020, due to the presence of the pandemic, with dairy, canned goods, and cleaning products being the most in-demand (El Universo 2020a, b).

8.3.4.1 Determine the Forecasting System that Best Suits the Behavior of Demand

Two ways were established to determine the model to be applied: qualitative, based on observation, and quantitative, where Dickey-Fuller tests were applied to test if the series is stationary and Mann-Kendall for trend.

Try Dickey Fuller

The procedure is based on proving the existence of a unit root in the autoregressive polynomial of the process (Castaño and Martínez 2009).

$$
\begin{aligned}
y_t &= \beta_0 + \beta_0 t + at \\
a_t &= \rho a_{t-1} + u_t t
\end{aligned}
\tag{8.1}
$$

where u is one process of noise white $N = (0, \sigma^2 \mu)$

The hypothesis herself raises how:

H_0: The series has a unit root (The series is stationary)
H_a: The series does not have a unit root (The series is not stationary).

Table 8.2 Summary of the ABC classification according to utility

(%)	Zone	N. items	%Items (%)	%Accumulated items (%)	Utility	Accumulated utility
0–80	A	234	14.3	14.3	$12.151.56	$12.151.56
80–95	B	363	22.1	36.4	$1.975.58	$14.127.14
95–100	C	1045	63.6	100	$1.670.72	$15.797.86
	Total	1642				

Table 8.3 Evaluation of the accuracy of the forecast (Ft) through the ASM error

MAP (%)	Prognosis quality
Ft ≤ 10	Very good
$10≤ ≥20	Well
$20≤ ≥30	Moderate
Ft > 30	Poor

Mann Kendall

It is used to validate positive and negative trends over a time series. It does not require data to be normally distributed or linear (Zaiontz 2019).

H_0: The *series* does not present a trend
H_a: The series present a trend.

The mentioned tests were performed in the XLSTAT software. The p-value of each product was compared with the null and alternative hypothesis against $\alpha = 0.05$. The results are given in Appendix 7.

With the tests carried out previously, it is possible to define demand behavior. Table 8.2 shows a summary of the information to be considered for evaluating the appropriate forecast model according to the main characteristics required by the model. (For Appendices 7 and 41, please see https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

XLSTAT and Minitab software were used to run forecasting models and sales pattern validation tests.

For the validation of these models, emphasis was placed on the ASM (Mean Absolute Percentage Error), which is defined as a performance indicator that measures the size of the error in percentage terms (Nieto Figueroa and Vélez Correa 2016). The quality of the criterion is defined in terms of the lowest ASM of the tests carried out previously. Table 8.3 presents the ranges through which the accuracy of the prognosis is evaluated.

8.3.5 Inventories

Nahmias (2007) states that the EOQ is the most basic model of inventories such as (Q, R) and (s, S), but other assumptions are also integrated. Vidal and Goetschalckx (2000) agree that EOQ is the fundamental model since it commits to fixed order costs and costs for maintaining the inventory and allows the development of the most complex existing models. (see appendix 42 at https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing) below are details of the existing EOQ models with their respective variations. It proceeds to determine if the demand is deterministic or stochastic. Within this category, the demand may vary. According to Taha (2012), the coefficient of variation can be used (V) to assess the nature of the demand using the following guidelines:

- The demand is deterministic if the average monthly demand is constant and V < 20%.
- If V > 20% but is approximately constant, then the demand is probabilistic and stationery.

This calculation was performed in Minitab 17 software, and an excerpt is presented in Table 8.4.

It is observed that for all the codes, the coefficient of variation is greater than 20%. This indicates that the demand is stochastic and stationary, for which the Q and R models must be applied. Before determining the QR, you must define associated costs, such as.

The cost of ordering was calculated based on information provided by the company, where it was determined that only one person was available to order products. It is then decided to use formula (1), where it is known that the working hours dedicated to this activity are carried out once a month, with 100% use of the time for the continuous review of inventories and related activities. In addition, it is known that the salary for the operator is \$520/month. The order numbers refer to the number of units stored monthly.

$$\text{Order cost} = \frac{\frac{\text{Staff working hours in charge}}{\text{month}} * (\%\text{time spent}) * \left(\frac{\text{Wages}}{\text{hours}}\right)}{\frac{\text{orders}}{\text{month}}} \tag{8.2}$$

$$\textbf{Order cost} = \frac{\frac{60h}{\text{month}} * (1) * \left(\frac{\$2.70}{\text{hours}}\right)}{\frac{50540}{\text{month}}} = \frac{\$0.003}{\text{orders}}$$

Table 8.4 Extract of the coefficient of variation for disaggregated products

Code	CV
9764	45,11
10,866	56,96
9431	41,41
9394	52,30

On the other hand, the maintenance cost was obtained from the information in Nahmias (2007). This cost is proportional to the number of inventories that are physically present at a point in time. Among those that make up this cost is different aspects; regarding this investigation, the following was included:

- The cost of managing physical space for product storage.
- Taxes.
- Expired products.
- Cost of a different opportunity.

The costs associated with providing the space to store products and the costs related to the opportunity; next, the related costs for storage are calculated (8.3):

$$\text{Storage Cost} = \frac{\frac{\$356}{\text{month}}}{\frac{50540}{\text{month}}} = \frac{\$0.007}{\text{product}} \tag{8.3}$$

On the other hand, the costs of basic services were taken into account, which in this case included the following:

- ($90–$100) electric light
- Internet access ($30–$50)
- Water (approximately $40–$60)
- Phone (approximately $40–$60).

These prices are related to the quantity of this product monthly. Within formula (8.4), these costs were calculated:

$$\textbf{Cost of basic services} = \frac{\frac{\$222}{m^2}}{\frac{50540}{\text{month}}} = \frac{\$0.004}{\text{product}} \tag{8.4}$$

In addition, costs related to taxes were included, especially those associated with the Servicio de Rentas Internas (SRI)—English: Internal Revenue Service—(2019) that must be assumed by the company, which is 12%, according to information provided by it.

Regarding opportunity costs, these are understood as what the company sacrifices when making an economic decision. An annual interest rate managed by Banco Pichincha was used to calculate this cost, which is 4.87%.

Obsolete costs were considered products that have expired and therefore represent losses that the company perceives for the product that is lost due to its sale and investment. Therefore, the company established that the cost incurred by these problems is 1%.

To determine the cost of holding inventory, the following rates must be added to obtain:

$$\boldsymbol{I} = 19.3\%$$

This value indicates the rate of maintaining the inventory of each product being analyzed. To obtain the cost of maintaining this rate, it must be multiplied by the cost of the product being analyzed and replicated for all products considered within this project.

According to the results obtained in Table 8.4, it was then determined that the appropriate model for inventory management is the service level of Q and R. Within Annex 8, you can find the comparison of the coefficient of variation, the type of sales, and the selected model. Said model presents a policy of continuous inventory review. The said model requests a quantity Q when the inventory reaches a reorder point R and a fixed lot size (Nahmias 2007). (For Annex 8, click on the link from the introduction).

This model is mainly used when the demand is handled as stochastic for the continuous review system, which is always accompanied by a continuous review in which service policy must be determined and taken into account by an optimization approach. Therefore, the decision variables within this model are Q and R (Nahmias 2007).

$$\textbf{Reorder point} = \mathrm{R} = \underline{d} * \mathrm{LT} + \mathrm{z}\sqrt{\mathrm{LT} * \sigma_d^2} \tag{8.5}$$

where:

$\underline{\boldsymbol{d}}$ average demand
$\boldsymbol{\sigma_d^2}$ Standard deviation of average demand
LT lead time, which is equal to 1 month

Safety Inventory = IS = z * σ_d^2* $\sqrt{}$LT
Expected number of orders = λ/R.

8.4 Results

8.4.1 Forecasts

The 20 clusters obtained were each tested with the Moving Average, Double Exponential Smoothing, Winters, Arima, and Simple Seasonal models, depending on the test analysis performed previously. The results of the models with the best fit for each cluster are presented in a summary Table in Appendix 9. The MAPE is within the ranges established according to the literature to consider a good model. (For Appendix 9, click on https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing). The results for forecasts are presented for cluster 7.

As seen in Fig. 8.4, according to the qualitative analysis, the sales pattern shows seasonality. The Mann-Kendall and Dickey-Fuller test mentioned above shows that the series shows a trend and is not stationary (Tables 8.5, 8.6 and 8.7).

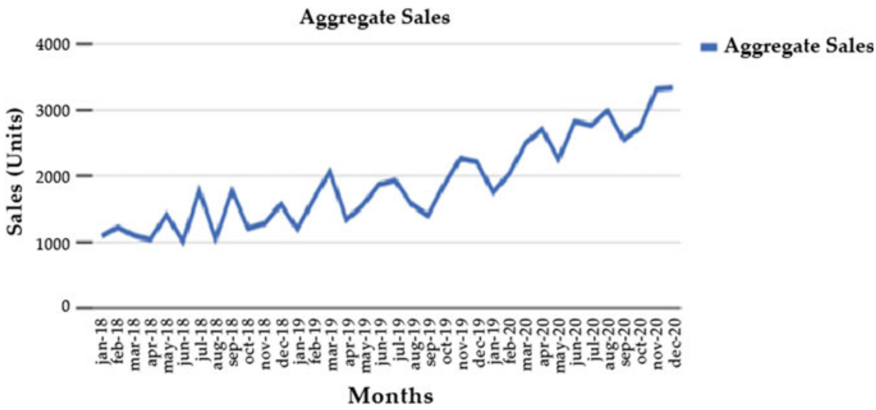

Fig. 8.4 Sales pattern corresponding to cluster 7 (elaborated by the authors)

Table 8.5 Summary of MAPE of Holt-Winters for cluster 7 (Done by the authors)

L	2	3	4	5	6	7	8	9	10	11	12
MAPE	14,03	13,51	11,27	13,79	14,81	14,07	12,63	14,42	15,62	16,75	13,97

Table 8.6 Summary of MAPE of ARIMA for cluster 7 (Done by the authors)

Model	(0,0,0)	(0,0,1)	(0,1,2)	(1,1,0)	(1,0,2)
MAPE	24,96	33,45	21,02	35,12	31,34

Based on the results presented above, the following models were applied to forecasts.

The previous tables show the forecast analysis applied to cluster 7 (Appendices 12, 13 and 14). We choose the most appropriate model according to the MAPE and adjust the model to the real sales data. Then the quality of the prognosis is evaluated with the information presented in Table 8.3, where it is indicated that with a MAPE < 30%, the prognostic model is considered good. The model with the best quality and precision, since it presents a low error concerning the other models, is Holt-Winters, with a Mean Absolute Percentage Error [MAPE] of 11.27%. The model is good. (For the Appendices 12, 13 and 14, click on https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing) (Fig. 8.5).

Table 8.7 Summary of MAPE of double exponential smoothing. Double exponential smoothing for cluster 7 (Done by the authors)

Alpha	Beta	MAPE
0,16	0,023	15,11

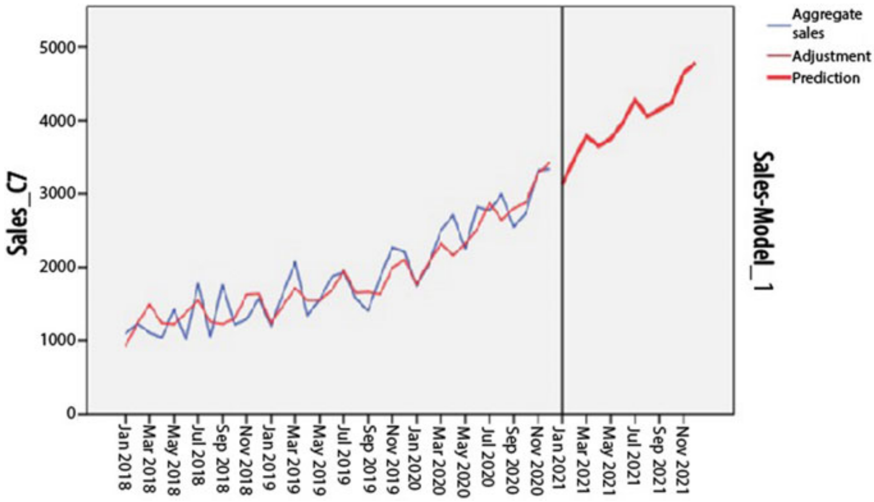

Fig. 8.5 Forecast for Cluster 7 (Holt-Winters) (Done by the authors)

8.4.2 *Inventories*

In Table 8.8, you can find the coefficient of variation of the SKUs with which they work. It can be demonstrated that a coefficient of variation >20 is handled, so it can be concluded that the demand is probabilistic and that the inventory management model that best fits is a periodic service review type 1 of Q, R. Define the term according to what was found in the literature, a review was chosen as periodic because the level of development of the company does not allow for continuous review. As Nahmias (2007) suggests, the application of the type 2 service is feasible in supermarket-type companies with QR readers, with a link between the items sold and those in the warehouse. However, this is not the case for the company in the case study, so it was decided to use a periodic review to maintain inventories. The coefficients of variation for the remaining products are found in Appendix 10. These values were calculated using Minitab software for the 234 predicted products. (Appendix 10 is at https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

Table 8.8 Extract of the results of the Inventory management

	Q/units	Reorder point	Safety stock	Expected number of orders	Total average cost
10,866	336	270	147	23	$1822,91
1168	669	612	88	16	$137,93
9683	335	380	131	23	$330,49

Within the data included in calculating the inventory system, the following is required: average demand, annual demand, lead time, the level of service that will be provided according to the needs of the company, a Z value, the cost of maintaining and the cost of preparing.

The level of service that was determined for the treatment of these products was 95%, with a Z of 1.65. It can be established that a high level of service constitutes a huge effort within companies' supply chains. Therefore, considering several factors, it was determined that 95% constitutes a satisfactory service level to respond to demand and maintain inventory costs. It should be noted that, like the forecasts, inventory management was carried out on category A products due to their utility to the company.

The Table in the appendix presents a sample of the results obtained regarding inventory management. This Table details the reorder point that includes the number of units that must be reached in the product inventory to start ordering a new batch of products. The safety inventory of each product per month is also mentioned. The Q shown corresponds to the number of units ordered in a preparation batch. In addition, the number of orders that are expected to be placed throughout the year, according to each product analyzed, and finally, the cost that the company incurs for the maintenance of the product analyzed. These values are detailed in Appendix 11 for all products within category A. (For Appendix 11, click on https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

8.4.3 BPM

For the implementation of the information system where the research carried out in terms of forecasts and inventories for the products of the supermarket under study is consolidated, Microsoft Excel software was used to create a template through macros for the automation of various workflows in those that comprise forecast and inventory templates. For the operation of this system, use is made only of the sales data in units provided by the management of the "Ecuadorian supermarket". All this was done to facilitate data exchange between the different templates.

The program contains buttons so the user can navigate the different windows. For example, in the forecast category, the user must select the SKU, and then the program suggests the model that should be used according to the previous study. However, forecasts can be made with any other models within ARIMA: ARIMA, Double Exponential Smoothing (Holt), Additive Winters, Simple Moving Average, and seasonal average. Sales data can be entered up to the year 2050. For a better visualization of the behavior of the predicted data series, the program produces a graph showing how the different factors are configured through the years (periods): stationarity, seasonality, and trend, according to each case.

For the inventory template, the information entered on the sales made is consolidated so that the stock is automatically updated, and the user has evidence of the current stocks of the products and the respective costs that they imply. Finally, in

Appendices 35, 36, 37, and 38, the images of the three main windows are attached: graphical visualization of sales, calculation of forecasts through different methods, and inventory calculation. These are part of this study's ERP designed for calculating forecasts and inventories. To access an explanatory video of the information system's creation and a user manual, go to Appendix 34. (See appendices 34,35, 36, 37 and 38 at https://drive.google.com/drive/folders/1H3G5KLyPuRaEBF-I-eRaBnWVtUd5mbA4?usp=sharing).

8.5 Conclusions and Recommendations

8.5.1 Conclusions

Based on the information provided by the company, it was determined that the main problems are within the company due to factors such as expired products, a lack of stock, non-existent products, and long payment lines. For this problem, two methodologies were combined to analyze forecasts and inventories. From the ABC classification of the products, we only worked with the data located within category A, which responded to a total of 234 products, representing 80% of the total profit in supermarket sales. Of the 234 products, for 120 of them, the data for the years 2018, 2019, and 2020 were considered because the variability due to COVID-19 during 2020 was null in terms of sales of these products. On the contrary, for the remaining 114 products, the year 2020 was excluded from their study because, during that year, due to the presence of the pandemic, these products presented high sales peaks and caused high variability concerning the two previous years. Products in this group include rice, grains, cleaning products, eggs, bread, and milk.

Regarding the analysis that implied the study and application of different forecast models, 20 clusters were obtained. With each of these, the following forecast models were worked on: moving average, double exponential smoothing, winters, ARIMA, and simple seasonal. Finally, it was selected as the optimal model for the respective cluster according to the lowest percentage of ASM. Therefore, the model most used in the clusters was "Simple Seasonal," which was applied to 7 of the 20 clusters. It is also worth mentioning that the statistical tests also showed that the time series of the clusters mostly had a positive trend, which was obtained thanks to the "Mann-Kendall" test.

Because a type of stochastic sale was determined, that is, it is random and variable in time, most of the inventories were worked with the Q and R models. This was determined through the "Coefficient of Variation" (greater than 20%) obtained for each type A product. In addition, the type II service level was used due to the commercial category to which the supermarket belongs, thus obtaining a satisfactory service rate of 95%.

Using unsupervised learning, the grouping and classification of category A items were practiced according to the behavior of the time series. Of course, it is also recommended that each of the clusters generated by the program be studied by an expert to see if the different groupings make sense or not. In the present case, the products were grouped according to sales behavior. For example, cluster 7 includes candy-type products that the supermarket generally delivers to its wholesale customers.

For the analysis of forecasts and inventories, only sales information was available. Therefore, we work based on the behavior pattern. For the forecasts, after the ABC classification, they were added according to the period, that is, month by month, as mentioned above.

The optimal forecast model was evaluated by the error percentage indicated by the MAPE. To be validated as good, it must be between 20 and 30% to be considered moderate; however, if the percentage reaches a percentage higher than 30%, it is considered a poor model according to the cited literature. In addition, the lack of literature associated with the handling and classifying of products in supermarkets was evidenced.

Therefore, the present investigation can serve as a reference point for future related studies. As a result, a proposal for the classification, rotation, and correct handling of products, as well as the implementation of a control system model (ERP) that was designed based on the needs of the supermarket under study but that can be adapted to other cases.

8.5.2 Recommendations

The joint analysis of the demand data is important to appreciate the percentage of demanded products that remain unsatisfied due to the lack of availability within the commercial premises.

Share and educate the other supermarket members using the EXCEL template generated for the present case study since it is considered relevant that the information consolidated within the program is shared across the different departments so as not to leave information loose and can be constantly updated.

8.5.3 Limitations

This research has the limitation that variability and fluctuations in the sales behavior of some products occur due to the COVID-19 pandemic, where many products were in massive demand. Then it cannot be guaranteed that the forecasting models obtained in the present study for specific products will remain the same in subsequent years because the situation in the country is not yet stable.

The historical data provided by the company does not reflect 100% accuracy in the forecasts made because there are only three years of historical data. As the company grows, these can change in a couple of years. For a forecast to indicate high reliability, the time of the historical data should be longer.

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Chapter 9
Analysis of Failure Modes and Port Disruptions in Port Terminal Operations: A Case Study in the Port Area of Barranquilla, Colombia

Fernando González-Solano, Gina Galindo-Pacheco, and Daniel Romero-Rodríguez

Abstract Port operations experience high uncertainty in supply chains, and their importance in trade is significant since the sea carries out most global trade. Any disruptive event that strikes port facilities can affect local and national economies. This research studies a series of port disruptions with their respective failure modes based on a case study in the port of Barranquilla, Colombia. Then, the importance of these port disruptions is evaluated through a relational analysis of variables using the ISM methodology. Finally, we discuss real disruptive events that have occurred in Latin American ports. As a result, we find that hurricanes and terrorist acts are the events that have the greatest potential to affect port activities, and transportation failure is the most frequent failure type.

Keywords Port failure modes · Port disruptions · Port terminal operation · ISM

9.1 Introduction

Growing global challenges that pose disruptive events with the potential to affect all types of infrastructure generate the need to study the different modes in which a system can fail. One of the most relevant systems that sustain international commerce is port terminals. These are critical elements in global supply chains since they are the inbound and outbound gateway for national trade. In fact, there are estimates

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that 90% of world trade is transported by sea (Salas et al. 2018), and according to UNCTAD (2018), trade through ports doubled between 2000 and 2017.

Most Supply Chains (SCs) involve ports in their operations (John et al. 2016; Hossain et al. 2020). Paradoxically, ports are considered among the most important causes of uncertainty in SCs (Sanchez-Rodrigues et al. 2010). Moreover, some of the global challenges or risks that the world could face in the short term, as defined by the World Economic Forum, have been affecting port operations in the past and have the potential to affect them in the future, which increases the uncertainty in port operations. Among such challenges are infectious diseases, climate change, cybersecurity failures, digital power concentration, terrorist attacks, and human damage to the environment (Forum 2021).

Hurricanes are among the events that have affected the most port operations in recent years: the port of Galveston in Houston was affected by Hurricane Harvey in 2017; the port of Dampier in Australia was affected by Tropical Cyclone Veronica in 2019; the port of New York/New Jersey in the U.S.A. was affected during Hurricane Sandy in 2012, and the port of Haimen in China was affected by Typhoon Lekima in 2019. All these ports took approximately ten days to return to their normal operation conditions (Verschuur et al. 2020). In addition, a problem in the navigation of a container ship in the Suez Canal in March 2021 blocked this logistic passage for six days, causing the congestion of approximately 400 vessels at both ends of the Suez Canal (Uranga 2021). The economic losses accounted for approximately US$54 billion (Lee and Wong 2021). The COVID-19 pandemic also affected port operations due to the closures of port trade routes. Also, when trade restrictions were lifted, port congestion increased. These events' economic effects significantly impacted container freight costs, which increased 100% between the beginning and the end of 2021 (Drewry 2021). As can be seen, these extreme events have the potential to cause important port disruptions.

A port disruption is an event that blocks the movement of goods through the port facility, lasting for one or more days (Thekdi and Santos 2016). A port disruption may generate different failure modes in which a port could partially or interrupt its operations. Failure modes are, at this moment, defined as the loss of key capabilities of a system, which reduces or eliminates the ability of the system to perform its objective (Berle et al. 2011).

Cao and Lam (2018) state that a seaport catastrophe can cause severe physical damage to the loading and unloading docks, gantry, and warehouse cranes, which can cause long-term port downtime to ripple throughout the supply chains and industrial clusters that are served by the port. Partial or total closure of a port could result in cargo congestion, vessel queues, backlogs in storage loading and unloading facilities or disruptions in the manufacturing of different goods affecting different local, regional, and global supply chains with severe economic consequences (Wilson 2007; Thekdi and Santos 2016; Sanchez-Rodrigues et al. 2010).

The impact of port disruptions depends on the severity of the disruptions. For example, strikes at ports could result in a breach of contractual obligations; ship collisions at port facilities could cause tanker spills and subsequent port closure, and improper handling of cargo or equipment could lead to productivity and efficiency issues (Loh and Thai 2015).

According to Berle et al. (2011), studying failure modes in port operations is essential to define a Port Business Continuity Plan (PBCP). To prepare the route for the development of a PBCP, it is necessary to carry out a complete analysis of the failure modes and their relationship with port disruptions. This will allow the establishment of the most critical failure modes and port disruptions.

A relational analysis between port disruptions and their respective failure modes is complex because of three types of relationships. First, there are interactions between port disruptions (Hossain et al. 2020). For example, the occurrence of a hurricane could lead to flooding or cargo damage; a terrorist attack could cause a fuel spill or an explosion in the port infrastructure; likewise, an explosion could cause a fire in the port facilities or a fuel spill. Second, there are also interactions between the failure modes. For example, a failure in human resources could generate a failure in operations due to a lack of operational personnel; also, a failure mode in the financial flow could cause a failure in supplies due to a lack of resources to finance the purchase of fuels for machinery operations.

Finally, the third type of relationship is between disruptions and failure modes. For example, a hurricane could generate several failure modes at the same time, failures in supplies, transportation, and communications. Hence, the main objective of this research is to analyze failure modes in port operations and port disruptions with their interactions, based on a particular case of an inland water port located in the city of Barranquilla, Colombia. The purpose is to present a hierarchical relational scheme between port disruptions and their respective failure modes using the ISM (Interpretative Structural Modeling), and it represents a novel focus on the problem.

In the remainder of this book chapter, we present a literature review about port disruptions, failure modes and relational variables. Then, we develop a case study with relevant information about the characteristics of the port environment, port disruptions, and failure modes generated by each disruption. We discuss a historical analysis of failure modes and disruptions in LATAM ports. Finally, we present the relational modeling between the disruptions and failure modes to establish their hierarchy and importance.

9.2 Literature Review

This literature review is divided into two topics: port disruptions and failure modes in port operations.

9.2.1 Port Disruptions

This section discusses the literature on the types of port disruptions and the approaches used to analyze them.

Port disruptions can be categorized into two groups: (1) internal and (2) external. Internal disruptions occur inside the port terminals, berthing docks, inland facilities, and land or rail entry and exit gates. The internal events that were found in the literature are machine breakdown (Darbra and Casal 2004; Roshamida et al. 2016; Junaid et al. 2020), Explosions (Yu et al. 2021), IT system failure, Fire (Cao and Lam 2018; Hosseini and Barker 2016) and Cargo damage (Hossain et al. 2020). On the other hand, external events originate outside the port facilities, such as in the sea, river, land, rail access channels, port city, connected supply chains, and governmental restrictions. The external events that were detected in the literature are natural disasters (Darbra and Casal 2004; Hossain et al. 2020; Hosseini and Barker 2016; Lam and Su 2015; Cao and Lam 2018; Junaid et al. 2020), terrorism (Greenberg et al. 2006), ship collision (Lee and Wong 2021; Loh and Thai 2016; Roshamida et al. 2016), Health issues (Roshamida et al. 2016) fuel spills (Lam and Su 2015), military conflict (Nazarenko and Smirnova 2021), cyber-attack, stakeholder insolvency (Hossain et al. 2020) and government restrictions (Junaid et al. 2020; Hossain et al. 2020; Roshamida et al. 2016).

Loh et al. (2017) identify a set of port disruptions with associated probabilities and consequences using a risk matrix approach. They identify port disruptions with 225 surveys, where they use a scale from 1 to 5 to assess such probabilities and consequences. Roshamida et al. (2016) also use a risk matrix approach with information from an expert. In risk matrixes, authors often use subjective information tools, such as rating scales or experts' opinions, instead of objective information (e.g., historical data), for computing probabilities and assessing the impacts of port disruptions. In the case of applying expert judgment, it is recommended to gather the opinion of several experts and to use an average valuation table to improve the validity of the analysis.

In contrast, some authors, such as Lam and Su (2015), use objective data to assess port disruptions' impacts and probabilities. They use ten years of historical data from Asian ports to measure the probability and consequences of port disruptions. The most relevant port disruptions in Asian ports identified by Lam and Su (2015) are accidents, port strikes and natural disasters. Zhao et al. (2020) comprehensively analyzed Agri-food Supply Chain (AFSC) risks by identifying various risk factors, structuring interrelationships among them, and distinguishing key risks using ISM and fuzzy MICMAC analysis. Surya et al. (2017) categorized risk in a perishable food supply chain to make a driving power and dependence power chart of risk categories. Also, they performed a hierarchy of risks to identify those most independent and those most dependent on other variables.

9.2.2 Failure Modes

Failure modes are defined as the loss of critical functions and capabilities that could reduce or eliminate the ability of the system to perform its mission. Failure modes in port operations relate to supply, financial flows, transportation, communication, internal operations, and human resources (Berle et al. 2011). Supply failure is the lack of supplies to maintain the operation, such as electricity, containers, fuel, trucks, ships, and surveillance. Financial flow failure is the lack of financial resources to maintain operations and invest in infrastructure expansion. Transportation failures relate to problems associated with closures at the port entrance and port exits, truck congestion on access roads, and accessibility problems in navigable channels. Communication failures can be understood as the lack of communication systems, such as failures in systems due to cyber-attacks, data breaches, damage to systems infrastructure, failures in the internet access, in control towers, in radio frequency of ships and ports, and data exchange applications (WhatsApp, telegram, emails), among others. Internal operations failures relate to positioning, vessel berthing, vessel departure, container placement, bulk storage, and general cargo; problems in the movement of cargo through the port at loading, unloading and clearance; and problems caused by cargo violation due to narcotics theft, smuggling, and improper handling. Human resources failure is a lack of human resources essential to the operation, such as failures due to deaths, diseases, epidemics, pandemics, massive brain drain, human error, and lack of access of workers to the port, among others.

In the literature, Berle et al. (2011) is the only article that addresses port disruption and failure modes. A related paper given by Ardila-Rueda et al. (2014) identify the following failure modes: supply, demand, transportation, facilities, communication systems and cargo violations. Ports failure modes identified by Berle et al. (2011) are the same as those reported by Ardila-Rueda et al. (2014) for SCs, except for failures related to demand and facilities, which appear in Ardila-Rueda et al. (2014), but which are not included in Berle et al. (2011). Therefore, it is reasonable to include both demand and facility failures in port settings. Demand failure relates to operational shutdown due to a drop in demand for the port's services. Examples of demand failures come from states of emergency due to riots, quarantine due to pandemics or epidemics, or bankruptcy of customers, among others. In the facility, failures may be associated with fires, chemical spills, crimes in the building area, protests, riots, drug trafficking, and terrorism, among others.

Moreover, to these eight failure modes, it is worth adding a ninth failure mode related to legal issues. Ports must comply with legal regulations, which, in the case being violated, may cause eventual disruptions in the port operations. Some failures related to legal issues are loss of commercial exploitation licenses and lack of compliance with maritime and port protection decrees, among others.

9.3 Case Study

This section presents a brief overview of port disruptions and failure modes in ports in Latin America (Latam). Then, it focuses on ports in Colombia. Finally, it analyzes in depth the port of Barranquilla, Colombia, using a combination of ISM and MICMAC (cross-impact matrix multiplication applied to classification) to derive conclusions regarding the relationships among port disruptions and failure modes for our case study.

It is important to remark that failures in port operations are caused by several disruptive events, which are sometimes interrelated. Moreover, failure modes are also interrelated, one with the other. For example, a transportation failure may be related to road closures, which could cause port operations to come to a complete standstill. Thus, a failure in transportation could lead to a failure in operations. Also, consider that a failure in financial flow could lead to defaults on payments to port operators and failing operations.

In Latam, ports have been affected by several types of failure modes in recent years. Among those that stand out the most, we can highlight the following:

- Valparaiso Port, Chile, December 2018. A failure related to human resources occurred during a worker's strike, which subsequently caused a failure in operations since all the ports activities were halted for 35 days (PortalPortuario1 2018).
- Guayaquil Port, Ecuador, October 2019. There were road closures due to protests connected to the national strike. Consequently, the cargo mobilized in the port was partially reduced for 11 days. In this case, a failure in transportation generated a stop in operations (PortalPortuario2 2019).
- Gran Rosario Port, Argentina, February 2018. Affectation in ports due to transporters' stoppages occurred. Nearly 70% of grain and cereal shipments were not received (PortalPortuario3 2019).
- Penco Port, Chile, Junio, 2016. A workers' strike caused 12 days of stoppage in operations due to differences in salary readjustment material. A human resources failure was generated, causing a stop in operations (PortalPortuario4 2016).
- Bio Bio Port, Chile, April 2020. Total port closures for approx. Four days due to tornado warning. Operations were disrupted due to government restrictions (Carrasco 2020).
- Santo Domingo Port, Dominican Republic, September 2017. The port closed for three days due to the passage of Hurricane Maria. In this case, it was observed failure in transportation and, consequently, a stop in operations (PortalPortuario5 2017).
- Callao Port, Peru, April 2022. The central government restricted the transit of people for less than 24 h in Lima, Peru, due to a national strike. As a result, the port reduced its operations to 50%. A transport failure was generated, and this caused a stop in the operations (MundoMaritimo2 2016).

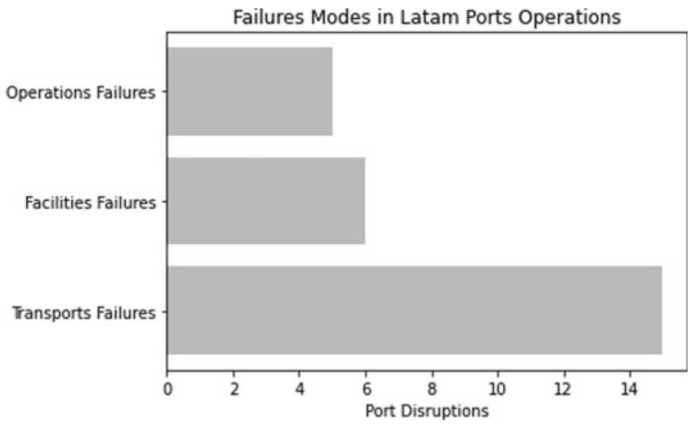

Fig. 9.1 Failure modes in Latam ports operations

The most common failure in port operations in Latam is transport failure, with 15 events in the last six years. Furthermore, the failures with the highest frequency are failures in facilities with six events and failures in internal operations with five events, as shown in Fig. 9.1. Although the sample size of disruptive events in Latam operations is not large, it shows a clear trend toward transport failure mode. Furthermore, from the situations presented above, it is possible to observe that failures in transportation are the most frequent in Latam ports, with a subsequent stop in operations.

In the case of Colombia, there are four major ports, Buenaventura, Cartagena, Barranquilla, and Santa Marta. In Cartagena and Santa Marta, no historical events would have threatened the continuity of operations, which differs from the situation in Buenaventura and Barranquilla. The first has been affected by the social situation of the geographical area where it is located, in which strikes and disturbances often occur. In 2021, a national strike directly affected the Buenaventura port, during which more than 400 thousand tons were immobilized and caused several shipping companies to temporarily cease their calls at the port (MundoMaritimo1 2021). This social situation generated two failure modes: transportation due to the blockade of the access roads to the port and operations due to the impossibility of exporting the merchandise retained at the port.

In the case of Barranquilla, the only port in Colombia with a navigable channel in a river, the port continuously suffers from sedimentation problems in the river, as mentioned before. Seven ships have been running aground in the navigable channel in the last two years, which caused operations to be shut down and vessels diverted for some periods. Only in 2022, the following events occurred:

- Bulk carriers with 14,974 tons of cargo ran aground before entering the navigable channel in May 2022. This caused a 4-h closure of operations in the port area of Barranquilla (Caracol 2022).

- A vessel loaded with coke coal ran aground in the navigable channel when leaving the port of Barranquilla. It was loaded with 21,000 tons in July 2022, generating a failure in operations of more than 10 h (Hernandez 2022).

In all these cases, we mainly have two failure modes: transportation and operations. Failures in transportation occur since a grounding blocks the water access to the port, which, in turn, causes stoppages in the operations.

As mentioned before, our case study focuses on one port in Barranquilla. The analysis, at this moment implemented, follows a methodology for studying failure modes and their relationships. Each step of our methodology pursues an objective, as shown below:

Step 1: Identify the most relevant disruptions in the port.
Step 2: Identify the relationships between port disruptions and failure modes in port operations using the ISM methodology.

9.3.1 Most Relevant Disruptions in the Port Under Study

The port of Barranquilla specializes in general and bulk cargo. This is an inland water port whose access channel is the Magdalena River, with a connection to the Caribbean Sea. One of the main problems of this water affluent is the high sedimentation levels. The Magdalena River has two characteristics that have generated problems: its strong flow and the accumulation of sediments. The average annual flow is 7,100 m^3/s, depending on the time of year. There is a low flow from January to March, and between October and December, the flow is high due to heavy rains during this time of year. In the case of sedimentation, there is a total sediment of 200 million tons/year. The Magdalena River transports, on average, 0.9 kg of sediment for each cubic meter of water, which places it eighth in the world in terms of the amount of waste transported (Otero 2012). These two situations generate risks in the ports with this river as an access channel. On the one hand, high flows can cause flooding of port facilities, and on the other, the high sedimentation can lead to the grounding of vessels and closures in the access channel.

The selected disruptions were categorized into two groups, external and internal (Table 9.1). The external disruptions are those in which the port does not have any interference to prevent them from occurring, and the internal disruptions are those in which the port does have mechanisms to prevent them.

The nine failure modes discussed in Sect. 2.2 are used to analyze this case study. In summary, these nine failure modes relate to (1) supply, (2) financial flows, (3) transport, (4) communication systems, (5) operations, (6) human resources, (7) facilities, (8) demand, and (9) legal issues.

Table 9.1 Port disruption in the case study

COD	External port disruptions	COD	Internal port disruptions
D1	Hurricane	D6	Strike workers
D2	Heavy rains	D11	Breakdown machinery
D3	Floods	D12	Explosion
D4	Terrorisms	D13	IT system breakdowns
D5	Disturbance in the port city	D14	Oil spill
D7	Transport workers protest	D15	Fire
D8	Grounding of a vessel	D16	Health issues
D9	Dock collision	D17	Forecast error
D10	Vessel's collisions	D21	Narco-trafficking
D18	Military conflict	D22	Stowaway
D19	Cyberattack		
D20	Governmental restrictions		

9.3.2 Relationships Between Port Disruptions and Failure Modes in Port Operations

The ISM methodology was applied to identify the relationships between port disruptions and failure modes. In this regard, it is necessary to establish the type of relationships between any pair of events as follows.

V: Event *i* will help to achieve event *j*.
A: Event *j* will help to achieve event *i*.
X: Events *i* and *j* will help to achieve each other.
O: Event *i* and *j* are unrelated.

Annex 9.3 presents the first matrix of the ISM methodology, where three-way relationships are evaluated: (i) port disruptions *i* with port disruptions *j*, (ii) port disruptions *i* to failure modes *j*, and (iii) failure modes *i* to failure modes *j*. To better understand Annex 9.3, let us consider the analysis for hurricanes. Even though hurricanes are not frequent in the port area under study (in fact, there is no historical record of any hurricane in this area to date), they are an increasingly latent threat since, in recent years, the trajectory of various cyclonic phenomena, such as storms or hurricanes, is getting closer to the northern region of Colombia. Therefore, it is necessary to consider this disruptive event in the ports event map. Typically, this type of event generates heavy rains and flooding. Also, it can cause collisions among the ships docked at the port. Also, a hurricane could damage the machinery for loading and unloading containers, bulk, or general cargo. It could also generate oil spills and, ultimately, produce several types of failures: in the supply of electricity and oil to carry out operations; in transportation, due to damages in ports access roads; in communications, due to problems in the ports servers; in operations, due to the forced closure of operations caused by heavy rains and high wind speeds; in facilities, because a devastating hurricane could totally or partially destroy port facilities; and finally in demand, since under hurricane weather conditions, customers are not likely to move their cargo to the port. The relationships between a hurricane and these events are recorded in Annex 9.3.

For further illustration, let us discuss the relationship between terrorism and the other events in Annex 9.3. In the case of terrorist attacks, the most studied scenarios on port facilities include terrorists hijacking a ship and crashing into the port facility or crashing it into another ship, damage to port machinery, explosions and fire, damage to port servers and fuel spillage. The failure modes that a terrorist act can generally relate to supply since containers for the operations could be destroyed; transport, since the access channels could be destroyed; communication systems, if telecommunication equipment is damaged; and human resources, if workers are injured. Notice that the only relationship of X type in Annex 9.3 is between explosions and fire.

Following the initial evaluation using the ISM methodology, where the direct relationships between variables are assigned, an assessment of the indirect relationships between variables is carried out. For example, a hurricane does not directly generate a fire, but it could directly generate an oil spill, which could generate a fire. Therefore, a hurricane could indirectly generate a fire, i.e., if A affects B, and B affects C, then A indirectly affects C. Annex 9.4 shows the analysis of the indirect relationships between the model's variables. In this methodology step, the number of relationships increases because direct and indirect relationships are combined. A value of 1 means a relationship between variables i and j, whereas a value of 0 means that there is neither a direct nor indirect relationship between them. There may be indirect relationships between two variables that involve more than two levels, e.g., A affects B, B affects C, and C affects D; therefore, A would affect D. However, for this study, we only consider two-level indirect relationships.

ISM has two main objectives, (1) to determine the driving power that a variable has over the others and to identify which variables are the most influenced in the entire system, and (2) to determine the dependence power of the variables to establish which are the most influential in the system. Table 9.2 shows the driving and dependence power of port disruptions and failure modes. Hurricanes have an impact percentage of 61% over all the other disruptions and failure modes. The hurricane has a driving power of 19 since it affects 19 of the 31 variables in the model among port disruptions and failure modes. Moreover, a terrorist event would devastate the port facility since it would affect all the failure modes being analyzed. The port disruptions that have the greatest power over the others are, in addition to hurricanes, terrorism, explosions, fire, and cyber-attack. In other words, these port disruptions have the greatest impact on the entire system. This indicates that the port terminal should focus on developing contingency and mitigation plans to absorb the impact and restore the system should

Table 9.2 Driving and dependence power of port disruptions (DP1 = Driving Power; DP2 = Dependence Power)

COD	Variable	DP1	DP2	COD	Variable	DP1	DP2
D1	Hurricane	19	1	D17	Forecast error	8	1
D2	Heavy rains	11	2	D18	Military conflict	11	1
D3	Floods	11	3	D19	Cyberattack	10	8
D4	Terrorisms	17	1	D20	Governmental restrictions	9	1
D5	Disturbance in port city	10	3	D21	Narco-trafficking	4	2
D6	Strike workers	8	5	D22	Stowaway	4	1
D7	Transport workers protest	8	1	F1	Supply failures	1	19
D8	Grounding of a vessel	6	4	F2	Financial flow failures	6	16
D9	Dock collision	8	3	F3	Transport failures	1	20
D10	Vessel's collisions	7	3	F4	Communication failures	3	14
D11	Breakdown machinery	7	8	F5	Operations failures	1	20
D12	Explosion	12	10	F6	Loss of human resources	6	12
D13	IT system breakdowns	8	10	F7	Facility failures	1	13
D14	Oil spill	10	14	F8	Demand failures	1	7
D15	Fire	12	10	F9	Legal issues	4	19
D16	Health issues	9	1				

one of these disruptions occur. Likewise, the port disruptions most dependent on the occurrence of others are oil spills, explosions, fires, cyber-attack, and machine breakdowns. This implies that these disruptions could be avoided by working on the causes of the disruptions that precede them.

To better understand the relationships between port disruptions and their respective failure modes, 10 disruptions were selected among the 23 available and the 9 failure modes. A directed graph was constructed in Fig. 9.2. Failure modes 1 (supply), 3 0d, dñr{3 lrllAQWIW Itransportation), and 5 (operations) are the most critical because they are the most likely to occur in the port terminal. The port should develop resilience scenarios assuming the occurrence of any of these failures to evaluate the implementation of resilience strategies based on the most likely failure scenarios. In addition, disruptions 1 (hurricanes), 4 (terrorism), and 8 (forecast errors) are not dependent on others, but they have the potential to trigger other disruptions.

As can be seen, the proposed methodology has delivered a relational analysis between disruptions and failure modes that can serve as a basis for the development of resilience scenarios and the design of strategies to contain and mitigate the impact of different disruptive events, depending on the failure modes. In addition, it is important to highlight the disruption of vessel grounding. Although it does not stand out among the main ones in the relational graph, in the daily operation of the port of Barranquilla, it is highly relevant since when a vessel runs aground at the entrance or in the path of the navigable channel, the access of incoming vessels to the port area is completely blocked. This situation causes a failure in transportation, which

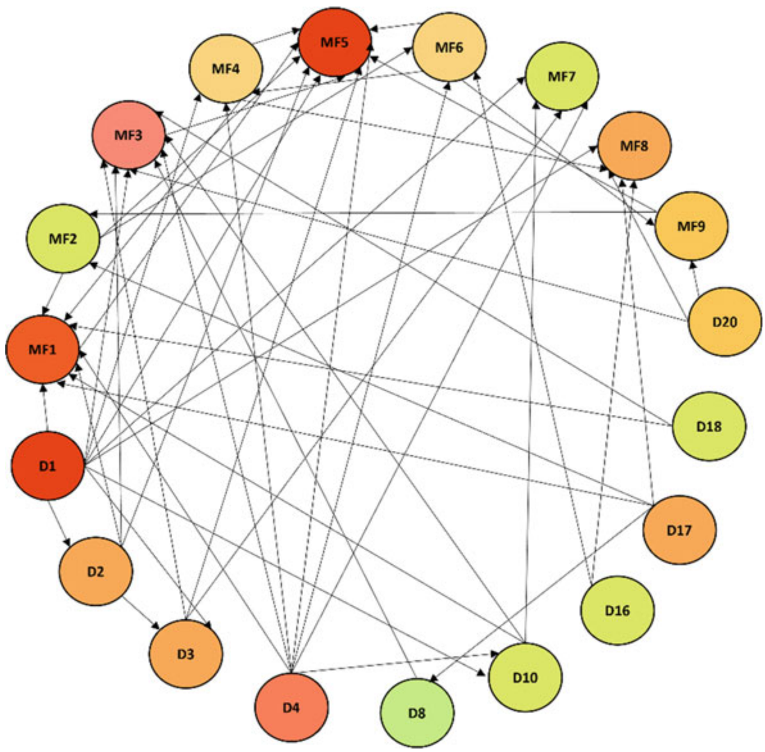

Fig. 9.2 Relation between the most relevant port disruption and failure modes

subsequently causes a failure in operations. Moreover, failure in operations could cause a subsequent failure in the financial flows, depending on the number of days that the port area has been inoperative. Usually, groundings occur in this navigable channel due to the high sedimentation of the Magdalena River since this area is the mouth of this water tributary, which is the largest in the country and flows through 22 of the 32 departments of Colombia.

After applying ISM to this case study, we conducted an analysis based on the MICMAC methodology. In this methodology, all disruptions and failure modes are grouped into four categories in the same matrix. In Fig. 9.3, we can see the results of applying the MICMAC methodology. Each category involves the following:

- Category I: weak dependence power and weak driving power. Port disruptions and failure modes of this category are called autonomous elements.
- Category II: strong dependence power and weak driving power. Port disruptions and failure modes of this category are called dependent elements.
- Category III: strong dependence power and strong driving power. Port disruptions and failure modes of this category are called linkage elements.

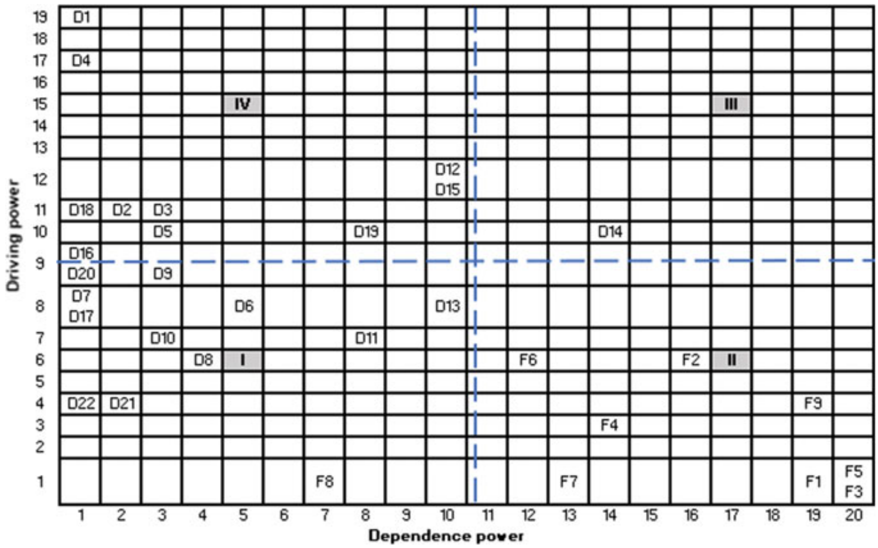

Fig. 9.3 MICMAC methodology

- Category II: weak dependence power and strong driving power. Port disruptions and failure modes of this category are called independent elements.

The operational and transport failures are the failure modes most dependent on the other failure modes and all port disruptions. A total of 20 of the 31 variables are related to them. These should be the priority failure modes in designing resilience scenarios with their contingency and mitigation strategies. At a medium priority level, we find failures related to legal issues and supply. Their priority level is given because their occurrence depends on the occurrence of many other variables, so it is also recommended to develop resilience strategies for these failure modes. According to the methodology, these variables are known as dependent variables.

Moreover, we have group IV, where there are the independent variables, among which hurricanes and terrorist acts stand out because they have a high impact on the other variables. However, they are not affected by any other. This means that they are events with a low probability of occurrence but a high impact on the whole system. In category III, we have linkage variables. Oil spill falls into this category because it balances the power to influence others and their influence. They are linkage events because their probability of occurrence is medium–high, and, at the same time, they have a medium level of consequences on the other variables.

9.4 Conclusions

In the research development, three objectives were defined as part of the case study analysis, the Port of Barranquilla in Colombia. Concerning the first objective, which focuses on identifying types of port disruption, 22 port disruptions were identified. Likewise, based on the literature, it was possible to identify nine failure modes that apply to our case study. Next, a relational analysis was performed between the variables identified in the first objective. Three relationships were evaluated: among disruptions, between disruptions and failure modes, and failure modes. According to our findings, transportation, operations, and supply failures are the most dependent failure modes, and the events considered independent are hurricanes and terrorist events.

Concerning failure modes that have affected ports in LATAM in recent years, it stands out that the transport failure mode is the most common. Transport failures in Latin America are typically caused by citizen protests and transport stoppages that block access roads to ports. This is due to generalized social problems throughout the continent. In the same way, workers' strikes have also been detected as a source of human resources failures, which subsequently cause a failure in operations.

Identifying the most relevant failure modes is vital to define failure scenarios. Such scenarios are keys to designing effective resilience strategies that can absorb the impact of a disruption and contribute to the restoration of operations on time. It is more efficient to define resilience strategies based on failure modes than on disruptions because a strategy focused on disruptions only serves the effects of that disruption. However, multiple disruptions can cause a failure, so when we design resilience scenarios based on failures, we can cover the consequences of most disruptions.

Annex

See Annexes 9.3 and 9.4.

Annex 9.3 Port disruption evaluation with ISM

COD	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	F1	F2	F3	F4	F5	F6	F7	F8	F9
D1		V	V	O	O	O	O	O	V	V	V	O	V	V	O	O	O	O	O	O	O	O	V	O	V	V	V	O	V	V	O
D2			V	O	O	O	O	O	O	O	O	O	V	O	O	O	O	O	O	O	O	O	V	O	V	O	V	O	O	O	O
D3				O	O	O	O	O	O	O	V	O	V	O	O	O	O	O	O	O	O	O	V	O	V	O	V	O	V	O	O
D4					O	O	O	O	V	V	V	V	V	V	V	O	O	O	O	O	O	O	V	O	V	V	V	V	V	O	O
D5						V	A	O	O	O	O	O	O	O	O	O	O	O	O	A	O	O	O	O	V	O	O	V	V	V	O
D6							O	O	O	O	V	O	O	O	O	A	O	O	O	O	O	O	O	O	V	O	O	V	O	O	O
D7								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	V	O	V	O	O	O	O	O	O
D8									O	O	O	O	O	V	O	O	A	O	A	O	O	O	O	O	V	O	O	O	O	O	O
D9										O	O	O	O	V	O	O	O	O	O	O	O	O	V	O	V	O	O	O	V	O	O
D10											O	O	O	V	O	O	O	O	O	O	O	O	V	O	V	O	O	O	O	O	O
D11												O	O	V	O	O	O	O	O	O	O	O	O	O	O	O	V	O	O	O	O
D12													V	X	X	O	O	A	O	O	O	O	O	O	V	O	V	O	V	O	V
D13														O	A	O	O	O	X	O	O	O	O	V	O	V	V	O	O	O	O
D14															V	O	O	O	O	O	O	O	O	O	V	O	O	O	O	O	V
D15																O	O	O	O	O	O	O	V	O	O	O	V	O	V	O	O
D16																	O	O	O	O	O	O	O	O	O	O	O	V	O	V	O
D17																		O	O	O	O	O	V	V	O	O	O	O	O	V	O
D18																			O	O	V	O	V	O	V	O	O	O	O	O	O
D19																				O	O	O	O	V	O	V	V	O	O	O	O
D20																					O	O	O	O	V	O	O	O	O	V	V
D21																						O	O	O	O	O	V	O	O	O	V

(continued)

Annex 9.3 (continued)

COD	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	F1	F2	F3	F4	F5	F6	F7	F8	F9
D22																							O	O	O	O	V	O	O	O	V
F1																								A	O	A	O	O	O	O	O
F2																									O	O	O	V	O	O	A
F3																										O	O	O	O	O	O
F4																											V	A	O	O	O
F5																												A	O	O	O
F6																													O	O	V
F7																														O	O
F8																															O
F9																															

Annex 9.4 Analysis of the indirect relationships between the model's variables

COD	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	F1	F2	F3	F4	F5	F6	F7	F8	F9
D1	1	1	1						1	1	1	1	1	1	1				1				1	1	1	1	1		1	1	1
D2		1	1								1		1						1				1	1	1	1	1		1		
D3			1								1		1	1					1				1	1	1	1	1		1		
D4				1					1	1	1	1	1	1	1				1				1	1	1	1	1	1	1		1
D5					1	1					1														1	1	1	1	1	1	1
D6						1					1			1											1	1	1	1			1
D7					1	1	1																1		1			1	1	1	
D8								1				1		1	1										1						1
D9									1			1		1	1								1		1				1		1
D10										1		1		1	1								1		1						1
D11											1	1		1	1										1		1				1
D12												1	1	1	1				1				1	1	1	1	1		1		1
D13								1					1						1				1	1		1	1	1			
D14												1	1	1	1								1	1	1		1		1		1
D15												1	1	1	1				1				1	1	1	1	1		1		1
D16						1					1					1									1	1	1	1		1	1
D17								1						1			1						1	1	1			1		1	
D18												1	1	1	1			1			1		1		1		1		1		1
D19								1					1	1					1				1	1	1	1	1	1			
D20					1	1														1				1	1			1	1	1	1
D21																					1			1			1				1

(continued)

Annex 9.4 (continued)

COD	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	F1	F2	F3	F4	F5	F6	F7	F8	F9
D22																						1		1			1				1
F1																							1								
F2																							1	1		1	1	1			1
F3																									1						
F4																							1			1	1				
F5																											1				
F6																							1	1		1	1	1			1
F7																													1		
F8																														1	
F9																							1	1				1			1

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Chapter 10
A Proposal for the Distribution of Medicines and Medical Equipment in Mexico

Lourdes Loza Hernández and Mariana Vargas Sánchez

Abstract The connection among various places in the world is thanks to transport, which generates advantages in areas like economic development, international support in the face of catastrophes, and cultural and knowledge exchange, to mention some. The need to move people and goods locally and internationally determines the control of transportation systems; however, there are uncontrollable external factors. Corona Virus Disease (COVID-19) is a disease that arose in China, and due to its characteristics and the lack of information about the virus, it was difficult to prevent its spread around the world, causing a global pandemic. A fundamental activity for controlling the spread of the virus and medical assistance is the adequate distribution of medicines and medical equipment to hospitals. Mechanisms are currently being sought in Mexico to efficiently carry out this public sector activity. Therefore, this work offers to the decision-makers in the health sector a proposal for the distribution of medicines and medical equipment to the different hospitals in Mexico. The proposal presented applies quantitative methods, specifically allocation methods and the Clarke and Wright heuristic, to support the results. The proposal offered a viable, effortless, and helpful alternative to personnel involved in distribution activities and recommendations to the practitioners in the health sector and logistic areas.

Keywords Allocation methods · Clarke and wright heuristic algorithm · Distribution goods · Supply chain · Vehicle routing problem · Health sector

10.1 Introduction

The World Health Organization (WHO) reports that the Corona Virus Disease (COVID-19 or SARS-CoV2) outbreak emerged in Wuhan, China, on December 31, 2019. It was named by the International Committee on Taxonomy of Viruses (ICTV) severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (World

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Health Organization, WHO 2020a), and it was declared a pandemic on March 11, 2020 (WHO 2020b).

SARS-CoV2 is a single-stranded RNA virus of the beta coronavirus genus, Coronaviridae family. Some biological characteristics are high transmission rate, prolonged incubation period, asymptomatic carriers or mild symptoms, progression to respiratory distress syndrome in patients, and death, viral shedding after relief of symptoms, environmental transmission, and fomites (Ponce de León et al. 2020).

Medical needs have increased due to the pandemic compared to the needs in normal conditions, so the resources requested by the medical units must be covered to treat the conditions presented by SARS-COV-2 and everyday needs, which are the resources they commonly request in their planning. The Spanish Society of Critical Intensive Medicine and Coronary Units (SEMICYUC) states that the emergence of the pandemic generates an imbalance between clinical needs and the availability of health resources and that the duty to plan, the principle of distributive justice, and the maximization of global benefits must prevail (Grupo de Trabajo de Bioética de la Sociedad Española de Medicina Intensiva, Crítica y Unidades Coronaria (SEMICYUC) 2020).

Medicines for Europe, which represents the generic, biosimilar, and value-added European pharmaceutical industries, consider it important to face the market problems that can be generated by COVID-19 (Medicines for Europe 2020). The problems Medicine for Europe focuses explicitly on are: manufacturers may have difficulties meeting delivery deadlines; distributors could accumulate supplies to fulfill public service obligations or due to different incentives in the market that lead to suboptimal distribution to patients; hospitals and pharmacists often carry out financial reimbursement agreements based on a reference price, however, if there are returns of supplies or greater demand for products ordered, the reference price is modified (Medicines for Europe 2020).

The United States Food and Drug Administration (FDA or USFDA) is a federal agency of the Department of Health and Human Services that proposes a continuous review of the supply chain so that drugs are delivered on time and avoid disruption, considering the likelihood of COVID-19 affecting the supply chain (Food and Drug Administration (FDA) 2020). The severe problems in the distribution of medical equipment during the coronavirus disease have led to the modeling of multi-depot vehicle routing under uncertainty during the COVID-19 pandemic (Nozari et al. 2022). Also, Sanz et al. (2020) give recommendations to working groups and practitioners who must work with critically ill patients; one of those recommendations is to develop a strategic plan for interhospital transport in critical situations establishing a central department to lead and control the critical care units and define an efficient plan for distributing resources (the medicines and medical equipment) in all care units according to their demand.

Also, during the influenza pandemic, Ekici et al. (2014) developed a model and heuristics which estimate the spread pattern of the disease geographically. The objective was to forecast in advance the spread of disease and determine an allocation of network resources for food distribution. Donghyun et al. (2016) address the issue of vaccine distribution by introducing graphical techniques and techniques based on maximum flow to solve the problem. Rastegar et al. (2021) built a mathematical model to equilibrate influenza vaccine distribution to critical healthcare providers and first responders in developing countries. Wu and Wang (2021) developed a virtual platform for emergency supplies distribution; the main idea is to balance the logistics information necessary for efficiently and accurately handling the emergency supplies during the distribution steps in the supply chain of the health sector.

All countries must acquire and distribute the necessary resources to attend to and reduce COVID-19 infections. The number of confirmed cases and daily deaths were a general concern to governments and citizens. In Mexico, the first confirmed case of COVID-19 was on February 28, 2020, initiating spread control and prevention activities in the country (Mexican Government 2020).

When an unforeseen event of great magnitude occurs, such as the COVID-19 pandemic, where there was a time gap for health organizations to establish protocols and action measures, part of the population could have interpreted that time as a lack of competence, decreasing trust in those responsible for health care (Coll et al. 2021). The Pan American Health Organization (PAHO) states that "the Ministry of Health must take the necessary precautions for emergencies, creating warehouses in geographical areas or strategically located places, with effective procedures for their dispatch to places in need" (Pan American Health Organization 2022). Some tangible resources, such as material, human or procedural resources, protect individuals and compensate for vulnerability; intangible resources enable people to overcome difficulties and achieve successful adaptation. For this, it is necessary to identify the population's needs to grant resources when and how they need them (Uriarte 2010). Hirawan (2020) comments in his work that optimizing the distribution of social assistance to the community is critical, especially during the COVID-19 pandemic.

The shortage of resources to fulfill basic needs directly impacts the quality of human life, "the lack of minimal health care can imply, almost without exception, the destruction of the human being" (Zúñiga-Fajuri 2014). The institutions that provide health care services must have a resource supply system to promptly meet the population's needs because the population's economic, social, and political impact will depend on this (Ramírez 2006). The unavailability of access to medicines has a high rate of morbidity and mortality (Ramírez 2006), hence the relevance and importance of satisfying the demand through the acquisition and distribution of medicines. From another point of view and supporting the health sector, Kumar (2021) examines the viability of using blockchain technology in a public distribution system, which helps institutions in the supply chain's activities to overcome shrinkage issues, misplacement, and ghost demand.

The effects that natural events have on the health of human beings depend on the danger of these. Considering that the effects are of high risk, it is vital to plan, as a preventive measure, the distribution of the necessary equipment and medicines in high-risk areas to minimize human suffering and accelerate the resilience of the affected population Pan American Health Organization and World Health Organization (2020a).

The Pan American Health Organization (2001) mentions that the humanitarian logistics problem involves acquiring emergency goods and equipment and managing supplies. They consider that all activities related to providing material assistance to people affected by extreme situations of natural events (such as biological events) require a minimum organizational framework that allows efficient management and greater use of resources. However, the logistics for handling humanitarian supplies should not be improvised in the moment of the emergency; it must be incorporated as a preponderant activity in the planning and preparations for emergencies of organizations in this field.

Martínez (2020) in his work proposes a route for the distribution of food aid under extreme natural events to minimize the response in the delivery of kits to affected people this through a mathematical model that considers limitations of road accessibility with periods for the distribution of aid.

In response to urgency requirements from patients with or without SARS-CoV-2 in Mexico, in this paper, the public health sector in Mexico is considered a case study. According to the National Development Plan, the current administration restructured the consolidated purchases of medicines, centralizing this activity in the Ministry of Finance and Public Credit. They changed the supply chain process of the health sector and the distribution mechanisms of medicines throughout the country, and a detailed report of this restructuring process is described by Rodríguez (2020).

Subsequently, the National System for the Distribution of Medications was created, whose objective "is to supply all institutions in the health sector with medications and medical supplies", which should be distributed in approximately 25,000 first-level medical units, 1,500s-level units and around 500 national institutes. However, due to the lack of planning and coordination of laboratories (suppliers) and distributors, there was a disruption in the supply chain of medical supplies in hospital care centers (Badillo 2021). Therefore, alternatives are sought to carry out this distribution activity in the public sector efficiently.

Then, this paper offers a proposal to this sector that allows them to distribute medicines and medical equipment through quantitative methods. For the case study, a central warehouse and six intermediate warehouses of supplies are considered, from where the vehicular units will depart to distribute medicines and medical equipment to 197 medical units of hospital care, all of them located in different states of the Mexican Republic. It seeks to determine the shortest routes for delivering supplies to hospital care centers, representing the case study as a Vehicle Routing Problem (VRP), using allocation methods and Clarke's and Wright's (CW) heuristic algorithm.

The work was developed in two phases. First phase: clusters were created to assign hospital care centers to the closest distribution depot minimizing the distance traveled by the available vehicles. Second phase: the CW method was applied with the information obtained from the first phase to generate the best routes with the least number of vehicles with fixed capacity under a deterministic demand.

The document includes four sections that show the content and development of the work. The first section presents the introduction to the problem being addressed and some background about the method applied; the second section shows the case study and its specific characteristics; the third section shows the results. Finally, the fourth section reports the conclusions of the work carried out, as well as some proposals to support the decision-makers and recommendations to the community of practitioners in this sector.

10.2 Methodology

This work is developed as follows:

1. Literature review about quantitative models for freight transportation and distribution of goods, considering the restriction of the case study.
2. Case study information: Compile the information that allows a detailed description of the case study, considering the necessary parameters for applying the quantitative method. Locate distribution centers and hospital care centers for the case study.
3. Application of Clarke and Wright's heuristic proposing solution scenarios, considering the available infrastructure that allows the best use of resources.
4. Obtaining the results and comparison of scenarios to identify the best proposal for decision-makers.

10.2.1 Distribution of Goods

The VRP is used to find the optimal route that a fleet of vehicles will visit or cover a set of clients under a series of restrictions (Laporte 2009). Depending on the problem you want to address, the VRP will have modifications. The variants of the VRP depend on the characteristics of the vehicles, delivery points, vehicle capacity, demand for delivery points, and supply of warehouses, among others. The methodology consists of grouping the delivery points into clusters and then determining the routes for each, dividing the problem into two phases.

10.2.1.1 First Phase

One of the heuristics to define clusters of delivery points in the vehicle routing problem is the Fisher and Jaikumar algorithm, which is a two-phase process. In the first phase, *m* seeds are located, and a cluster is created for each of the seeds. The purpose is to minimize the distance between the seed and the client, satisfying the capacity restriction (Laporte 2009). Clusters are created by solving a generalized assignment problem, and the second phase consists of generating the vehicle route for each group (Cordeau et al. 2002).

For the allocation, a function is defined that consists of minimizing the total allocation cost where d_{ik} is found as follows:

$$d_{\mathrm{ik}} = c_{0\mathrm{i}} + c_{\mathrm{i,sk}} - c_{0,\mathrm{sk}} \tag{10.1}$$

Furthermore, it means that the cost of assigning client *i* to cluster *k* is equal to the cost of going from deposit to client *i*+ the cost of going from client *i* to seed client sk—the cost of going from deposit to seed client sk, that is when costs are symmetrical.

The sweep heuristic creates the clusters by rotating a ray from the warehouse, and the clients join until the capacity limit is reached. It is like a sweep similar to the hands of the clock, with an initial point around the warehouse to identify the delivery point that will determine a cluster based on the vehicle's capacity. When the vehicle's capacity is reached, it starts another new route. Then the clusters are routed, solving the problem of the traveling agent exactly or approximately. This algorithm can be applied in plane problems; each node corresponds to a point in the plane (Romanuel and Montero 2014; Olivera 2004).

Another method of clustering is the constructive heuristic; it selects the clients randomly and assigns them to the closest depot. The main restriction is the deposit capacity; the clients will be assigned until this capacity is reached, and the remaining clients will be assigned to the next closest deposit; all nodes must be covered (Toro-Ocampo et al. 2016).

10.2.1.2 Second Phase

Exact and heuristic methods can be applied to solve the VRP. Some of the exact methods are Branch and Bound (BB) algorithm provides solutions that are systematically listed, and the responses obtained from each level of the branches are evaluated concerning their contribution to the objective function. The search tree is comprehensive but has limited depth (Laporte 2009). Branch and Cut (BC) and Branch and Price (BP) are derived from BB. Gutiérrez-Jarpa et al. (2010) mention in their literature searches the application of the BC method to solve the Multiple Vehicle Routing Problem with Time Windows (VRPTW) as addressed in Bard et al. (2002), where it is required to find the minimum number of vehicles to satisfy to a group of clients who have the same needs and the vehicle units that will provide the service are the same.

The literature shows that VRPTW can also be solved with the BP method (Gutiérrez-Jarpa et al. 2010), depending on the determined objective. The routing problem considering multiple repositories can be solved with Iterated Local Search. In their algorithm, Ospina-Toro et al. (2018) propose to find the solution through the following steps: first, obtain an initial solution using different clustering techniques, then the intensification stage using the Variable Neighborhood Search (VNS) algorithm and applying random disturbance schemes. Following these steps, it allows us to find locations that can be optimal location. However, the process continues exploring the solution space until there is no better solution than the one found in previous iterations.

In the case of the Heuristics methods, the CW saving algorithm was initially developed for the VRP, and they can be applied for both directed and undirected problems (Blocho 2020). The CW savings method aims to minimize the total distance traveled by all vehicles and indirectly minimize the number of vehicles required (Ballou 2004). Calculate the savings by combining two clients on the same route to select the best route (Clarke and Wright 1964). The method starts with an unfeasible solution where the supply is sent individually to each customer (Fisher and Jaikumar 1981). A feasible solution consists of n roundtrip routes between the warehouse and a customer (Fisher and Jaikumar 1981).

Ospina-Toro et al. (2018) use this as a reference to describe how the heuristic works iteratively. Moreover, the process ends when combining the routes is no longer possible. Finally, the number of vehicles used to visit all the delivery points and the best routes are obtained (Laporte 2009). Clarke and Wright (1964) solve a problem with a central warehouse and several delivery points where the vehicles will have the capacity to satisfy the demand. Spekken and De Bruin (2013) implemented the CW for single-vehicle route optimization in agricultural field work. The Bramel and Simchi-Levi heuristic, as well as the Fisher and Jaikumar algorithm, consists of two phases. In the first one, the client clusters are created, and then the routes that the clients of each cluster will visit (Muriel and Simchi-Levi 2013); the difference consists in the determination of the clusters solving a problem of the location of concentrators with capacities (CCLP) (Bramel and Simchi-Levi 1995).

The advantage of applying these heuristics is their ease of use to obtain the solution. It does not require a high computational effort or specialized knowledge of the personnel to apply the heuristics and carry out the implementation, as well as the low software and hardware requirements for performing the calculations automatically.

10.3 Results

10.3.1 Case Study

Management of medicines and medical equipment in the health system is one of the essential elements for any country, especially in the situation that the world is currently experiencing. In Mexico, mechanisms are being sought to efficiently distribute medicines and medical equipment in the public sector because, according to the National Development Plan, the current administration carried out a restructuring of the consolidated purchases of medicines, centralizing this activity in the Ministry of Finance and Public Credit (Rodríguez 2020).

The restructuring determined that it was necessary to change the distribution mechanisms of medicines throughout the country. The National System for the Distribution of Medications must distribute in approximately 25,000 first-level medical units, 1,500s-level units, and around 500 national institutes. However, due to the lack of planning and coordination of laboratories (suppliers) and distributors, there was a disruption in the supply chain of medical supplies in hospital care centers (Badillo 2021). Therefore, alternatives are sought to carry out this distribution activity in the public sector efficiently.

This work proposes to health decision-makers a way to distribute these medical supplies efficiently to different hospital care centers, improving the use of available resources. The proposal applies quantitative methods, specifically assignment methods and the Clarke and Wright heuristic, to show viable alternatives.

The case study is based on 197 hospital care centers located in different states of the country, which are supplied by a central warehouse and six smaller warehouses, also located in the states of the country (location defined by the federal government). Both hospital care centers and warehouses belong to the public institutions of the National Defense Ministry (SEDENA), the Mexican Institute of Social Security (IMSS) and the Institute of Social Security and Services for State Workers (ISSSTE). Statistical information from the National Institute of Geography and Informatics (INEGI) reported that approximately 89 million medical consultations were made during 2019 to the population enrolled in the federal government's medical service.

However, the medical resources that each health center service requires to satisfy the demand of the population are considered confidential information. So in this work, the demand was defined randomly with a uniform distribution between 500 kg and 3.5 tons of weight for hospital care centers. The aim is to show how the proposal works and get a solution to the problem, considering that information has to replace the real demand in each hospital and make the calculations again.

The number of vehicles used to transport supplies to the hospital care centers is assigned according to the available resources in the warehouse to satisfy the demand for each cluster obtained in the first phase. This lets the proposal say how many vehicles are needed to get supplies to the right places or how many trips the vehicles must make to meet the demand. Based on what the hospital staff knows, each vehicle can make as many trips as needed to meet the demand.

Also, the capacity of the vehicles used to transport supplies is defined by the guidelines established by the Ministry of Communications and Transport (SCT) in the Official Mexican Standard NOM-012-SCT-2-2014 as follows: "On the weight and maximum dimensions with which motor transport vehicles that travel on the general communication routes of Federal jurisdiction can circulate". With this, Type C3 vehicles corresponding to trucks with three axles and 8–10 tires, were selected for the proposal as a transport standard with a gross vehicle weight of 16 tons for displacement on type D roads (two-lane highway, feeder network) and 17 tons for type C roads (two-lane highway, secondary network) (SCT 2014).

The SCT details these types of roads as (i) "Highway Type C Secondary network; These are highways that, according to their characteristics, provide service within the state scope with medium lengths, establishing connections with the primary network, and (ii) Type D Highway Feeder network, they are highways that, according to their geometric and structural characteristics, mainly provide service within the municipal scope with relatively short lengths, establishing connections with the secondary network" (SCT 2014).

In this work, the limited human resources in each distribution center are not considered because each hospital center has internal policies for managing its personnel; therefore, all hospitals are treated with the same priority in the proposal. Also, the central warehouse does not consider the windows time to deliver the resources, according to the information from the warehouse supervisor.

10.3.2 Scenarios

Based on the inputs described before, three scenarios were carried out to determine the routes of distribution as possible alternatives for the decision-makers with the available resources:

Scenario 1: Determination of routes from a central node to all hospital care centers. Figure 10.1 shows the distribution.

Scenario 2: Determining routes from 7 warehouses to the hospital care centers, where one is the central warehouse and 6 are intermediate warehouses. Hospital care centers are attached to each warehouse through the minimum distance, where the six intermediate warehouses are supplied from the central node, and it also supplies hospital care centers. The intermediate warehouses are located according to the information obtained from the health department staff. Figure 10.2 shows the distribution.

Scenario 3: Determination of routes from 6 intermediate warehouses to hospital care centers, where the hospital care centers were assigned in a previous phase to

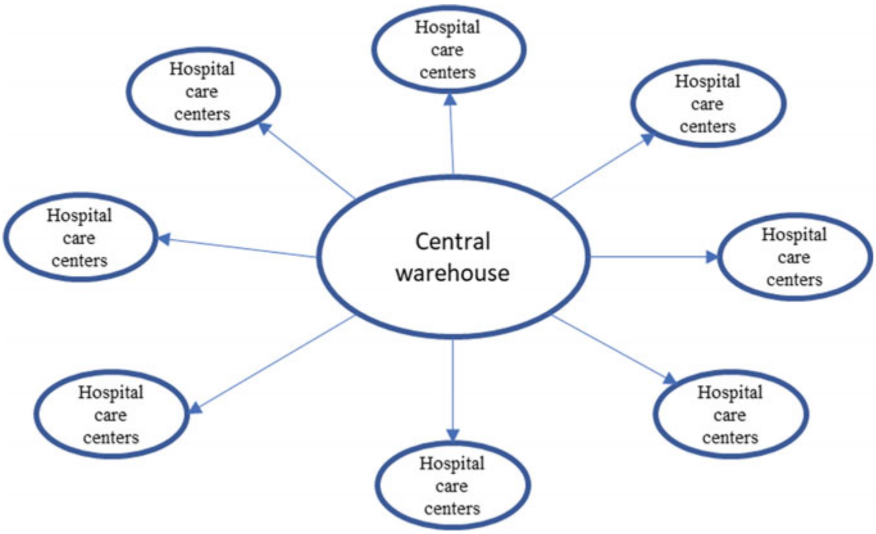

Fig. 10.1 Distribution for scenario 1

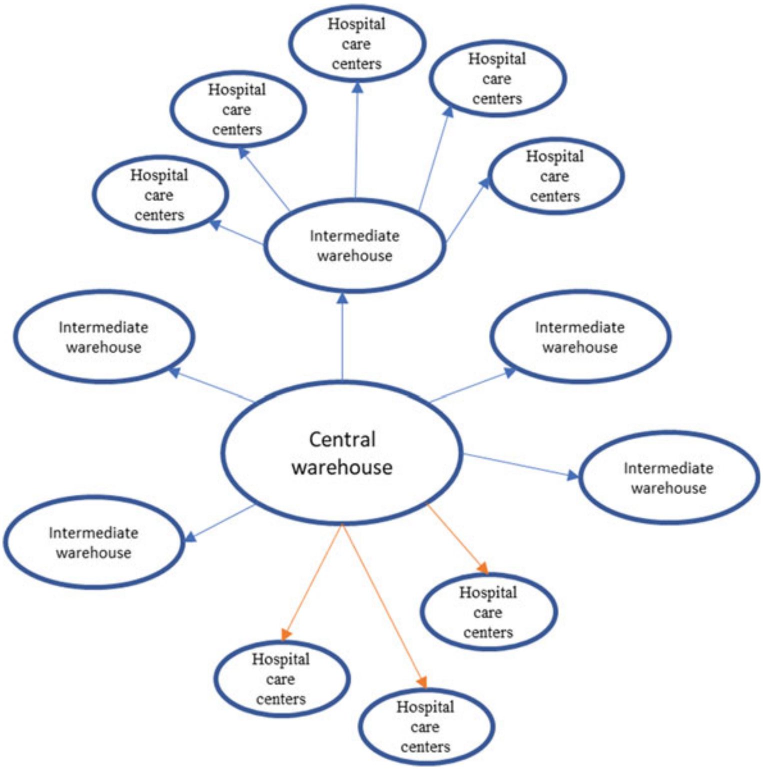

Fig. 10.2 Distribution for scenario 2

each intermediate warehouse, considering the shortest distance to each of them and the intermediate warehouses are supplied from the central node, in this scenario the central warehouse does not supply to the hospital care centers. Figure 10.3 shows the distribution.

The three scenarios are compared under the distance traveled, the number of vehicles used, and the number of nodes visited on each route.

10.3.3 Assignment of Hospital Service Centers to Intermediate Deposits or Central Warehouse

To carry out the assignment of hospital service centers to warehouses, the location of intermediate deposits and central warehouse was initially obtained through the coordinates (x, y) got by using the Google Earth application (Google Earth 2022), after that the distance matrix was calculated for each scenario according to the assignment obtained.

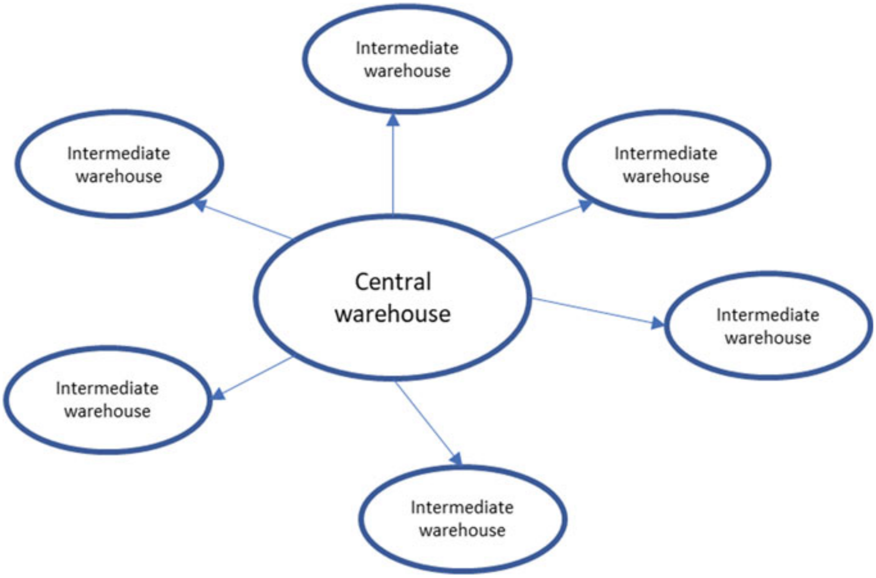

Fig. 10.3 Distribution for scenario 3

Scenario 1: Only the coordinates (x, y) of each service center and the central warehouse were considered. Subsequently, the distance matrix was calculated.
Scenario 2: The distance matrix was calculated from each hospital care center to each intermediate warehouse and the central warehouse, considering that the central warehouse also dispatches supplies to hospital care centers, as mentioned before. Once the distances had been calculated, for each service center, the closest warehouse to dispatch the supplies was identified; in other words, the minimum distance was selected, and from what warehouse belonged to the distance to assign the warehouse. In this way, the clusters with their corresponding hospital care centers were defined, where the number of hospitals care centers belonging to the intermediate warehouses is not the same because it is considered as a priory the minimum distances between them; therefore, if the number of hospital care centers had been considered equal for each cluster, it would generate trips with no minimum distances. Finally, the clusters were grouped, and Table 10.1 and Annex 10.6 show each cluster's hospital centers.

In this scenario, the number of obtained clusters was 7. Table 10.1 shows how each cluster was grouped and its total demand, which must be satisfied from the central warehouse to the intermediate warehouses. In this scenario, it is important to mention that the demand must be calculated in advance in the intermediate warehouses and their capacity to satisfy the hospital care centers on time, which implies more changes in the internal organization and control of each intermediate care center in the intermediate warehouses. It concludes the first stage of the methodology.

Table 10.1 Scenario 2. Assignment of hospital service centers to intermediate depot

Cluster	Hospital care centers *	Demand** (Kg)
1	6	9,533
2	49	92,131
3	11	16,211
4	26	45,721
5	56	102,311
6	5	7,707
7	44	70,534

* Number of hospital service centers assigned to cluster
** Total demand for hospital care centers assigned
Source Own elaboration

Scenario 3: The distance matrix was calculated, where the central deposit does not deliver to hospital service centers, so the number of clusters is only 6 (Fig. 10.3). The central deposit corresponds to cluster number 6 of scenario 2, based on the information provided by the decision maker. The process is the same as scenario 2 without cluster number 6. Table 10.2 shows how each intermediate warehouse was grouped, considering the minimum distances as a priority. Annex 10.7 shows the relationship between cluster and hospital care centers.

The demand of each cluster is calculated by adding up the demand of the hospital service centers that belong to it (Tables 10.1 and 10.2). The total demand obtained is the demand the central warehouse must cover in this scenario, thus avoiding the lack of inputs in any destination and balancing the distribution network.

Table 10.2 Scenario 3. Assignment of hospital service centers to the intermediate depot

Cluster	Hospital care centers*	Demand** (Kg)
1	6	1,589
2	49	92,131
3	11	16,211
4	26	45,724
5	56	102,311
7	49	78,241

* Number of hospital service centers assigned to cluster warehouse number 6 is considered the central warehouse
** Total demand for hospital care centers assigned
Source Own elaboration

10.3.4 Application of the Clarke and Wright Heuristic

In phase I of the methodology, the allocation clusters were defined, which serve as input for applying the CW algorithm for each cluster in each scenario. The algorithm was implemented in the Matlab software, version 2018 (MatLab 2018) and executed for each cluster obtained in Annexes 10.6 and 10.7. Therefore, given that one of the constraints of the scenarios is the vehicle capacity (16 tons), when the demand from the intermediate warehouse or the hospital service center exceeds the vehicle capacity, fictitious destinations are generated with the maximum capacity of the vehicle with the same location, to obtain the distance traveled and covered the demand of the intermediate deposit through a certain number of trips. A vehicle from the central node can make as many trips as necessary to cover the destination demand. Considering that the central node supplies the intermediate deposits in each scenario, it is necessary to integrate the distance traveled to these deposits from the central node. For scenario 1, the algorithm was applied directly considering the demand of the hospital care center requires and the vehicle capacity needed to build the route. For the execution of the implemented algorithm, the locations of each destination are the coordinates (x, y) initially obtained and calculating the distances to define the routes of each cluster.

10.4 Analysis of Results

The number of hospital service centers served by each intermediate warehouse and the distance traveled on each route were obtained for all scenarios. Scenarios 2 and 3 include the distance traveled from the central warehouse to the intermediate warehouses, as it was explained previously, considering the demand that the clusters require for their hospital care centers; therefore, vehicles travel several times until the intermediate warehouse has the total demand for the hospital care centers assigned. Table 10.3 shows the distance to each intermediate deposit of scenarios 2 and 3.

Table 10.3 Distance: central depot—intermediate depots scenario 3

Intermediate depots	Route	Distance (Km * 100)
1	3	0.49
2	4	0.14
3	5	0.36
4	2	1.45
5	1	2.42
7	5	0.36

Warehouse number 6 is considered the central warehouse
Source Own elaboration

Table 10.4 Comparison of scenarios

Scenario	Vehicles used	Distance (Km * 100)	Destinations visited by route (Average)
1	22	422.22	8.9
2	31	427.78	7.3
3	32	448.56	7.2

Source Own elaboration

The comparison of the number of vehicles to be used on the routes obtained, the total distance traveled, and the average number of hospital care centers visited for each of the scenarios developed is shown in Table 10.4.

Table 10.4 shows that the shortest distance traveled is obtained through scenario 1, where a central warehouse distributes to all hospital care centers. Also, the number of vehicles to be used for distribution is less than in any of the scenarios, where the vehicle capacity is maximized and helps to minimize the costs (oil, human resources, equipment, and vehicle maintenance). However, the number of destinations visited on each route is greater than in scenarios 2 and 3, which could cause delays in deliveries due to the number of hospitals to visit on a single route. In this case, the time spent for the delivery of medicines is not considered because the vehicles travel both in urban areas and on highways, which does not allow considering an average travel time of the vehicle as literature proposes for their delivery, nor the time spent in the loading and unloading of goods in the hospital care centers, which would be very good to integrate into other investigations. On the other hand, comparing the distance traveled and the vehicles and capacity used in them allows decision-makers to identify opportunities for improvement in managing and controlling health resources.

Therefore, it is important to mention that the assignment of clusters with intermediate warehouses does not show an advantage over the distance or the number of vehicles to be used for the delivery of medical supplies, also to have intermediate warehouses would increase the costs to the government because they need more people to hand medicines and medical resources (unload and load) as well as all the activities involved in the intermediate warehouse management such as cost for rent, human resources, security, inventory control, special equipment for handling medicine, etc. Then, scenario 1 is the best way to supply medical resources to the hospital care centers even though it is a central distribution policy, where it will be necessary to improve the management and control in all of the activities developed as well as the adequate infrastructure.

Table 10.5 shows the routes and the hospital care centers calculated by the CW algorithm and the vehicle's sequence.

Figure 10.4 is an example of the graphical representation of the routes obtained from the application of the CW algorithm through MatLab for scenario 1 (Annex 3 shows the routes), where a color represents the route got, and the small black points on the line are the hospital care center visited (the scale is determined according to the location by decimal coordinates).

Table 10.5 The sequence of routes for scenario 1

	The sequence of hospital care centers visited												Destinations	Distance*
1	9	52	38	36	27	37	43	44	31				9	46.79
2	28	47	45	35	42	53	32	51					8	34.81
3	142	141	123	140	128	126	125	124					8	31.14
4	14	30	41	34	39	46	48	16					8	39.31
5	10	55	11	2	15	66	58	54					8	26.18
6	156	139	136	120	116	107	115	129	111	127	122	134	12	36.28
7	151	117	130	137	138	133	135	145					8	25.43
8	154	112	146	147	162	155	131	144					8	21.04
9	105	40	29	33	49	50	3	17	8	67			10	26.38
10	69	60	61	74	59	72	57	71	73	78			10	10.98
11	63	25	77	68	82	81	76	85					8	26.27
12	65	86	157	165	166	153	161	150	160	20			10	15.17
13	13	94	26	102	98	87	104	91					8	18.46
14	75	12	1	92	93	97	4	19	18				9	11.95
15	89	103	106	95	5	6	62	7	23	22	24	84	12	18.02
16	121	70	21	164	148	163	158	114					8	14.29
17	179	83	118	79	80	64	119	132					8	8.61
18	100	56	143	108	109	110	113	152					8	4.06
19	188	180	90	187	88	96	99	101	149				9	2.19
20	172	169	192	194	171	189	167	168	191	170			10	0.54
21	195	176	178	197	193	174	190	186	159				9	1.32
22	183	173	184	182	185	181	175	196	177				9	0.14

[*] Distance is calculated by (Km * 100). Each route corresponds to a vehicle
Source Own elaboration

Routes:1 (green line at the top), 7 (blue line in the middle), 9 (naive blue line in the south), and 12 (yellow line west-south), obtained in scenario 1 by MatLab, are geolocated on the map where is easy to translate the results on the map and visualize the routes easily, also to show that decision-makers require very low effort to read them (Fig. 10.5).

Route 22 is in the country's center, mostly Ciudad de Mexico and Estado de Mexico. Figure 10.6 shows their location, and the traveled distance is very short, according to Table 10.5, because all the hospital care centers are very close, and in Fig. 10.4 is challenging to see.

The graphical location of the intermediate warehouses to group the clusters of scenarios 2 and 3 are shown in Fig. 10.7, where it reveals that the intermediate warehouses are in the center of the country as the central warehouse, which could be a disadvantage in the distribution problem because there is no big difference in the distances traveled between them and the central warehouses for the case study.

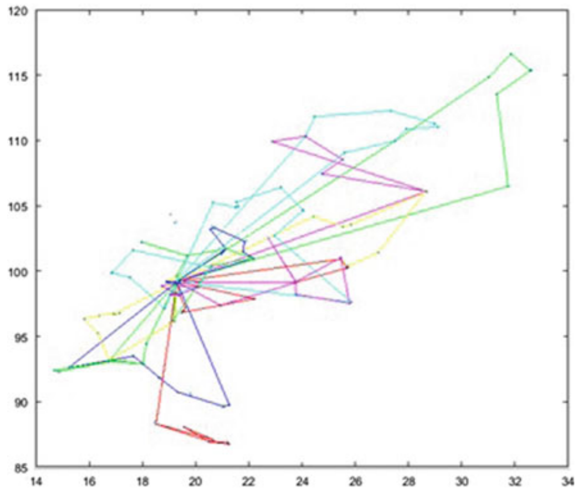

Fig. 10.4 Routes obtained for scenario 1. The coordinates (x, y) of the location of the hospital care centers were obtained with Google Earth

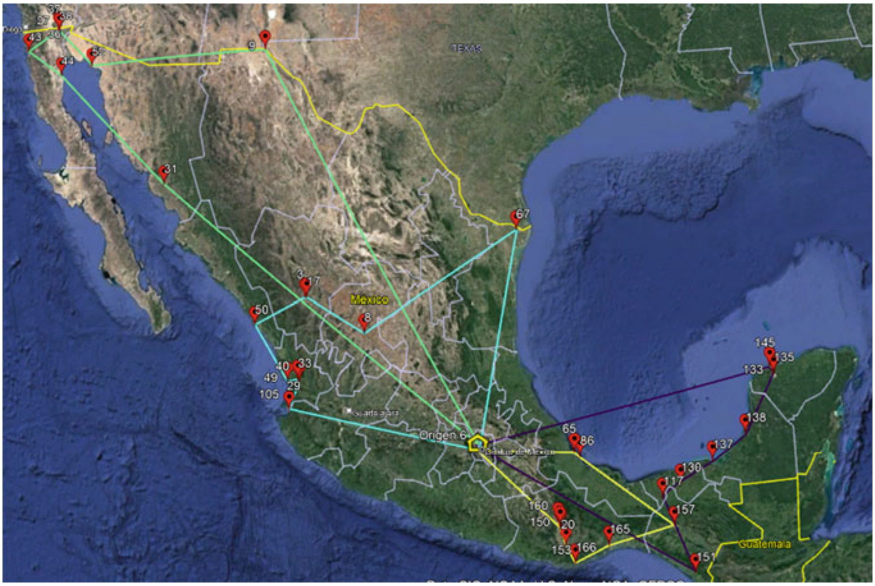

Fig. 10.5 Routes obtained for scenario 1 (routes 1,7, 9, and 12). The coordinates (x, y) of the location of hospital care centers were obtained with Google Earth. *Source* Own elaboration supported by Google Earth software

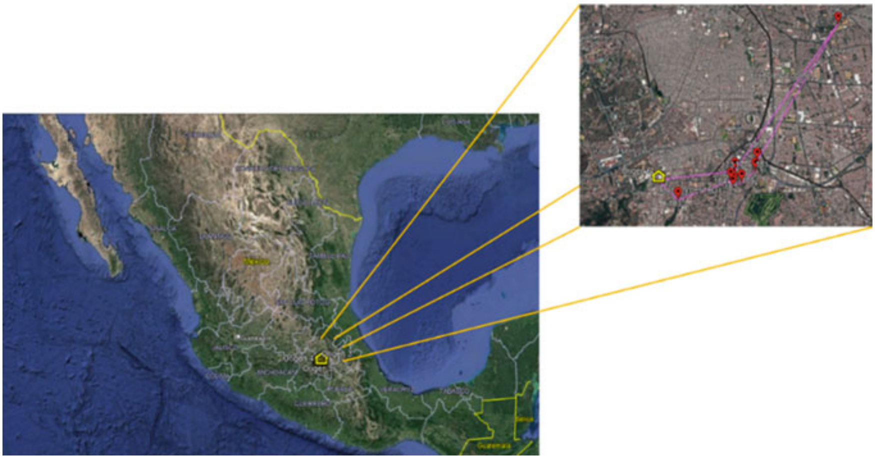

Fig. 10.6 The location route 22. The coordinates (x, y) of the location were obtained with Google Earth. *Source* Own elaboration supported by Google Earth software

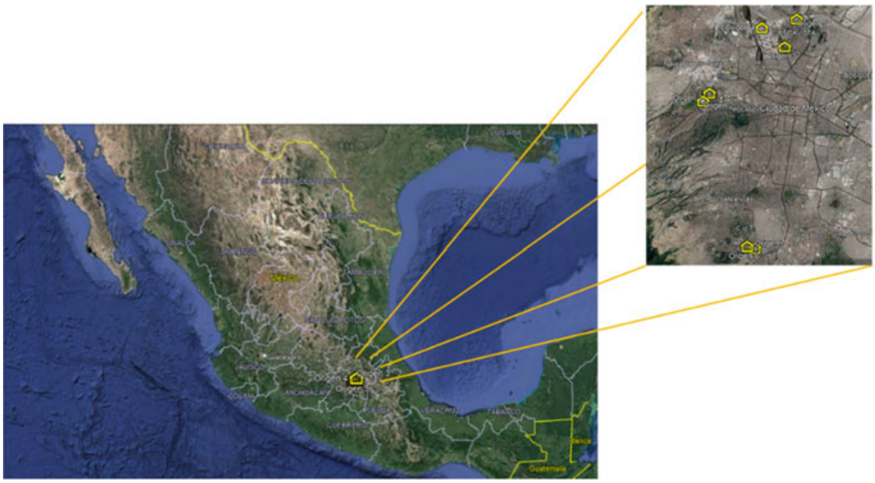

Fig. 10.7 The location of intermediate warehouses for scenarios 2 and 3. The coordinates (x, y) of the location were obtained with Google Earth. *Source* Own elaboration supported by Google Earth software

10.5 Conclusions and Recommendations

The application of quantitative methods to solve real problems facilitates the decision-making of the personnel involved in these activities since having information obtained from proven methods that solve certain problems gives support and security to select the best alternative.

Currently, due to the COVID-19 pandemic, there is an urgent need to optimally distribute medical supplies in any sector. Therefore, in this document, a Mexican case study for the public sector health system was analyzed by three scenarios with the resources available and the restrictions on them. The application of easy quantitative methods for the personnel in charge of the distribution of medicines and medical equipment was one of the objectives and gave them a viable alternative focused on minimizing the distance traveled by vehicles and the number of vehicles used to distribute the medicines. The applied methodology is developed in two stages: clustering the hospital care centers to one of the warehouses and applying the Clarke and Wright heuristic algorithm to find the routes to deliver the medical good. The results show that alternative or scenario 1, where a central warehouse is the only one considered to distribute the supplies directly to the hospital care centers, obtains a distance shorter, in which 22 routes are determined with the visit of approximately 8.9 service centers per route, assigning one vehicle per route. Therefore, it is concluded that the assignment of clusters with intermediate warehouses (scenarios 2 and 3) does not show an advantage over the distance or the number of vehicles to be used to deliver medical supplies.

This indicates that the use of intermediate distribution warehouses is not always the best alternative for distributing merchandise; for the case study analyzed, the location of the central warehouses does not help to improve distribution because they are in locations that are very close to each other. In this case, it is recommended to relocate the intermediate warehouses to speed up dispatch and improve the use of resources by applying simple methodologies for locating facilities that support the personnel in charge of this activity. Currently, the policy of the Mexican health system (centralization of resources) is supported by the results because the best alternative found is the one where from a central warehouse to hospital care centers are dispatched the health resources in this case. On the other hand, the results obtained by the quantitative methodologies potentially help the decision-makers because the routes obtained through the application of these methods indicate the distribution sequence (at the same time, supports the accommodation of medications in the vehicle to speed up unloading), maximizes the use of vehicle capacity because a route (assigned vehicles) contains a greater number of delivery points considering the available capacity of the vehicle when integrating a new center of hospital care, in addition to minimizing vehicle travel, which represents savings in fuel use, vehicle maintenance, personnel in charge of distribution, equipment for loading and unloading medications, minimizes the time spent making-decisions, to mention a few resources.

With this proposal, the decision maker has enough information to safely select the best-performing alternative with arguments based on the application of quantitative methods and create scenarios that show the feasibility of its results based on the resources available to the public health system in Mexico.

It is important to highlight and promote the application of simple methodologies that support the personnel in charge of these distribution activities since many of them do not have experience in the application of complex quantitative methodologies or in the use of information technologies, which makes more complicated the implementation; however, the ones used in this case study can be easily implemented in a commercial spreadsheet.

The advantages of using these methodologies for the decision maker are that they allow the integration of real demand in a simple way and allow the alternatives to be easily strengthened, integrating more information on restrictions and constants to the case study. Unfortunately, in developing countries, the lack of statistical information is a critical problem, but this kind of work shows how important is to have data. Also, this work contributes as an incentive for the people working in distribution activities to collect data to use them to improve their activities.

For this reason, some extensions to the proposal are the determination of the demand for hospital care centers, limited supply in intermediate warehouses and the restriction on the number of vehicles to use, opening the application of other methodologies with other potentialities. Also, determine priorities for the hospital care centers according to the size of the hospitals, people's demand, requirements of medicines, and kind of hospitals based on the specialty assigned.

Annex

See Annexes 10.6 and 10.7.

Annex 10.6 Clúster and hospital care center-scenario 2

Cluster	Hospital care center number	Total
1	42, 52,90, 174, 180, 191	6
2	1, 4, 5, 6, 13, 18, 19, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 45, 46, 47, 48, 49, 50, 51, 53, 87, 89, 91, 92, 93, 94, 95, 96, 97, 98, 99, 101, 102, 103, 104, 105, 193	49
3	167, 168, 169, 170, 171, 172, 187, 188, 190, 192, 194	11
4	2, 3, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 21, 22, 23, 24, 25, 26, 54, 55, 62, 66, 68, 69, 75, 88	26
5	56, 57, 58, 59, 60, 61, 63, 64, 65, 67, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 107, 111, 113, 115, 116, 118, 119, 120, 122, 123, 124, 125, 126, 127, 128, 129, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 145, 189	56
6	106, 148, 163, 164, 179	5
7	20, 100, 108, 109, 110, 112, 114, 117, 121, 130, 131, 144, 146, 147, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 165, 166, 173, 175, 176, 177, 178, 181, 182, 183, 184, 185, 186, 195, 196, 197	44

Source Own elaboration

Annex 10.7 Cluster and hospital care center-scenario 3

Cluster	Hospital care center number	Total
1	42, 52, 90, 174, 180, 191	6
2	1, 4, 5, 6, 13, 18, 19, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 45, 46, 47, 48, 49, 50, 51, 53, 87, 89, 91, 92, 93, 94, 95, 96, 97, 98, 99, 101, 102, 103, 104, 105, 193	49
3	167, 168, 169, 170, 171, 172, 187, 188, 190, 192, 194	11
4	2, 3, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 21, 22, 23, 24, 25, 26, 54, 55, 62, 66, 68, 69, 75, 88	26
5	56, 57, 58, 59, 60, 61, 63, 64, 65, 67, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 107, 111, 113, 115, 116, 118, 119, 120, 122, 123, 124, 125, 126, 127, 128, 129, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 145, 189	56
7	20, 100, 106, 108, 109, 110, 112, 114, 117, 121, 130, 131, 144, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 173, 175, 176, 177, 178, 179, 181, 182, 183, 184, 185, 186, 195, 196, 197	49

Source Own Elaboration

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Chapter 11
Optimization of the Distribution Process with a Multi-criteria Decision Model in the Poultry Industry

Hafid Joseph Córdova-Lavado, Breinner Alexander Ramos-Rodríguez, Daniel José Calderón-Romero, and Rodrigo Leonardo Aliaga-Maguiña

Abstract The management of the supply chain faces increased challenges for its optimization. The poultry industry, which has a large share of global food, is no exception. A particular challenge is more critical than others due to the product's short perishability and the reduced times of the merchandise in the warehouse. Thus, the importance of having an optimal distribution process increase. This study will conduct a qualitative analysis to determine the leading causes that prevent us from achieving optimal distribution performance. Based on the critical success factors, improvement actions can be proposed. Finally, the improvement actions will be evaluated through an AHP process, and the evaluation criteria will be based on the most relevant performance indicators in the industry. Thus, the best viable option can be determined quantitatively according to the weighting in the most important criteria. The investigation will determine that implementing an integrated data warehouse will be the most optimal solution for a distribution process in the poultry industry.

Keywords Poultry industry · Supply chain management · Distribution process · Analytical hierarchy process · Qualitative analysis

11.1 Introduction

The poultry industry is one of the primary sources of food supply worldwide. This industry, together with the demographic growth of countries, the increase in the

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purchasing power of individuals and the processes of urbanization around the world, has been growing and gaining sources of wealth and represents a major source of development for some countries, especially for the developing ones around the world stated by FAOUN in 2022.

In this sense, considering poultry meat production as the main area of the poultry industry, it is important to consider its contribution and impact on variables such as products sold, Gross Domestic Product and consumption, the latter being a macroeconomic variable that defines the consumption behavior and preferences of an individual in each society (Mankiw 2010). In this way, we can understand the relevance of good management.

Considering as a reference just the consumption, chicken meat is one of the products with a strong resilience that are in the worldwide market because even though the supply or the market trends are affected, the behavior of the consumption of this product is not strongly affected, especially in more traditional economies. Considering the last topic mentioned, the Organization for Economic Co-operation and Development says that considering traditional economies, we can find Peru in the top 5 of the world's most chicken meat consumers, taking 4th place in this rank (OECD 2022).

The development of the product in the Peruvian market, about the consumption habits of Peruvians, chicken is the most consumed meat in the country. Peru is the fourth country in the world, and the first in South America, regarding per capita consumption of chicken meat. Peru's per capita chicken consumption in 2020 was around 50.6 kilos, far behind the second most consumed in this item, eggs, with 15.2 kilos (OECD 2022). Taking an internal view inside Perú, the ministry forecasts the production in national land. The result was 1.5 million tons of chicken production, representing high participation in the Latin-American market (MIDAGRI 2020). In addition, some studies say that chicken consumption will increase by 5,2% annually, and this trend provides information on sustained growth in the future (Sitio Avícola 2022). In addition, there is good participation in every city like Lambayeque, Trujillo, and Lima, which are the top 3 in poultry during 2021, and his participation was 9,6%, 5,5% and 4,3%, respectively (INEI 2021).

However, recently this industry has faced a challenging issue in Peru. In May 2021, the international price of hard yellow maize reached one of the highest levels in the last five years due to the direct conditions for the correct functioning of its supply chain, also due to the COVID-19 crisis. Since October 2021, the hard yellow corn has had sustained growth in terms of the selling price in the international market, rising 150% over previous periods, as well as the other input used for the breeding of this type of poultry, which is the soybean, had a variation concerning the price of 48% over previous periods. Thus, it has represented a rise in operative costs (Cervantes 2021).

Thus, those studies emphasize opportunities and threats the industry faces globally and locally. However, it is necessary to find essential factors key to the industry. According to an article published in the academic portal of the IEEE and the University of London on the design and optimization of supply chains in the poultry industry, the critical success factors are product quality and fast delivery times. According to this research, poultry meat being a perishable product, the shelf life is short; therefore, the product cannot be stored for a long time in inventory. So, the distribution process is key in the industry. This article proposed a distribution network optimization model by decreasing the distance between distribution centers and customer facilities (Boudahri et al. 2011).

The objective of the following research will be related to the industry's critical success factors and will be to identify the optimal solution for the applied case. Therefore, this research will take as a case study a poultry company in northern Peru: El Rocío. Through this case, the opportunity for improvement will be supported by the following research question: How can we improve the distribution process of processed chickens considering the challenges of product quality and reduced delivery times?

11.2 Literature Review

11.2.1 Assessing the Main Process Under Study: Distribution Process in a Poultry Company

There is much research done on supply chain management. To contextualize our research question, it is necessary to acknowledge what is meant by the distribution process, according to Chopra and Meidln (2013). The supply chain comprises several steps where suppliers, manufacturers, distributors, and clients can be found. Every actor manages to do inbound and outbound logistics, where we identify the distribution process. The key objective of the supply chain is to maximize customer value and minimize the costs of bringing that value. Thus, the distribution process relates to the actor who received the value. Additionally, it is essential to differentiate between pull and push strategies. Pull-strategy is the most used strategy for industries with a massive consumption market.

Currently, poultry companies face two main challenges when evaluating the distribution process just for poultry companies. First, due to the COVID pandemic, there is a need to mitigate these negative impacts through stocking policy and highly volatile price variation. Production plans tend to change, impacting profitability and customer satisfaction. For that reason, several supply chain networks were proposed to assess those challenges. Secondly, it was identified that demands depend on the poultry business's selling price and expiration date. As chickens can be considered a commodity good, price is the only attribute differentiating them from others. Additionally, as the good has a short shelf life, optimal distribution process management accomplishes the promised lead time, influencing demand perspectives (Yazdekhasti et al. 2021).

11.2.2 Assessing the Main Criteria for the Selection of Proposed Solutions: Key Performance Indicators in Agri-Food Supply Chains

To analyze the performance of a process, the concept of Key Performance Indicators (KPIs) was developed by Petersen in 2009. The relevance of indicators lies in measuring specific objectives, decision-making based on them, and strategic control of them for continuous improvement. However, formulating indicators is easier said than done. Moreover, the construction of KPIs depends on the industry and the field under study. There are indicators for logistics, information systems, quality, and engineering (Franceschini et al. 2019).

On the other hand, the supply chain of the agriculture and food industry differs from the rest due to the management of biological processes, greater risks and volatility, its short perishability, and high sensitivity to the population's eating habits. A research proposed a classification model to measure the performance of this industry, grouping many studies on the subject and subdividing them as follows: efficiency, flexibility, response level, and product quality. The indicators' categorization will help us evaluate the best proposal for improvement in the distribution process (Aramyan et al. 2006).

11.2.3 Assessing the Implication of a Multi-criteria Analytical Model for Decision Making: Analytical Hierarchy Process (AHP)

When evaluating options, it is imperative to do so with consistency, logic and much sense. Saaty (2008) proposed a decision-making model based on mathematics and psychology to deal with the intangible aspects when evaluating options. This method allows us to quantify decision-makers' judgments and the relative importance of criteria and assess the best possible option.

Studies on the AHP model have already been carried out in the poultry industry. Research is conducted on determining optimal broiler housing based on the so-called AHP method. The alternative selected was in line with the stakeholders' perspectives (Lima et al. 2021). Additionally, an investigation has been carried out to measure the productivity of the farms. Through a causality tool, the main causes of low productivity were detected. The purpose of the study was to propose efficient measures to increase productivity and evaluate them with AHP, analytical hierarchy process methods (Kurniawan et al. 2021).

11.3 Methodology

The first phase consists of establishing the optimal situation based on the identified opportunity for improvement. It is necessary to propose a clear objective because this provides a clear vision of where you want to go. In the second phase, it is imperative to conduct a causal analysis to identify the causes that deviate us from the optimal situation. Through secondary research and the relationship diagram, we will be able to identify the causes that are most influential on others and, therefore, the most critical ones. Using a tree of problems and objectives in the same phase, the second-order causes of the critical causes already identified in the previous step will be identified.

In the next phase, improvements will be proposed based on filtering the causes. Finally, in the last phase, with the solutions already proposed, an AHP process will be carried out, where, based on the weighting of the most relevant criteria of the industry and the critical judgment of a stakeholder, the most optimal solution will be found.

11.3.1 Phase 1—Description of Optimal Situation and Objectives and Description of Case Study

Optimal situation or opportunity for improvement found in the poultry industry: "Efficient and effective distribution process of the processed butchered." Key objectives: optimal service level, high-quality products, short lead time, reduced inventory and reduced merchandise waste.

11.3.2 Phase 2—Qualitative Analysis

11.3.2.1 First Order Causality: Relations Diagram

As part of the management's continuous improvement strategy, through internal analysis complemented by secondary research, a list of factors was drawn up that prevent a poultry company from reaching the optimal situation of the distribution process, as shown in Table 11.1.

For the evaluation of qualitative variables, the study used one of the tools for quality improvement proposed by a committee of the Japanese Union of Scientists and Engineers (JUSE), the relations diagram (Vilar 1998). The objective is to achieve an overview of how the causes are related and understand the root causes of problems to choose the most important ones (Lemos 2016).

During the diagram's elaboration, firstly, the main problem was displayed in the middle of Fig. 11.1. Then, the factors found in Table 11.1 were added to the main

Table 11.1 Relation diagram factors

Factors	Importance
Inaccurate predictability in the planning demand of orders	The planning of the orders must go hand in hand with a forecast of the demand since, in this way, it is possible to map the optimal quantity of production, allowing cost savings and saving in excess merchandise. If this forecast is not carried out or accurate, it will not generate value for the product and will lose customer loyalty. It will affect certain product specifications; therefore, the companies will tend to fall into a critical situation (Sánchez 2017)
Refrigeration systems errors	The refrigeration system within an organization serves to preserve raw materials, products in production or finished products, all at a specific temperature based on the specification of each product to continue with its life cycle. The errors can be classified in consideration of the design, limitations in the installation inconveniences and maintenance challenges (Chaverra 2020)
Unaccomplished product quality standards	The quality of the products is vital for the organizations because it gives them competitiveness in the developed sectors. Similarly, it is a way to add value to organizations in a globalized world and constantly changing. If it is not well-known what aspects are to be improved and to what extent, the process would be defective and in vain for the organization's value (Cubillas and Rozo 2009)
Delays in the delivery orders	Order delays create a problem throughout the supply chain. The organization and the economy that the company manages to develop a solid job in the chicken distribution process should be considered. Consequently, delays and disorder are generated in the delivery of orders to each of the clients, which generate economic losses for the organization, and in the same way, losses on the products that one manufactures. (Amaya 2010)
Stealing of merchandise during the distribution process	Merchandise theft is a variable that grows stronger every day worldwide, involving different issues and variables within transport logistics, not only during transit but also in inspection areas or stops made during the journey. For this reason, many companies are directing their efforts to give cargo greater protection. Security will help a higher rate of successful deliveries and, therefore, a distribution process without major inconveniences. (Carvajalino 2020)

(continued)

Table 11.1 (continued)

Factors	Importance
Leaders with poor management capabilities	Leadership is not necessarily accompanied by the presence of the individual in a position of authority, so it is not optional. On the other hand, this leadership comes from the exercise of the individual over time within the organizational environment, giving him powers that allow him to perform tasks effectively and efficiently. An individual without leadership in a position of power is nothing more than a boss. Therefore, the mismanagement of his environment limits the possibilities of growth personally and for the company in general. (Heifetz et al. 2009) A leader without leadership in a distribution process position could generate cost overruns and risks that directly affect the value of the product perceived by the customer and the workers' loyalty (Heifetz and Linsky 2002)
Lack of innovation in the operation of the distribution process	In this market with a larger supply, the customers expect to cover more than only their basic needs to consider something valuable enough and build loyalty with a defined company. That is why companies need to comply with the value they expect to get, which relates to the internal processes that the company has. Building a resilient supply chain, supported by constant innovation, is important for the company's sustainability. This innovation along the supply chain, not only with technology, helps the value creation and the efficacy of the processes, which are factors that help the company grow (Leal et al. 2014)
Information systems are not suitable for operation activity	In this market, information has a significant role in the company's processes to reach the goals that could help them comply with the customer's expectations. The dilemma is to evolve and incorporate the technologies in a way that could give the company the necessary information to comply with these expectations that permit the company to be sustainable. The lack and obsolescence of this system represent a significant disadvantage to the company's growth (Piattini et al. 2018). Specifically, in the distribution chain, the lack of efficient information systems could make it impossible to deliver the total value of a product and increase the risk of cost overruns in the chain to make the sale effective

(continued)

Table 11.1 (continued)

Factors	Importance
Insufficient information for inventory planning	As was mentioned before, the information and the providers of this information are key factors for sustainability. That is why this information contributes to the company's efforts to comply with the customer's expectations and improve the efficiency and performance of the supply chain. The lack of information could not permit the companies to focus their efforts on aspects that help them give more value to the products or services they offer. A planning process without sufficient information could generate cost overruns and affect the value they offer and the company's growth (Kitsios et al. 2002)
Lack of communication between the stakeholders and the company	As we know, stakeholders play a key role in the company's business because they share interests with the companies and their processes. Being a set of interconnected relationships, it is important that the business could manage the factors in its context to maximize the expected value and mitigate the possible risks that could appear because of the activities of these actors. The importance of good management of the company's relationships with stakeholders lies in the risks and interests that represent their influence and the company's growth capacity (Wasieleski and Weber 2017)

problem. Consequently, cause-effect relations were established between the varied factors using arrows. Each cause, therefore, influences others but is also influenced by other causes. Therefore, each of them has a count of inputs and outputs. For our analysis, it was only necessary to compare the number of outputs because it was necessary to identify the most influential ones. The higher the punctuation, the higher the causality. Then we selected the most relevant five factors with higher causality to focus on them. Next part, a subsequent analysis was done of the most relevant factors.

The factors with more outputs:

- O:5, Leaders with poor management capabilities
- O:4, Little innovation in the operation of the distribution process
- O:3, Information systems are not suitable for operation activity
- O:3, Insufficient information for inventory planning
- O:3, Inaccurate predictability in the planning demand of orders

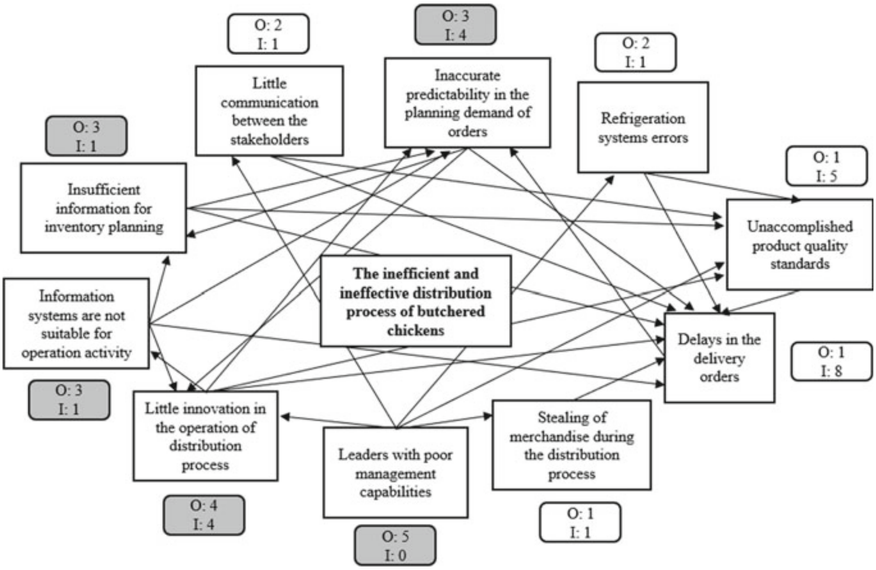

Fig. 11.1 Diagram and variables

11.3.2.2 Second-Order Causality: Issue Tree and Objectives

Decomposing the existing problem or opportunity for improvement into several first and second-order causes is a strategic form of problem-solving. A publication in the McKinsey&Company section in 2019 states that the issue tree and objectives propose a holistic view of the problem and identify areas of relevance (Felicia 2019). The tree of objectives and problems will be built based on the most influential causes identified in the relationship diagram since the second-order cause will be sought for each of them. Finally, with the second-order causes obtained from this analytical tool, we will obtain the necessary input for the improvement proposal phase.

11.3.3 Phase 3—Proposition of Possible Solutions Based on the Critical Causes

After analyzing the leading causes obtained from the relationship diagram and the issue-objective tree, a solution identification process needs to be executed. For this purpose, a second interview was realized in the research, and the most relevant improvement actions will be selected through a brainstorming method considering the critical causes identified. The brainstorming will be executed according to the adequate steps for McKinsey&Company (Coyne and Coyne 2011).

Table 11.2 Relevant KPIs in the poultry industry from Aramyan

Efficiency	Flexibility	Responsiveness	Food quality
Distribution cost	Customer satisfaction	Fill rate	Sensory properties and shelf life
Transaction cost	Volume flexibility	Product lateness	Product health and safety
Warehousing	Number of backorders	Customer response time	Product reliability
Storage	Lost sales	Lead time	
Damage and losses	Late orders	Shipping errors	
Efficiency	Flexibility	Responsiveness	
Distribution cost	Customer satisfaction	Fill rate	
Transaction cost	Volume flexibility	Product lateness	

11.3.4 Phase 4—Performing Analytical Hierarchy Process

11.3.4.1 Step 1: Establishment of AHP Criteria and Comparison Scale

Evaluate the solutions quantitatively and choose the best one based on the relevant industry criteria. A multi-criteria AHP decision model was proposed. The criteria are efficiency, flexibility, responsiveness, and food quality; the last three may fall into the efficacy category because all are about achieving objectives. All these areas, with their corresponding performance indicators, respond to a poultry company's strategic measurement, as shown in Table 11.2 (Aramyan et al. 2006).

- Efficiency: It is understood that efficiency refers to the utilization of resources. If their use is optimized, this could lead to a cost reduction.
- Flexibility: This indicates how a supply chain can respond to a changing environment.
- Responsiveness: The main objective is to reach a high level of service and be customer oriented.
- Food quality: In perishable goods, quality is essential. Indeed, adequate sensory properties in this industry last little time; thus, shelf life remains reduced.

In addition, it is necessary to establish a scale of comparison of criteria for decision-makers and evaluators. Table 11.3 displays the comparison scale.

11.3.4.2 Step 2: Scores of Each Action Improvement Regards KPIs

Concerning the case study and stakeholder perspective, each improvement action will be scored according to the most relevant industry indicators and categorized.

Table 11.3 Comparison scale

Level of preference	Rating #
Extremely preferred	9
	8
Highly preferred	7
	6
Strongly preferred	5
	4
Moderately preferred	3
	2
Equally preferred	1

11.3.4.3 Step 3: Criteria Assessment

Based on Table 11.3, we proceed with the evaluation of the importance of the criteria. The aim is to establish the weights of each criterion and determine its relevance.

11.3.4.4 Step 4: Options Assessment and Final Decision

Based on Table 11.3 and results obtained from step 2, improvement actions from phase 3 can be assessed. All solutions or actions are compared between them based on the selected criterion. Finally, with all those results, including those from the criteria assessment step, the improvement actions can be ranked, and it will be possible to make a final decision on the best way to reach the optimal solution.

11.4 Results

11.4.1 Phase 1—Description of Optimal Situation, Objectives and Description of Case Study: Analysis

The optimal situation was described in the methodology, phase 1. In this phase, the case study to be applied will be further elaborated. The company studied, El Rocio, is one of the most important in the poultry sector in Peru and operates vertically integrated from the farms to the distribution center. Its high-quality products have allowed recording sales valued at more than S/. 60 million, and sales are expanding on average by 10% every year.

The market share of El Rocio covers all the regions in the north of Lima until Tumbes; however, the long-term goal is to expand the market share to the east of the country in zones such as Cajamarca, Amazonas, and San Martin. In addition, the chicken farms are in the north of Peru, La Libertad. The principal supply for making food for chickens is corn, imported from the US and picked up in the rented warehouses in the port of Salaverry. Then, the corn is processed in the factory in Trujillo with other supplies, obtaining balanced food.

The company classifies the products into primary and secondary groups. Among the primary group are live chickens and butchered chickens, whose processes are executed by the company. Secondary products for sale are composed of eggs, feathers, and cold meat. Distribution of the primary group requires some considerations, like loading chicken into the truck employing crates. Likewise, the transport of slaughtered chickens requires a built-in refrigeration system to maintain the freshness of the product until it arrives at the customer warehouses.

11.4.1.1 Competitive Advantages

The company's competitive advantage is based on the following pillars:

- **Economies of Scale**. The principal policy is to acquire large quantities of raw materials like corn and breeder baby chicken eggs, getting a lower final price. Likewise, the early supply will allow El Rocío to assure their production for the next year in case of scarcity of raw materials because of the pandemic and international conflicts.
- **Taking Advantage of Synergies**. Having vertical integration allows the company to manage the principal process operations of the chain. For that reason, the company can respond faster to the industry's needs, reducing costs and guaranteeing the quality of products.
- **High-Quality Standards**. International certifications ISO 9001, ISO 14001, and HACCP obtained by the company demonstrate good service, high standards, reliability, and differentiation in the market. Variations of height, weight, and pieces of chicken offered for sale can satisfy the requirements of many customer segments that the competition cannot do. Finally, punctuality in delivery orders allows customers to receive products on time and in the right place because of good logistic administration.

11.4.1.2 Supply Chain Analysis

El Rocío S.A. has a push strategy in its supply chain for the following reasons.

- They work with a demand forecast and a production plan. They plan and are customer-driven.
- It focuses on mass production and sales.
- The main goal of process optimization and cost reduction.

11.4.1.3 Drivers of Supply Chain Performance

Logistics accomplish a fundamental role in companies making available for customers the product in the right place and at the exact time (Escudero 2013). Therefore, appropriate coordination is necessary from the beginning of the process until the final, especially in this demanding environment that requires a progressively more efficient and effective supply chain (Sánchez et al. 2021; Hofmann and Reiner 2006).

To achieve this objective, El Rocio evaluates the supply chain to understand how it can improve its performance. In this sense, we must assess the supply chain drivers that interact to determine the result of the process in connection with the response capacity and effectiveness: facilities, inventory, transportation, information, sourcing, and pricing. The structure of drivers defines how the strategic adjustment must be accomplished in the whole supply chain (Chopra 2020).

After analyzing all company drivers, they can progress their performance in the inventory, information, and facilities. It is relevant to mention that although there are opportunities for improvement in the other drivers, the critical approach of El Rocio is to optimally manage its inventories through timely access to information and maintaining a high level of response capacity. For that reason, Table 11.4, showing drivers of Rocio's, was elaborated.

11.4.2 Qualitative Analysis: Second Order Causality: Issue Tree and Objectives

In phase 2, part 1 of the methodology, the first-order causal analysis using the relationship diagram was conducted through secondary research. The second-order causal analysis will be applied to the case study for this step.

The problem tree in Fig. 11.2 allows us to find the deeper causes that affect the problem and the possible effects that can happen in the future. Some discoveries were that the company had poor management in staff administration, prediction of planning demand orders, system information, and application of good practices in the industry. Additionally, we can find risks for the future, like the operative standstill, instability of the company in the market, and the incapacity of achieving financial objectives. Understanding the context of the problem and the effects in mind and long term, we can begin planning strategies and solutions to revert the situation, as we see in the explanation of the opportunity for improvement.

Based on the problem tree, we elaborate on the objective tree, in which the main goal is that the company has an efficient and effective distribution process of butchered chickens. In that way, the fundamental areas of improvement are high innovation in the operation process, good planning demand orders, leaders with good management capabilities, appropriate system information for the process and valuable information resources for inventory planning. The first-order results are the high

Table 11.4 Drivers of Rocio's Supply Chain and proposals for improvement

Drivers	Present	Proposals
Inventory	Orders of chickens per year have a simple prediction of annual growth of 5%, generating high levels of inefficient inventory	Developing a complex quantitative prediction method allows for managing optimum inventories and avoiding waste
Transportation	There is no traceability of the units to act quickly from eventualities during the journey	Track the units to trace the optimal transport routes and deliver in less time
Information	There is no communication with the customer to know their needs or orders. Additionally, the information obtained on information systems is not integrated and takes 24 h to be actualized	Manage an integrated warehousing system for all distribution processes and work closely with the customers to improve communication. In this way, both parties can separate orders on time and guarantee the supply for the business
Facilities	Facilities like farms, incubators, butchering plants, and distribution centers are in La Libertad in the coastal zone	Analyze investments in new farms to increase production capacity and supply new markets in other zones of the country
Sourcing	Most of the main activities of the El Rocío supply chain are carried out by the same company to have a high response capacity, even at the cost of being more efficient	To be more efficient, the security service can be subcontracted (avoiding internal collusion and theft risks), and the transport service of the rented warehouses in the port to the company so that the own units can focus on the shipment of the products
Pricing	The final price of the chicken that will be sold to customers depends very much on the costs of the raw material supplied by the corn supplier. Due to the low-price policy, the income received is highly vulnerable to a rise in the price of corn	Implement agricultural areas to produce the required raw material (such as corn) and thus not affect the final price offered to the customer and the company sourcing of income

industry competitiveness, the better service level offered, efficient distribution cost, and an increasing market share. Also, in Fig. 11.3, we can visualize second-order means and purposes.

11.4.3 Proposition of Possible Solutions Based on the Critical Causes

Four alternative solutions were proposed and stated in the drivers of the supply chain part, Table 11.4. These alternatives were obtained by brainstorming with the team and assessed by the Chief Controller. During the brainstorming and the interview,

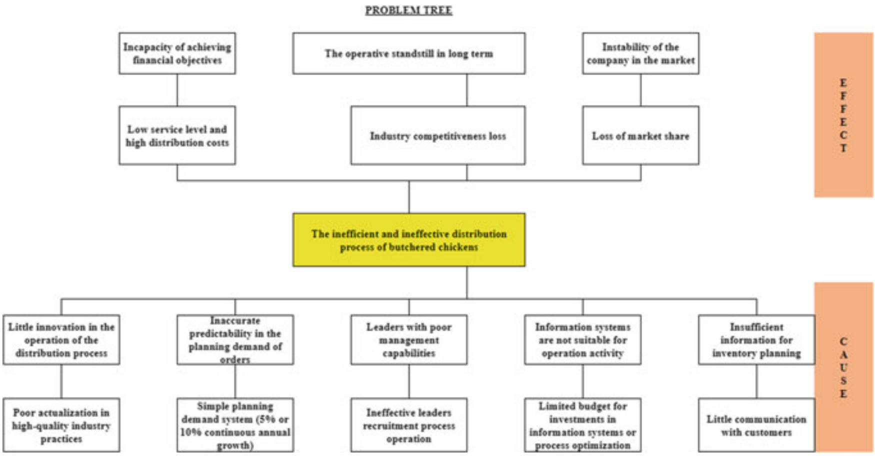

Fig. 11.2 Issue Tree

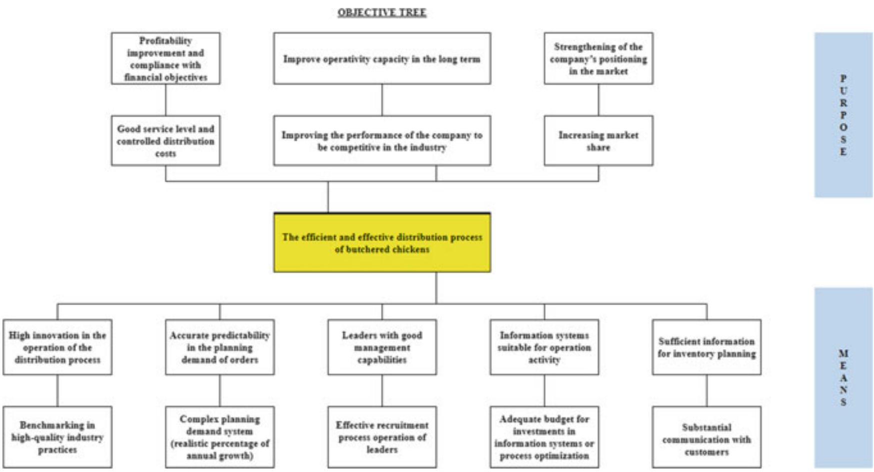

Fig. 11.3 Objective tree

the leading causes that induced a deviation from the optimal situation were considered. It is relevant to mention that none of these improvements' actions have been implemented before (C. Ramos 2022).

Improvement action 1: Implement an integrated data warehouse for the entire distribution process that allows access to data in real-time every 6 h of update. This data warehouse would support all other company applications.

Improvement action 2: Creating an innovation laboratory dedicated to processing improvement and product quality assurance. A team comprises a specialist in project development or continuous improvement, a production engineer, a strategic area, a purchasing area, and a member of the client company.

Improvement action 3: Using historical data to implement quantitative and qualitative demand forecasting methods. For this purpose, methods such as Monte Carlo and demand forecasting models will be used, which, based on predefined algorithms, will achieve better supply plans, production, and distribution process.

Improvement action 4: Innovate and digitalize the delivery of documentation required for the transport of orders. The manual process takes 3 h; therefore, this solution will digitalize the waybill and shorten the documentation times.

11.4.4 Execution of the Analytical Hierarchy Process

11.4.4.1 Step 1: Establishment of AHP Criteria and Comparison Scale

Step did in the methodology part in phase 4, step 1.

11.4.4.2 Step 2: Scores of Each Improvement Action Regards KPIs

Each improvement action was evaluated regarding the KPIs that the solution implementation can influence for this step. The managerial judgments intervened with the research with the group in charge of this investigation. (C. Ramos, 2022). For this, the KPIs of Table 11.2 was used, and the improvement solution's influence on each was verified. The discussion of results is displayed in the following Tables (Table 11.5, Table 11.6, Table 11.7, Table 11.8), where the color gray indicates the influence of the solution on the indicator.

Table 11.5 Final categorized score of improvement action 1, integrated data warehouse

Improvement action 1	Efficiency	Flexibility	Responsiveness	Food quality
Influence on KPIs	Distribution cost	Customer satisfaction	Fill rate	Sensory properties and shelf life
	Transaction cost	Volume flexibility	Product lateness	Product health and safety
	Warehousing	Number of backorders	Customer response time	Product reliability
	Storage	Lost sales	Lead time	
	Damage and losses	Late orders	Shipping errors	
Final score	3	4	4	2

Table 11.6 The final categorized score of improvement action 2—an innovation laboratory

Improvement action 2	Efficiency	Flexibility	Responsiveness	Food quality
Influence on KPIs	Distribution cost	Customer satisfaction	Fill rate	Sensory properties and shelf life
	Transaction cost	Volume flexibility	Product lateness	Product health and safety
	Warehousing	Number of backorders	Customer response time	Product reliability
	Storage	Lost sales	Lead time	
	Damage and losses	Late orders	Shipping errors	
Final score	4	2	3	2

Table 11.7 The final categorized score of improvement action 3—demand forecasting methods

Improvement action 3	Efficiency	Flexibility	Responsiveness	Food quality
Influence on KPIs	Distribution cost	Customer satisfaction	Fill rate	Sensory properties and shelf life
	Transaction cost	Volume flexibility	Product lateness	Product health and safety
	Warehousing	Number of backorders	Customer response time	Product reliability
	Storage	Lost sales	Lead time	
	Damage and losses	Late orders	Shipping errors	
Final score	2	3	3	1

11.4.4.3 Step 3: Criteria Assessment

This step was to analyze the criteria and establish a relevance index by comparing them based on Table 11.3: Comparison scale. Table 11.9 shows the level of preference for a specific criterion.

Then, with the above ratings, the matrix is completed in Table 11.10, where scores less than 1 represent those less preferred than their peers.

To find the priority index, first normalize the scores with the corresponding total and then average each score in each column to obtain the priority index for each row or criterion. The priority index is shown in Table 11.11.

From Table 11.11, we can see that the most relevant criterion is product quality, then the two most important criteria are efficiency and responsiveness. So, scoring better on these criteria has a higher priority for the company. Then, a degree of

Table 11.8 Final categorized score of improvement action 4, digitalization of delivery documentation

Improvement action 4	Efficiency	Flexibility	Responsiveness	Food quality
Influence on KPIs	Distribution cost	Customer satisfaction	Fill rate	Sensory properties and shelf life
	Transaction cost	Volume flexibility	Product lateness	Product health and safety
	Warehousing	Number of backorders	Customer response time	Product reliability
	Storage	Lost sales	Lead time	
	Damage and losses	Late orders	Shipping errors	
Final score	1	1	2	0

Table 11.9 Comparison of criteria

Pair comparison	Most important criterion	How important?	Rating #
Efficiency–Flexibility	Efficiency	Moderate to strong	4
Efficiency–Responsiveness	Efficiency	Moderate	3
Efficiency–Food quality	Food quality	Equal to moderate	2
Responsiveness–Flexibility	Responsiveness	Moderate	3
Food quality–Flexibility	Food quality	Moderate to strong	4
Food quality–Responsiveness	Food quality	Moderate	3

Table 11.10 Comparison matrix

Criteria	Efficiency	Flexibility	Responsiveness	Food quality
Efficiency	1	4	3	0.5
Flexibility	0.25	1	0.33	0.25
Responsiveness	0.33	3	1	0.50
Food quality	2	4	2	1
Total	**4**	**12**	**6**	**2**

Table 11.11 Normalization of the comparison matrix

Criteria	Efficiency	Flexibility	Responsiveness	Food quality	Priority
Efficiency	0.279	0.333	0.474	0.222	**0.327**
Flexibility	0.070	0.083	0.053	0.111	**0.079**
Responsiveness	0.093	0.250	0.158	0.222	**0.181**
Food quality	0.558	0.333	0.316	0.444	**0.413**

consistency of 0.059 was obtained for four criteria in the evaluation. This degree is lower than the permitted limit (0.1); therefore, it is concluded that the degree of consistency is acceptable.

11.4.4.4 Step 4: Options Assessment and Final Decision

To compare the improvement actions, the same preference ranges from Table 11.3 will be used for each criterion, making 4 Tables where each corresponds to one criterion. The following Tables 11.12, 11.13, 11.14 and 11.15 show the results.

Then, each score is normalized with the total obtained, and an average is made by columns in which the priority index of the solution concerning the corresponding criterion is obtained. In the end, each improvement action is obtained with its priority index. Tables 11.16, 11.17, 11.18, and 11.19 show the normalization process.

Table 11.12 Efficiency Comparison

Efficiency	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation
Integrated data warehouse	1	1/3	3	5
Innovation laboratory	3	1	4	5
Demand forecasting methods	1/3	1/4	1	3
Digitalization of delivery documentation	1/5	1/5	1/3	1
	5	**2**	**8**	**14**

Table 11.13 Flexibility comparison

Flexibility	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation
Integrated data warehouse	1	4	3	5
Innovation laboratory	1/4	1	1/3	3
Demand forecasting methods	1/3	3	1	4
Digitalization of delivery documentation	1/5	1/3	1/4	1
	2	**8**	**5**	**13**

Table 11.14 Responsiveness Comparison

Responsiveness	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation
Integrated data warehouse	1	3	3	4
Innovation laboratory	1/3	1	1	3
Demand forecasting methods	1/3	1	1	3
Digitalization of delivery documentation	1/4	1/3	1/3	1
	2	**5**	**5**	**11**

Table 11.15 Food quality comparison

Food quality	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation
Integrated data warehouse	1	1	3	4
Innovation laboratory	1	1	3	4
Demand forecasting methods	1/3	1/3	1	3
Digitalization of delivery documentation	1/4	1/4	1/3	1
	3	**3**	**7**	**12**

Table 11.16 Efficiency normalization

Efficiency	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation	Priority
Integrated data warehouse	0.22	0.19	0.36	0.36	**0.281**
Innovation laboratory	0.66	0.56	0.48	0.36	**0.515**
Demand forecasting methods	0.07	0.14	0.12	0.21	**0.137**
Digitalization of delivery documentation	0.04	0.11	0.04	0.07	**0.067**

Table 11.17 Flexibility normalization

Flexibility	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation	Priority
Integrated data warehouse	0.56	0.48	0.65	0.38	**0.520**
Innovation laboratory	0.14	0.12	0.07	0.23	**0.141**
Demand forecasting methods	0.19	0.36	0.22	0.31	**0.268**
Digitalization of delivery documentation	0.11	0.04	0.05	0.08	**0.071**

Table 11.18 Responsiveness normalization

Responsiveness	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation	Priority
Integrated data warehouse	0.52	0.56	0.56	0.36	**0.549**
Innovation laboratory	0.17	0.19	0.19	0.27	**0.183**
Demand forecasting methods	0.17	0.19	0.19	0.27	**0.183**
Digitalization of delivery documentation	0.13	0.06	0.06	0.09	**0.085**

Table 11.19 Food quality normalization

Food quality	Integrated data warehouse	Innovation laboratory	Demand forecasting methods	Digitalization of delivery documentation	Priority
Integrated data warehouse	0.39	0.39	0.41	0.33	**0.379**
Innovation laboratory	0.39	0.39	0.41	0.33	**0.379**
Demand forecasting methods	0.13	0.13	0.14	0.25	**0.161**
Digitalization of delivery documentation	0.10	0.10	0.05	0.08	**0.081**

Table 11.20 Final score per improvement action

Integrated data warehouse	0.389
Innovation laboratory	0.369
Demand forecasting methods	0.166
Digitalization of delivery documentation	0.076

Finally, the best possible solution can be parameterized and evaluated based on the weights of the criteria and the scores obtained per criteria for each solution. The final results are shown in Table 11.20.

Finally, improvement action 1 has the highest score of 0.389. This is because this solution scored highest on the most critical and weighty criteria. This consisted of food quality, efficiency, and responsiveness of the supply chain. This means that this solution highly influences KPIs related to the abovementioned categories, which also strongly favor stakeholders. Furthermore, this chosen strategy is aligned with the operational strategies from Weinberger (2009). This proposed solution is the hand with an information system strategy whose focus is to "have accurate, timely and reliable information for correct decision making. Measure gear and checks progress" (Weinberger 2009).

Improvement action 1: Implement an integrated data warehouse for the entire distribution process that allows access to data in real-time every 6 h of update. This data warehouse would support all other company applications.

Way of implementation—Perform an ETL process for data standardization (IBM Cloud Education 2020).

- Extract: Extraction of data from all sources in all functional areas.
- Transform: Transform, which involves cleaning and linking the data. Data must finally be organized.
- Load: Load all organized and integrated data into a central repository, which will be the primary source of information for the company.

11.5 Conclusions

The qualitative analysis to discover the critical causes provides our research with an adequate background to stress what deviates a company from an optimal distribution process in the poultry industry. Then, tools such as relations diagrams and issue trees enabled the identification of critical causes, the ones the research must focus on to have a higher probability of taking advantage of the improvement opportunity. Considering those critical causes, the execution of the Analytical hierarchy process in the case study enabled the optimal selection of improvement actions according to stakeholders' interests and the most important criteria, food quality, efficiency, and responsiveness.

The findings show that implementing an integrated data warehouse is the best option since integrated information in all functional areas can impact strategic decisions. This solution punctuates higher food quality, efficiency, and responsiveness, which are the most critical criteria. This solution can influence efficiency KPIs such as distribution, transaction cost, and warehousing allocation. On the other hand, regarding food quality, better management of lead time or service level can lead to greater product reliability. Finally, regarding responsiveness, an appropriate view of information can produce better customer relationships.

Another improvement action that could have been taken into account is the implementation of an innovation laboratory due to a score very close to the main solution, which was an integrated data warehouse. However, in one of the criteria of average weight, which is the level of response, this solution scores well below.

With an integrated data warehouse, better decisions can be made due to the permanent updating of information; on the contrary, in an innovation laboratory, an entire iterative or sequential process is required to apply the improvement. For this reason, the low level of response is justified. Lastly, demand forecasting solutions and digitization of delivery documentation are not considered because they score low on a critical criterion for the industry and the distribution process, food quality.

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Chapter 12
Geolocation for Tracing the Optimal Route for Claims Attention of Dairy Products

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Abstract Given their size, Mass consumption companies constantly resolve a large number of claims. Sometimes, these claims are not attended to with the necessary speed owing to non-optimized prioritization. The following article proposes using georeferencing, routing, and forecasting to improve this process. To achieve the above, the case of a leading company in the dairy industry will be analyzed internally and externally, as well as the application of quality tools.

Keywords Distribution · Optimal route · Forecast · Supply chain · Logistics · Transportation

12.1 Introduction

Managing a supply chain in a competitive environment in which companies must operate is challenging. For this reason, "the supply chain strategy helps managers to improve their business, but also the integration with their suppliers and customers" (Perez-Franco et al. 2016). In the present work, we analyze the context of a dairy company with a personalized customer service strategy that presents the problem of insufficient personnel to deal with claims, added to a process with a bottleneck.

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This study aims to draw an optimal route using MyRouteOnline, a route planning software, to achieve efficient claims attention.

12.2 Case Study: Analysis

Despite being a substitute product, dairy products are part of the primary family basket in Peru (Zavala 2010). This can be explained by its essential nature, which means that milk-based products contain rich quantities of calcium, proteins, and vitamins (Adzic et al. 2020). This characteristic makes the dairy product market less sensitive to globalization than other markets (Monenci et al. 2021). Therefore, during the pandemic, this industry persisted as one of the most critical aspects of production, processing, and distribution (Sharma and Sinha 2020). One particularity faced by the dairy industry in the Peruvian context is the lack of refrigeration in some households. In the first trimester of 2020, only 58.2% of homes had a fridge (INEI 2020). As milk-based foods are traded as conserved and usually preserved in aluminum jars, this has become an issue (García-Jaime 2019; Batista-Branco 2019; Gomez-Gonzalez 2019).

In this way, the relationship between dairy product businesses and their consumers and how it is handled acquires relevance. The relationship above is B2C, and one of its particularities for the supply chain is that agility has a beneficial impact on generating value for customers and, thus, satisfaction (Gligor et al. 2020). In addition, food distribution channels have the most significant potential to generate value (Gazdecki and Goryńska-Goldmann 2020). To capture positive impacts, agility may be within the different processes of the supply chain. One of these is dealing with complaints. It is considered an essential element of customer engagement because it demonstrates a company's commitment, which can be due to claims that may focus on customer needs and interests (McCole 2004). Specifically, this study focuses on complaints in the dairy industry.

12.2.1 General Analysis

To face a competitive industry, dairy companies should develop strategies. It can be based on Michael Porter's generic competitive strategies, which depend on the scope and advantage of cost leadership, differentiation, cost focus, and differentiation focus (Porter 1985). The generic strategy of the analyzed dairy company is cost leadership because of its process efficiency, trajectory, market knowledge, standardized products, and process efficiency. As a result, the company produces large volumes at low costs per unit (Weinberger 2009). Moreover, the company is constantly looking to decrease costs to achieve greater efficiency while maintaining high quality.

The company highlights a reduction in costs and competitive prices compared with the competition. Thus, regarding generating value, Osterwalder and Pigneur proposed a business model canvas where the value proposition might address customer needs through newness, performance, customization, “getting the job done,” design, brand, price, cost reduction, risk reduction, accessibility, and convenience (Osterwalder and Pigneur 2009). In this case, the value proposition considers the accessibility of its products and recognition of the brand throughout the national territory.

12.2.2 Supply Chain Analysis

The supply chain involves manufacturers, suppliers, retailers, and customers (Babu et al. 2009). Moreover, food industries are essential for sustaining the community’s health and nutrition; thus, operations must guarantee efficiency and be innocuous (Orellana et al. 2022). One of the highlights of the dairy industry in Latin America is that innovation emerges from the interaction between agents, incentives, and institutions (Castillo et al. 2021; Castillo et al. 2019). The above can be seen in the last mile logistics of the company, which works with distribution centers strategically located to deliver products to different customers around Peru. Regarding this characteristic, outbound distribution is estimated to be costly, accounting for up to 20 percent of the manufacturing cost (Chopra and DL 2020).

According to the Council of Logistics Management, supply chain management is the process of planning, implementing, and controlling the flow and storage of raw materials, in-process inventory, finished goods, and information related to the point of consumption efficiently and at the lowest cost to satisfy customer needs (Riveros and Silva 2004). In this company’s case, its supply chain begins with milk recollection in the different stables around cities, such as Arequipa, Moquegua, Cajamarca, and the surroundings of Lima. Subsequently, the milk is collected and produced in a factory in Lima’s industrial zone. The finished product is then distributed and marketed at different cellars, markets, and supermarkets throughout the country.

Therefore, we focus on the relationship between manufacturers and customers. To address these complaints, the company has a call center where customers can make their claims. In this way, once the complaint is made, if the precedence of the product is a refrigerated place, the claim is transferred to the quality area; otherwise, it does not proceed. Subsequently, the traceability of the product is performed to determine the attention priority level. According to the priority level, the pickup date was seated for face-to-face intervention. Therefore, the company seeks prompt and personalized attention to its customers because customers who feel valued in the connection and know that the organization is paying attention to their needs are more likely to become repeat customers (Aulia 2022).

One of the logistics controllers associated with the analyzed case is efficiency, which can be measured as the number of hours or days to attend to a claim in a particular area. Similarly, another driver is the company’s responsiveness to dealing with a high number of claims. It also highlights the transport availability controller and the information provided to customers to answer their questions about the product.

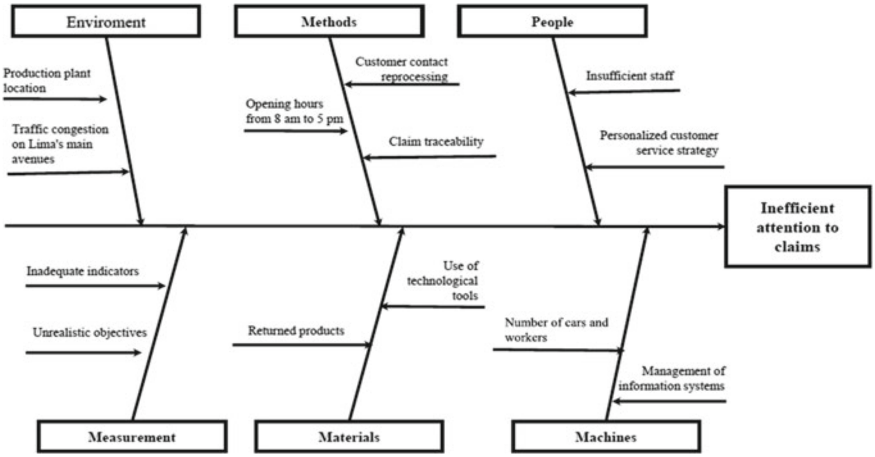

Fig. 12.1 Company's Ishikawa diagram

12.3 Identification of the Problem

The identified problem was inefficient attention paid to claims. Figure 12.1 shows the analyzed problem by applying a fishbone diagram. Thus, this study focuses on personalized customer service strategy, traffic congestion, use of technology, and information systems management to improve efficiency in the attention of defective product complaints.

One of the factors analyzed was the environment, pointing out the factory's location on the outskirts of Lima and, related to that, the traffic congestion on the major avenues. Another point is the methods used in the process, such as the range of attention from 8 a.m. to 5 p.m. and claim traceability. However, it is essential to consider the balance between the attention process and people. For example, the company has insufficient staff to claim attention, but these people offer personalized customer services. Another relevant aspect is the measurement, and at this point, the indicators used to monitor the process are inadequate, combined with unrealistic objectives. This process works with Excel; the machines are the specific number of cars and management information systems.

12.4 Methodology

To analyze and determine the optimal routes for picking defective products, it was necessary to determine a way to organize and prioritize the different districts that were going to be visited. The collected data correspond to the different claims received in 2021, sorted by district and place to visit.

Geolocation is a process in which information is obtained from a person, company, event, or city at a given geographical point (Serna 2017). This point can be determined by the coordinates, which usually come from satellites, to obtain the global position of the point. In this way, the application of geolocation in this work identifies the claim positions' geographical positions so that the possible optimal routes can be identified. This is possible because of the proliferation of GPS-equipped devices and map-based applications, which have enabled people to instantly obtain location data and other spatial information (Forman 2021; Reza et al. 2017).

The dairy company provided the data for use. Specifically, the reclamation history for 2021. This database contains 4141 records. Then, the address, latitude, and longitude columns were generated using the Google extension Geocoding by SmartMonkey. As a result, 88 records were eliminated, and the remaining 4053 records were correctly georeferenced. Subsequently, this database was uploaded to QGIS and converted into a geographic file. Figure 12.2 shows the historic claims according to their geographical origins.

Route optimization efficiently determines the best route from a warehouse or distribution center to its destination. This "effective" route must be executed in the fastest and most profitable manner possible (Verizon Connect, s.f.). Likewise, it should be noted that the best route often does not necessarily involve the shortest route. That is because route search optimization focuses on minimizing the total driving time, considering the number of visits and other variables such as time windows for delivery times, vehicle load, the distance between distributors and delivery points, and even congestion and traffic accidents.

To exemplify the methodology, we used the Miraflores district to identify the address of claims. In this study, we identify multiple points of sale of the company's products, such as markets, convenience stores, supermarkets, and nano stores that are much smaller and have less than 15 square meters of the store, or perhaps no stores at all but a street cart (Blanco and Fransoo 2013), highlighting which are related to a claim. Figure 12.3 illustrates the different sale points within the Miraflores district.

Given that the different claims correspond to addresses distributed all over Lima, it was necessary to establish a method to organize and prioritize the pickup. Therefore, the strategy used is based on the APEIM model (APEIM 2020), which separates the Lima districts into ten different zones. In this study, we work with data corresponding to nine out of ten zones, as listed in Table 12.1.

Figure 12.4 shows the geographic scope of each of these APEIM zones.

The districts for this investigation were selected based on the APEIM zones mentioned above. Therefore, route-optimization software was selected, focusing on minimizing distance, minimizing time, and balancing distance and time (MyRouteOnline 2011). MyRouteOnline, an access-free route optimization software that uses different parameters to determine the best route and obtain multiple stop-driving directions, was run (MyRouteOnline 2011). In the following section, we will show and discuss the results obtained from the software.

Fig. 12.2 Geolocation of historical claims 2021

12.5 Results

We determined the optimal routes for each zone by using the free version of MyRouteOnline. com. Figure 12.5 shows the route optimization for zone 1, which consists of the districts Puente Piedra, Comas, and Carabayllo and represents 12.2% of the total population in the Lima Metropolitan Area (CPI 2022).

Hence, considering six stops and the 49.2 km to commute, the optimized route should take approximately 4 h, as shown in Table 12.2.

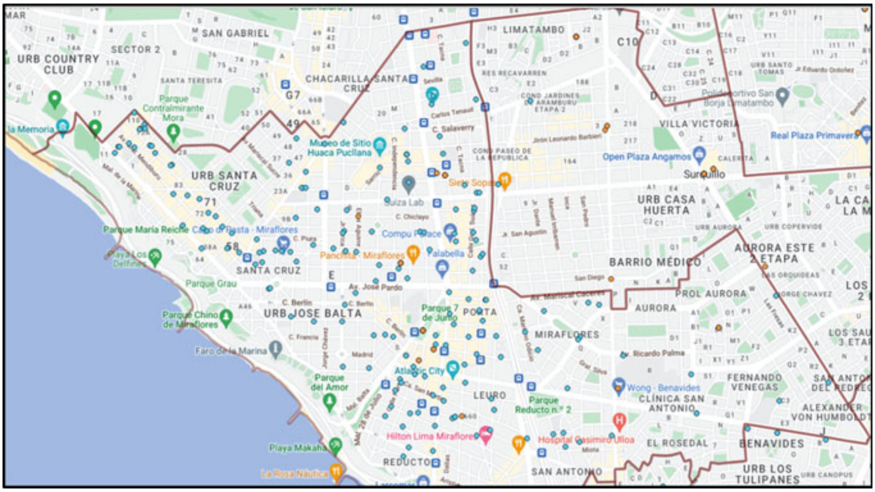

Fig. 12.3 Sale points in the district of Miraflores

Table 12.1 APEIM zones used in the analysis

APEIM Zones	Districts considered in the APEIM zone
Zone 1	Puente Piedra, Comas, Carabayllo
Zone 2	San Martín de Porres, Los Olivos, Independencia
Zone 3	San Juan de Lurigancho
Zone 4	Breña, Cercado de Lima, La Victoria
Zone 5	Ate, Lurigancho, San Luis, El Agustino
Zone 6	Lince, Pueblo Libre, San Miguel, Jesús María, Magdalena del Mar
Zone 7	La Molina, Miraflores, Santiago de Surco, San Isidro, San Borja
Zone 8	Chorrillos, Surquillo, San Juan de Miraflores
Zone 9	Lurín, Villa María del Triunfo

On the other hand, Fig. 12.6 shows the route optimization for zone 2, which is integrated by the following districts: San Martin de Porres, Los Olivos, and Independencia, representing 12.4% of the total population in the Lima Metropolitan Area (CPI 2022).

Thus, considering five stops and the 56.9 km for commuting, the optimized route should take approximately 3 h, as shown in Table 12.3.

Figure 12.7 shows the route optimization for zone 3, which is conformed by the San Juan de Lurigancho district and comprises 10.8% of the total population in the Lima Metropolitan Area (CPI 2022).

Considering six pickup stops and 36.92 km for commuting, the optimized route should take approximately 3 h and 23 min to reach its final destination, as shown in Table 12.4.

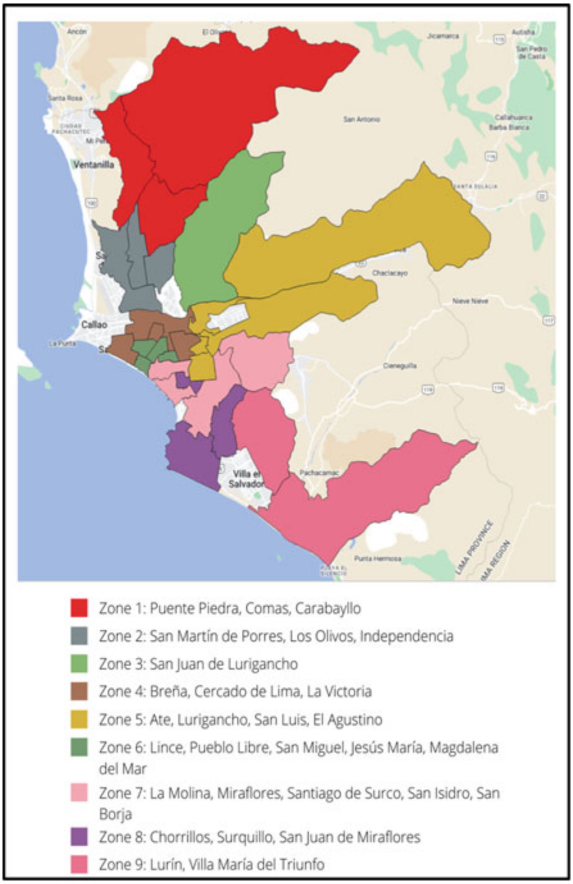

Fig. 12.4 Geolocation of APEIM zones

Figure 12.8 shows the route optimization for zone 4, which includes the districts of Breña, Cercado de Lima, and La Victoria. It is one of the areas with one of the most significant distances to travel in kms. However, it has the avenue of Ramiro Prialé, which facilitates commuting between districts.

This avenue's use means all five expected stops can be met in approximately 3 h and 14 min, as shown in Table 12.5.

Figure 12.9 shows the route optimization for Zone 5, which includes the districts of Ate, San Luis, and El Agustino. This route also uses Avenue Ramiro Prialé, which facilitates the transport of many vehicles between districts.

Therefore, all five expected stops can be met in approximately 3 h and 7 min, as listed in Table 12.6.

Figure 12.10 shows the route optimization for zone 6, which comprises Lince, Pueblo Libre, San Miguel, Jesús María, and Magdalena del Mar districts. The great vehicular congestion stands out in this area, making optimizing routes using main avenues difficult.

Fig. 12.5 Route optimization results for Zone 1

Table 12.2 Summary of route optimization results for Zone 1

	Description
APEIM zone	1 (Puente Piedra, Comas, Carabayllo)
Number of stops	6
Route duration (in h)	04:04
Distance (in kms)	49.2

Therefore, the travel time exceeded 4 h in attending the claim pickup points, as shown in Table 12.7.

Figure 12.11 shows route optimization for zone 7, which contains some of Lima's most residential and urban districts: La Molina, Miraflores, Santiago de Surco, San Isidro, and San Borja.

Therefore, it is possible to use routes independent of the main avenues to reach the six estimated service points. However, vehicular congestion in these districts means that the total time is approximately 4 h, as shown in Table 12.8.

Figure 12.12 shows the route optimization for Zone 8, which consists of Chorrillos, Surquillo, and San Juan de Miraflores.

The best option for this area is the use of main avenues, such as the Panamericana Sur to Chorrillos, with turns towards the target points located in adjacent districts, such as Surquillo, as shown in Table 12.9.

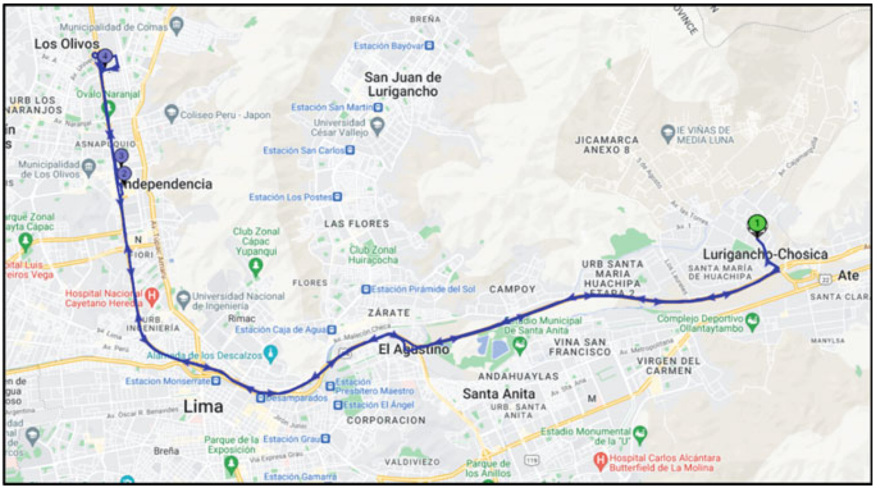

Fig. 12.6 Route optimization results for Zone 2

Table 12.3 Summary of route optimization results for Zone 2

	Description
APEIM zone	2 (San Martín de Porres, Los Olivos, Independencia)
Number of stops	5
Route duration (in h)	03:01
Distance (in kms)	56.9

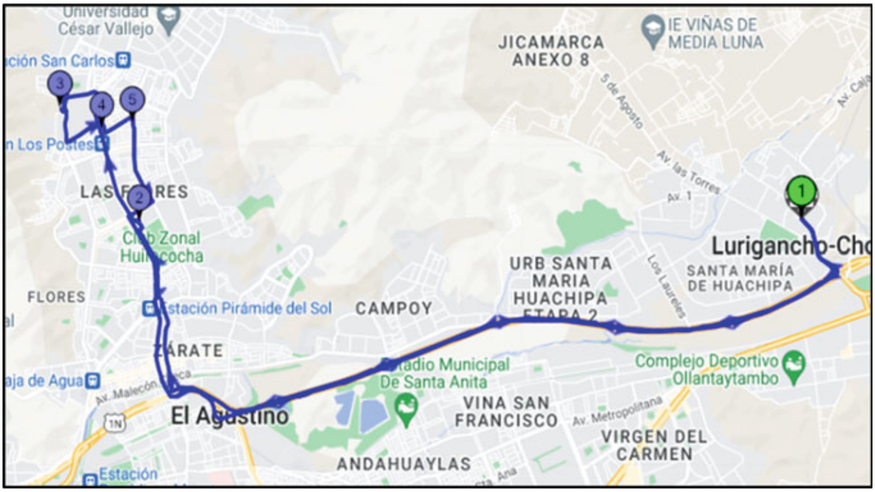

Fig. 12.7 Route optimization results for Zone 3

Table 12.4 Summary of route optimization results for Zone 3

	Description
APEIM zone	3 (San Juan de Lurigancho)
Number of stops	6
Route duration (in h)	03:23
Distance (in kms)	36.92

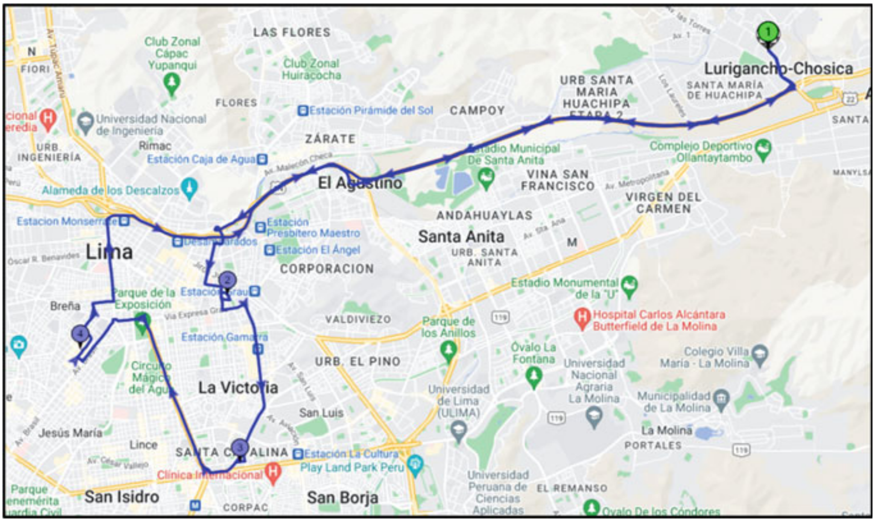

Fig. 12.8 Route optimization results for Zone 4

Table 12.5 Summary of route optimization results for Zone 4

	Description
APEIM zone	4 (Breña, Cercado de Lima, La Victoria)
Number of stops	5
Route duration (in h)	03:14
Distance (in kms)	50.55

Figure 12.13 shows the route optimization for zone 9, which includes the Lurin and Villa Maria del Triunfo districts. It is the area with the most kilometers to commute, but it has the Panamericana Sur avenue, which facilitates the transport of many vehicles between these two districts.

All four expected claims can be met in approximately three hours due to this avenue's use, as shown in Table 12.10.

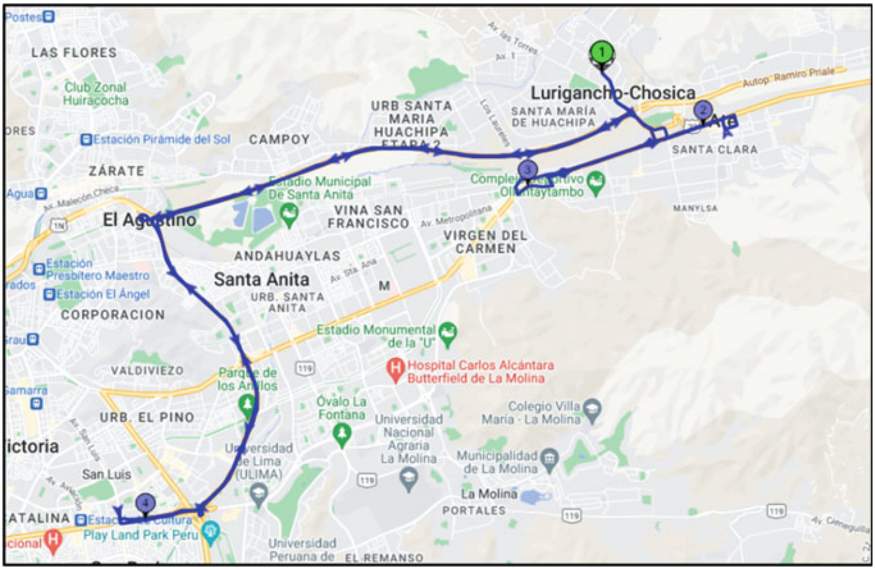

Fig. 12.9 Route optimization results for Zone 5

Table 12.6 Summary of route optimization results for Zone 5

	Description
APEIM zone	5 (Ate, Lurigancho, San Luis, El Agustino)
Number of stops	5
Route duration (in h)	03:07
Distance (in kms)	52.27

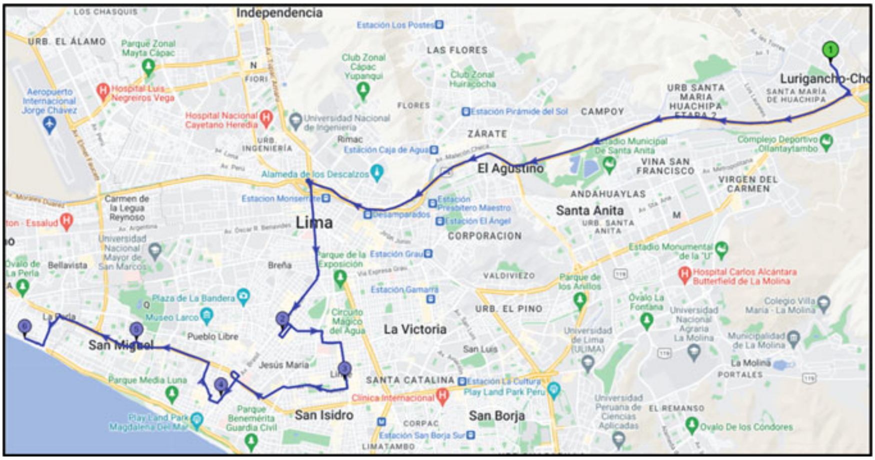

Fig. 12.10 Route optimization results for Zone 6

Table 12.7 Summary of route optimization results for Zone 6

	Description
APEIM zone	6 (Lince, Pueblo Libre, San Miguel, Jesús María, Magdalena del Mar)
Number of stops	6
Route duration (in h)	04:06
Distance (in kms)	39.42

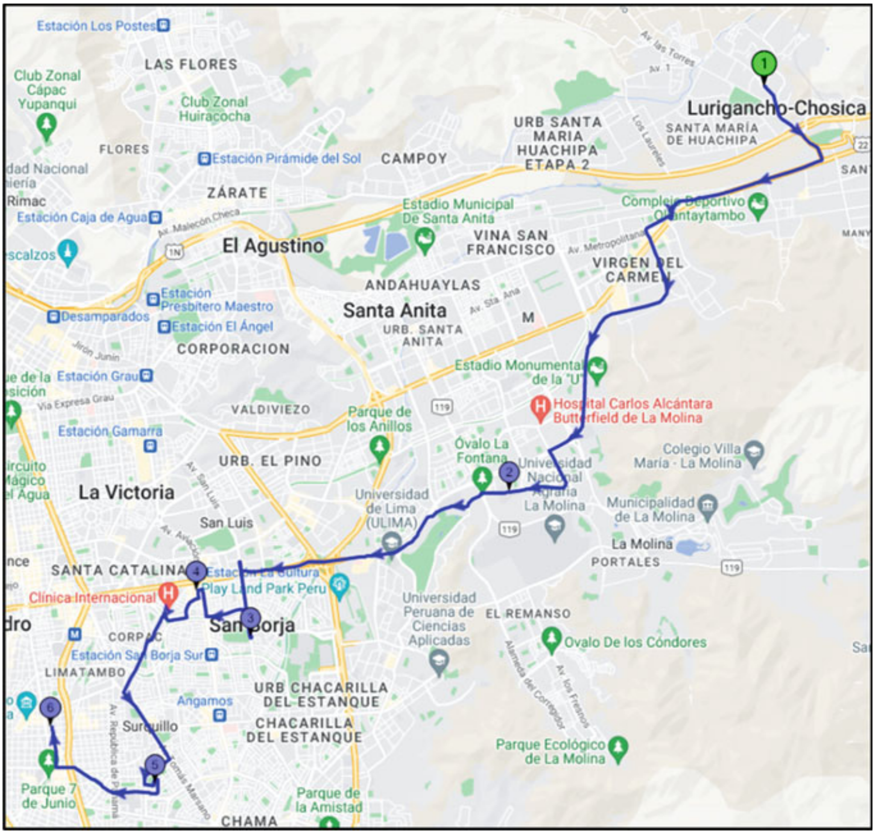

Fig. 12.11 Route optimization results for Zone 7

Table 12.8 Summary of route optimization results for Zone 7

	Description
APEIM zone	7 (La Molina, Miraflores, Santiago de Surco, San Isidro, San Borja)
Number of stops	6
Route duration (in h)	03:59
Distance (in kms)	30.2

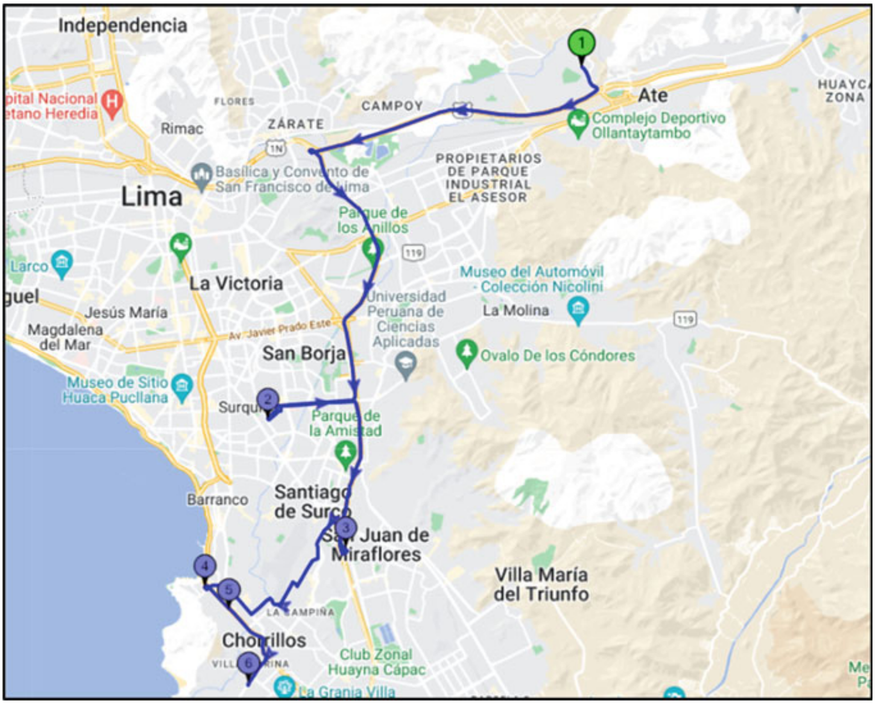

Fig. 12.12 Route optimization results for Zone 8

Table 12.9 Summary of route optimization results for Zone 8

	Description
APEIM zone	8 (Chorrillos, Surquillo, San Juan de Miraflores)
Number of stops	6
Route duration (in h)	04:07
Distance (in kms)	48.13

12.6 Results and Discussion

A summary of the results is presented in Table 12.11. From the summary of the results, the average travel duration to resolve the claims for each APEIM Zone is 3.48 h. It is important to consider that all claims must be addressed during the day for the convenience of retailers. Therefore, it is critical to fine-tuning the routes with new variables that can be determined by testing them.

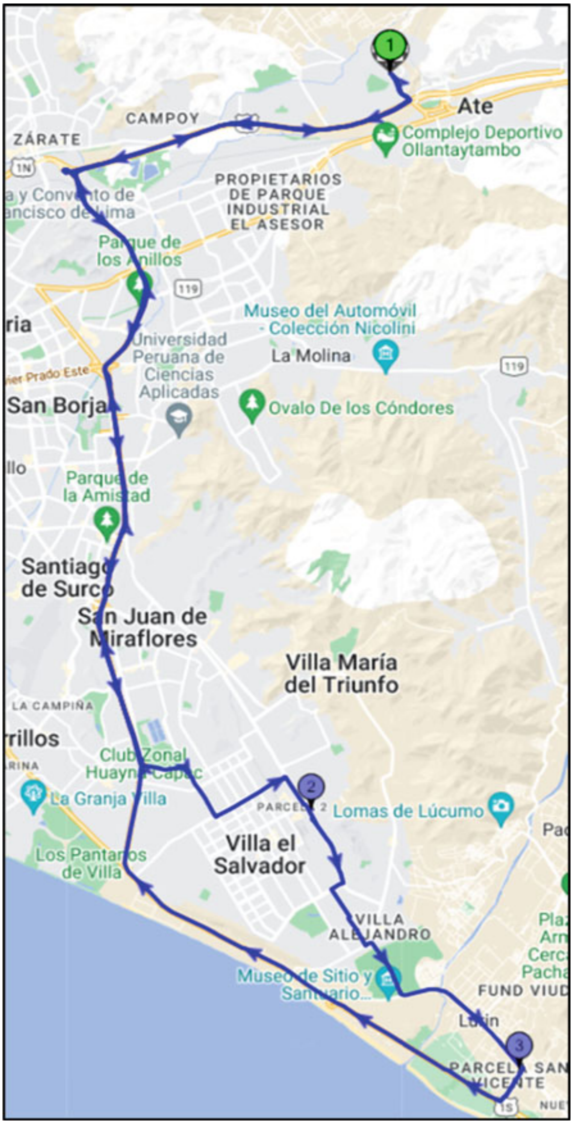

Fig. 12.13 Route optimization results for Zone 9

Table 12.10 Summary of route optimization results for Zone 9

	Description
APEIM zone	9 (Lurín, Villa María del Triunfo)
Number of stops	4
Route duration (in h)	03:13
Distance (in kms)	96.16

Table 12.11 Results Summary

APEIM Zone	Number of Stops	Route duration (in h)	Distance (in kms)
Zone 1	6	4.04	49.2
Zone 2	5	3.01	56.9
Zone 3	6	3.23	36.92
Zone 4	5	3.14	50.55
Zone 5	5	3.07	52.27
Zone 6	5	4.06	39.42
Zone 7	6	3.59	30.2
Zone 8	6	4.07	48.13
Zone 9	4	3.13	96.16

12.7 Conclusions and Recommendations

In a growing country like Peru, mass consumption companies receive more and more complaints from customers dissatisfied with their products (Greg et al. 2020). Prompt attention to complaints influences the reputation of the company and the demand for its products. Thus, Peruvian brands need to provide specialized customer services.

In that sense, when the company needs to deal with complaints for defective products and immediate pickup is required, research has shown that, on average, the number of stops needed to retrieve defective products is five for each APEIM zone in the Lima metropolitan area. Likewise, consider a 30-min stop. Each route takes approximately 3.5 h, or about 51.1 km, to address the complaint and provide a solution.

There were limitations throughout the investigation. Currently, the company does not extract the latitude and longitude values for each prompt, so the exact location of each complaint needs to be extracted and introduced on the QGIS platform. Although the provided data were sufficient to generate routes, the process might have been automatized by already providing the coordinates. In addition, the data provided were only about last year; having it for more years could have been helpful to elaborate on the significant points mentioned in the next paragraph.

For the actual research, the information used was for 2021; thus, we propose using more recent and historical data for subsequent investigations. The other significant points are based on the conclusions: First, prioritization criteria are established to attend to the claims. This can be achieved by considering different factors that characterize the zones given by the APEIM model to develop more precise criteria and deliver the service faster. Second, considering historical data, we determined how route optimization improves the current claim resolution time. Finally, a forecasting tool such as Holt-Winters can be developed based on a seasonal method.

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Chapter 13
Diagnosis and Improvement of Processes for a Distribution Center in a Mass Production Company

Mónica López-Campos and Arón Barahona Ríos

Abstract The main objective of this work is to diagnose and improve the proposal for a Distribution Center (DC) of a productive Chilean company. This implies recognizing the current state of the DC, analyzing its processes and bottlenecks, and obtaining time measurements. The research problem is associated with the current main problems: operation using overtime costs, dispatch delays, and storehouse collapse. The diagnosis stage considers the parameters to be measured, such as time, number of purchase orders, packing, dispatches, and receptions. This diagnosis allows us to understand that aisle operators (pickers) are a critical resource and that the first work processes to improve concern picking and dispatching. Thus, it is possible to improve the operation of the DC to enhance critical resources and processes. It is proposed to use two pickers and invest them in two tablets. It is estimated that this proposal could significantly reduce external storage costs because it implies an increase in the capacity to process orders by 42.5%, equivalent to 145 releases, which is 43 more than today.

Keywords Distribution center · Dispatches · Picking · Diagnosis · Simulation

13.1 Introduction

For some years, a Chilean mass production company has been experiencing increased operating costs in its distribution center (DC) and the value of rents for external warehouses. Concerned about this situation, the operations management department is developing an improvement plan. It is possible to analyze and make decisions based on the details of DC operation, and the first step was to diagnose the current situation of DC.

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From these observations, it is possible to observe the notorious collapse of the two warehouses in the DC. The first warehouse is used for flammable finished products, and the second is used for non-flammable finished products (miscellaneous). Collapse is to such an extent that the first task in the morning is to clear the aisles of the non-flammable warehouse from the pallets that did not reach their location on the racks. Because of the inefficiency of the DC, the excess of overtime has brought not only cost problems but also fatigue to the operational staff whenever they can make it noticeable.

To develop this research, it is necessary to recognize and differentiate the processes developed in the DC, defining the beginning and end. Once the set of processes is clear, it is necessary to determine the bottlenecks. Process mapping and data survey are then required. According to Frazelle (2016), to take any action within a warehouse, it is essential to recognize the state in which it operates, the associated processes, the product flow, and everything related to the most important resources: human, space, and technological. In addition, to carry out this project, we consulted related material in literature such as Ballou (2004) and Carranza (2004), and we studied similar practical cases as developed by Guaita (2008), Cortes (2010), López (2011), Horvat (2012), Pena and Forero (2012), and Milla and Silva (2013)

In short, this research answers how a company's DC works, recognizes its main shortcomings, integrates a comprehensive diagnosis, and recommends an improvement plan. The general objective is to diagnose the current situation of the DC of the company, create a simulation model of the current situation, and identify opportunities to integrate improvement plans. This work was performed using the BPMN language in Bizagi Modeler to describe flowcharts and arena to simulate the use of resources available on the DC. The following specific objectives were proposed to achieve this general objective:

- Recognizing the different processes of the DC and describing them using BPMN
- Obtaining current operating parameters.
- Designing the model in the Arena software using the analysis results
- Obtaining results and proposing improvement plans.

13.2 Diagnosis of the Current Situation

The first step for diagnosis corresponds to recognizing the processes within the company's DC. Once this recognition has been made, and the facilities have been personally toured, a description of the processes is made in terms of their operation and as a whole. When the description was complete, a BPMN model was developed to visualize the operation of the DC. Together with operations management, the most relevant processes for an improvement project are defined. Then, the data on the reception of the finished products, preparation of the orders, and their dispatch were measured. These data must be analyzed and modeled in arena. The results of these models were analyzed to generate improvement plans.

13.2.1 Recognition, Description, and BPMN

To recognize the processes in the company's DC, the DC has been visited and toured multiple times during operation. Many processes have been identified in these tours. To classify them, it has been decided to differentiate the operation into levels according to the complexity that needs to be analyzed. The dispatch manager generally receives the purchase orders (PO), which are transformed into a work order (WO). These WOs are distributed among the aisle workers who carry out picking. Once this is completed, the cranes must take the pallet with the prepared WO and move it to the dispatch area, where a dispatcher will review each WO and define whether it is complete. Otherwise, the dispatcher looks for the responsible picker and notifies him of the fault. The picker must complete the WO and transfer the missing merchandise with a manual pallet truck to the dispatch area. If WO is complete, the crane loads the delivery truck. In parallel, reception is carried out by a receptionist who checks the load that has arrived, defining whether the load is complete. If it is not complete, the load is received, and a notice of the differences is given. If it is complete, it is received only. When the cargo has been received, the cranes must order merchandise by code and store it in the corresponding warehouse. There are two warehouses: one for flammable products and the other for dangerous products (miscellaneous).

Two work schedules are identified. The first one will be called 8 a.m., starting at 8:15 a.m., at 10 a.m., having a 15-min break, at 12:15 a 45-min lunch, and then people will continue working until 6:15 p.m. The second schedule is called 10 a.m., starting at 10:00 a.m., at 12:5, there is a 45-min lunch and then works until 6:00 p.m., with a 15-min break. After recess, work will be performed until 8:00 p.m. It is important to note that from these schedules, the entry is fulfilled but not the exit; this is because, usually, the work has not been finished at the closing time, forcing overtime. Regarding the available resources, there are four tow trucks, nine pickers, two dispatchers, a dispatch manager, and a receptionist.

Concerning the availability of cranes, there is one for the internal movements of the flammable warehouse, another for the internal movements of the miscellaneous warehouse, and two for reception cranes. The crane for internal movements of the flammable warehouse is dedicated to movements within the warehouse, the transfer of the finished WO and the storage of the cargo received corresponding to the same warehouse. It is important to note that this crane does not load dispatch vehicles. The internal movement crane of the various warehouse is also dedicated to moving the WOs that the aisles have prepared and helps with unloading, loading, and storage. Unloading cranes are also dedicated to transferring the prepared WO to store the received cargo and load the orders. It is important to know that the warehouse for flammable products cannot enter a crane other than the one corresponding to that warehouse because of the technical restrictions implied by the storage of products with these characteristics.

There are nine pickers, among which there is a supervisor who, in addition to preparing their assigned WOs, is dedicated to supporting other pickers. The dispatch manager oversees the entire line that involves dispatching, and in this case, his main function is to distribute the PO in the WO to the pickers. There are two dispatchers whose mission is to check that the orders are complete, without surpluses or shortages, for which they review each WO that arrives at the dispatch area, managing the completion of the WO if needed. The receptionist oversees whether the cargo brought by the carrier corresponds to what appears in the dispatch guide. This system was modeled in the BPMN, as shown in Fig. 13.1.

13.2.2 Obtaining and Analyzing the Parameters

From the previous BPMN analysis, the key dispatch processes were defined as the picking carried out in the aisles of the DC, the transfer carried out by the cranes, the review carried out by the dispatchers, and the loading carried out by the cranes. The key process for reception is unloading conducted by the cranes. The parameters to be measured are as follows:

- *Picking*: Time and number of boxes. This process has been measured in two ways: how long the picker takes in its WO, called time *T*, and how long the picker takes specifically to place the boxes of a line on the pallet, called *the picking time*. This is because much time is wasted looking for the product, walking to the product, ordering, and cleaning where the product is located. Additionally, this process was performed independently for each warehouse.
- *Transfer*: time by WO. It measures how long it takes a crane to move a WO from the warehouse where it is located to the dispatch area
- *Review*: Time for WO. It measures how long it takes for a dispatcher to review a WO.
- *Loading*: time per loaded vehicle. It measures how long it takes for a route to be loaded.
- *Unloading*: time per unloaded vehicle. It measures how long it takes for a vehicle to be unloaded.

Each of these processes was followed and recorded 45 times. To determine the available capacity, it is also necessary to know how many POs are processed on a business day and how many pallets are received in each warehouse. These parameters are presented and discussed below.

13.2.2.1 Picking

It should be noted that this process is carried out in two warehouses, one for miscellaneous products and the other for flammable products. It is presumed that the latter operation is faster; thus, they will be reviewed independently.

- **Warehouse of flammable products**

The following results were obtained in a miscellaneous warehouse (Table 13.1).

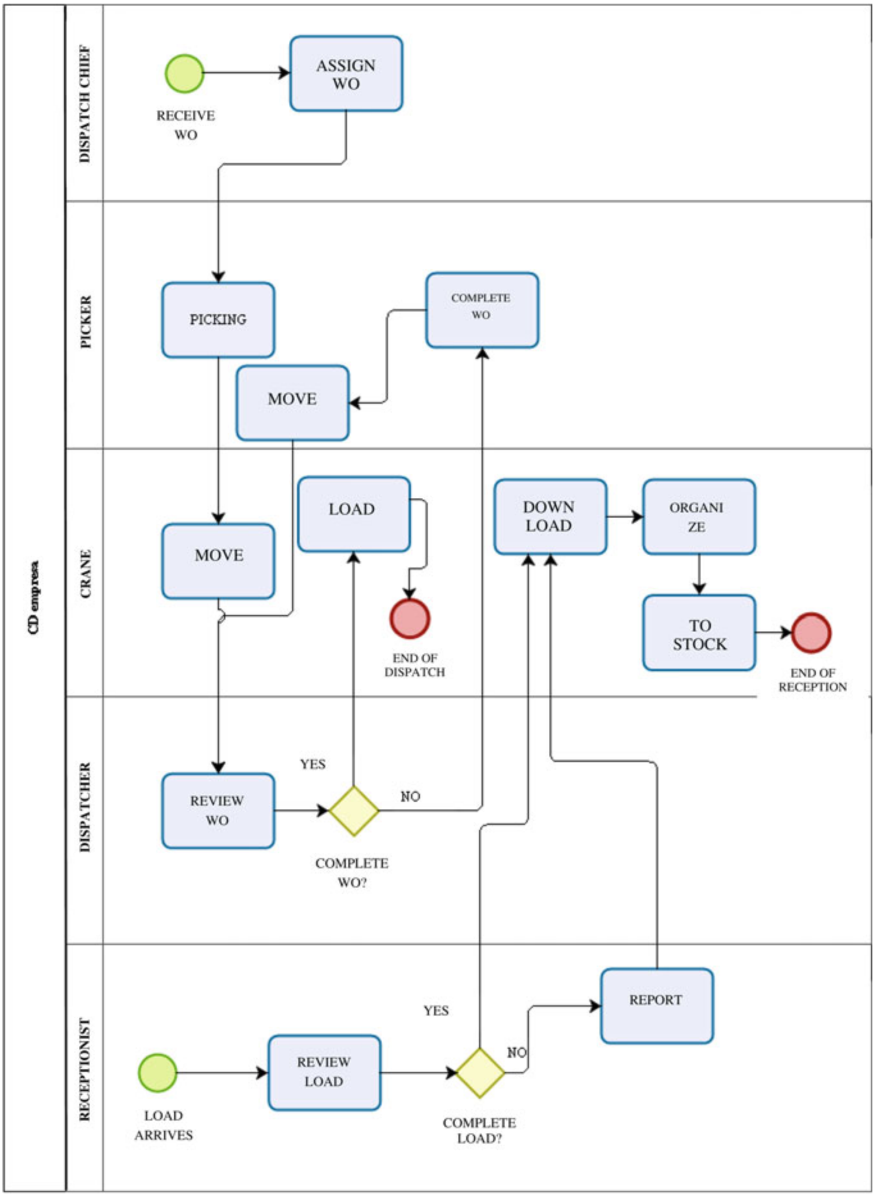

Fig. 13.1 BPMN of the DC

Table 13.1 Summary of the results in the flammable warehouse

Observation	T [min]	Picking [min]	Boxes
Total	315	161	1,289
Average	16	8	64
Deviation	24	19	103

These values corresponded to 20 observations. *Time T* is the time taken by the picker to pick up the pallet on the manual pallet truck, going through the search for each line of products, walking in each attempt to find it, and requesting that the crane came down the pallet if it was in height, ordering, and cleaning the area if it was messy and dirty, also considering the picking time. Picking time is the time the picker takes to pick up and place each box of a line on the pallet of the WO in preparation. It can be noted that the deviation is greater than the average; this is mainly due to abrupt differences in the time-box relationships that exist in some measurements. For example, one observation recorded the data of 10 boxes in 53 s, another recorded eight boxes in 22 s, and a third observation recorded three boxes in 22 s. It is possible to realize that the behavior is inexplicable mathematically because, in some observations, the picker presented more difficulties than others in handling the boxes, mainly because of the differences in the sizes of the boxes of the different products, some even reaching double, triple, and bigger than others.

It can also be said that the picking time for a box, on average, is 7.5 s, while its T time is 14.6 s. If the values of both times are compared line by line, it is obtained that Table 13.2 indicates.

The total efficiency is defined as the average ratio between the *picking time* and the time T of each line. That is, how much of the total time, in %, has been used for picking up the boxes and leaving them on the corresponding pallet. In this case, it corresponds to 39%; that is to say, 61% of the time is wasted in actions such as looking for the position in which the product to be picked up is located, walking more than necessary due to lack of concentration of the picker, or in ordering and cleaning the place where the picking will take place. The search is mainly based on how the products are stored, with a chaotic and random system, with the criterion that the arrangement is made by placing together the greatest possible number of equal products, regardless of whether there are locations with the same product currently in use. This results in a kind of rotation of positions as warehouse locations are released and occupied, generating a product search conflict.

It can also be verified from the recorded data that there is an approximately linear relationship between picking time and the number of boxes. See Fig. 13.2.

Equation 13.1, obtained from Fig. 13.2, has a box offset of $173.3/10.2 = 17$ because the data dispersion is very high. This equation can explain the linear relationship

Table 13.2 Comparison of T with picking

Observation	The difference [min]	Efficiency
Total	154	39%

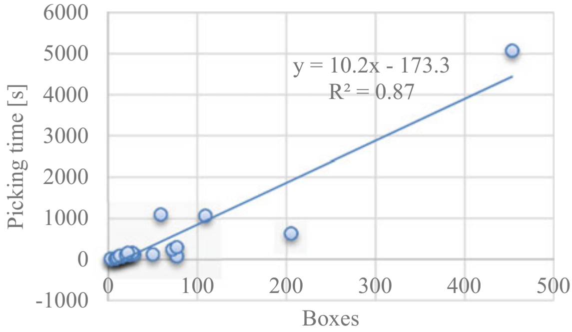

Fig. 13.2 Relationship between the number of boxes and picking time for flammable warehouse

between the number of boxes prepared and the time is taken to pick them, which was 87%.

$$y = 10.2x - 173.3 \tag{13.1}$$

where "y" is the picking time in seconds and "x" is the number of boxes.

- **Warehouse of miscellaneous products**

The following results were obtained for the warehouse of miscellaneous products. See Table 13.3.

These values correspond to 25 observations. Additionally, it is obtained that the total time to prepare a box is 13.8 s while putting it on a pallet takes an average of 7.1 s. As in the flammable warehouse, the deviation is close to the average, and the explanation is the same: there are differences in the sizes of the boxes of different products.

The following table can be obtained by comparing T time with the effective picking time. See Table 13.4.

Tables 13.3 and 13.4 follow that after 583 min (9.7 h), a picker inside the warehouse used 284 min (4.7 h, for operations other than obtaining efficiency. This is 42% on average per line.

Table 13.3 Summary of the results of the miscellaneous warehouse

Observation	T [min]	Picking [min]	Boxes
Total	583	298	2,535
Average	23	12	101
Deviation	21	16	121

Table 13.4 Comparison of *T* with picking

Observation	The difference [min]	Efficiency
Total	284	42%

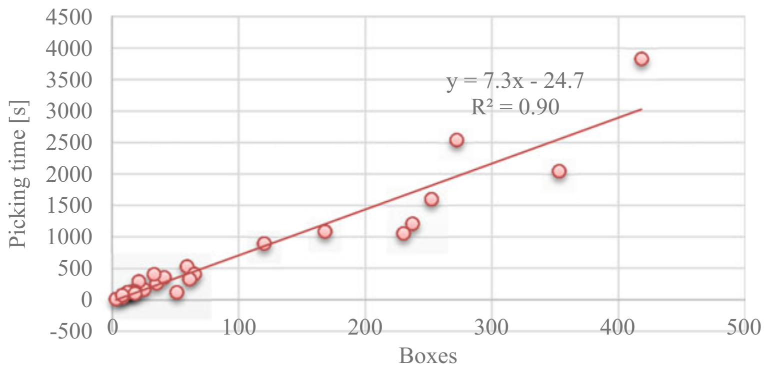

Fig. 13.3 Relationship between the number of boxes and picking time for miscellaneous warehouse

As in the other warehouses, the relationship between the number of boxes and the time spent preparing them is approximately linear. See Fig. 13.3.

Equation 13.2 in Fig. 13.3 shows a lag of 24.7/7.3 = 3.4 boxes, and the number of boxes explains 90% of the picking time.

$$y = 7.3x - 24.7 \tag{13.2}$$

In comparative terms between warehouses, it can be said that the amount of WOs in the miscellaneous warehouse is approximately 1.57 times larger. See Eq. 13.3.

$$\frac{2.535}{1.289} \times \frac{20}{25} = 1.57 \tag{13.3}$$

In Eq. 13.3, the first factor corresponds to the proportion of boxes prepared in the miscellaneous warehouse concerning the flammable warehouse. The second factor is the proportion of the number of observations.

In both cases (flammable and miscellaneous), the T time for a box was close to 14 s. The picking time for a box was close to 7 s, and the efficiency in the two warehouses was close to 40%. With this information, it can be said that the preparation of orders must be determined by the number of boxes and not by the warehouse type.

13.2.2.2 Transfer

All available cranes transfer WOs to their corresponding dispatch areas. This is measured when the crane selects a WO, moves it, and returns to the warehouse. Table 13.5 shows the results obtained for the transfer of the 45 WOs.

Table 13.5 shows that the transfer of 45 WO took 182 min; on average, it took 4 min, with a standard deviation of 1 min. This is complemented by the fact that the standard deviations of the boxes are 121 for miscellaneous warehouses and 103 for

Table 13.5 Summary of transfer results

Observation	Transfer [min]
Total	182
Average	4
Deviation	1

flammables. Thus, it can be understood that the transfer time does not depend on the boxes contained in the WO, but rather on the obstacles that appear on the path, such as other cranes, trucks, pickers, pallets, and garbage.

13.2.2.3 Review

Two dispatchers reviewed the transferred WOs, verifying that the transferred WO was the same as that in the PO. Table 13.6 shows the results obtained for the review of the 45 WOs.

It can be seen that the total review time of the 45 WOs is 149 min (2.5 h), which means an average of 3 min per WO, with a standard deviation of 2 min. This deviation is due to the review time depending on the number of boxes and, in part, the number of different products on the pallet. There are also delays when the WO is incomplete.

A major problem is generated during this process related to the time required to complete a delivery route. A route is composed of one or more POs, which in turn is composed of one or more WOs. Therefore, a route will not be available for loading if it has not been reviewed until the last WO of the route. It would be logical to think that the preparation of WOs has the same order in which they will be dispatched. However, there are currently no defined criteria for granting a preparation order (only the most important clients are given urgent dispatch). For example, the first WO of a route could have been prepared and moved at 8:30 a.m.; however, the route could have been completed at 05:00 p.m. Table 13.7 below shows the results of the parameters of this time window:

Table 13.6 Summary of review results

Observation	Review [min]
Total	149
Average	3
Deviation	2

Table 13.7 Summary of the time window results

Observation	Window [h]	PO	WO
Total	120	325	1,195
Average	2.7	7	25
Deviation	1.2	4	10

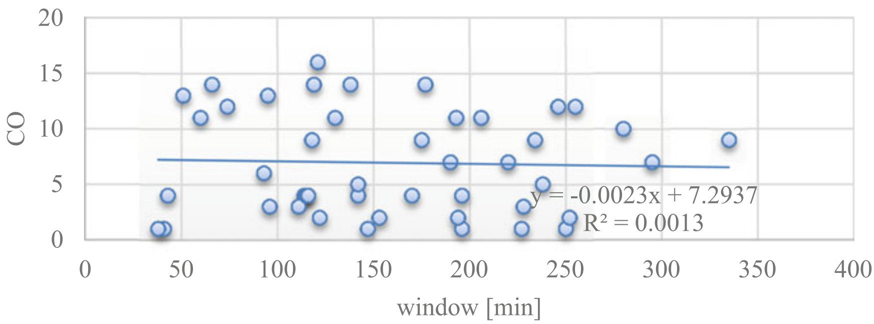

Fig. 13.4 Relationship of the time window with the amount of PO

In summary, 45 routes were followed, and the time window was extended by 120 h, with an average of 2.7 h per prepared route and a standard deviation of 1.2 h.

Figure 13.4 shows that the relationship between the window length and PO amount is not linear, which makes sense given that one route might have fewer orders than another, but the orders can be much larger.

Regarding the relationship between the time window and the number of WOs, it can be said that it has similar behavior and makes sense since there are orders with many or few WOs. This means that this time window is mainly due to planning, which the Logistics Manager validated.

13.2.2.4 Load

The loading process is performed when the dispatcher authorizes a route. Unloading cranes and miscellaneous warehouse cranes can perform this operation. A flammable warehouse crane is not used for this process because it is very specific and expensive equipment and is preferred to optimize its useful life. Table 13.8 presents the results of the upload process.

It can be seen that from a total of 45 observations, the total time has been 80 min, with an average of 1.8 min per pallet with a deviation of 0.6 min. The main difficulties observed in this process are the chaos generated by loading all routes simultaneously, accommodating the pallets in the tightest vehicles, and the limited space available for transit.

Table 13.8 Summary of load results

Observation	Load [min]
Total	80
Average	1.8
Deviation	0.6

Table 13.9 Summary of unloading results

Observation	Discharge [min]
Total	98
Average	2.2
Deviation	1.0

13.2.2.5 Download

The unloading process is carried out when the receptionist reviews the truck with merchandise and authorizes the reception. The time is measured when the crane picks up a pallet, unloads it, and accommodates it in the available area outside each warehouse until the crane returns to the truck. For this process, there are two cranes, called unloading cranes, and the results are listed in Table 13.9.

In the unloading of the 45 pallets, the time was 98 min, with an average of 2.2 min for each pallet and a deviation of one minute. The difficulties in this process are how the merchandise arrives inside the truck; sometimes, the same product arrives at different positions of the truck, which makes orderly arrangement difficult and generates unnecessary movements.

13.2.2.6 Entry and Exit

For the correct functioning of the model to be simulated, it is necessary to know how many POs are processed in a day, how many correspond to which warehouse and how many products are received in each warehouse.

It has already been seen that the workload is not proportional in each PO, so the intention of generating a standard load has been adopted, maintaining that a WO must be composed of 110 boxes. In the picking observations, it was possible to verify, through a histogram analysis, that the largest number of boxes was in the range of 100–120 boxes; 110 boxes per WO satisfy the requirements. Figures 13.5 and 13.6 show that the largest number of boxes prepared by the picker is close to 109 for miscellaneous and 116 for flammable. It aims to generate the WO with some boxes today that the pickers handle, reflecting a large part of their work.

Analyzing the databases, it is possible to define that during 2016, work was carried out in 244 days, processing 5,006,535 boxes in dispatch, equivalent to 45,514 WO. This implies that there are 187 WOs per day, and if the average number of POs processed in a day is 62, one PO must be related to three WOs on average. Additionally, it can be deduced that 33% of the POs correspond to flammable products and 67% to miscellaneous products. It is also known that 33,700 full pallets of finished products were received that year. On average, the pallets contained 220 boxes. Merchandise arrives daily for four reasons: returns, imports, transfers between warehouses, and transfers from the production plant. Table 13.10 summarizes this information.

A value of 0.33 means that imports are received every three days, approximately once a week. On average, 115 pallets were received daily.

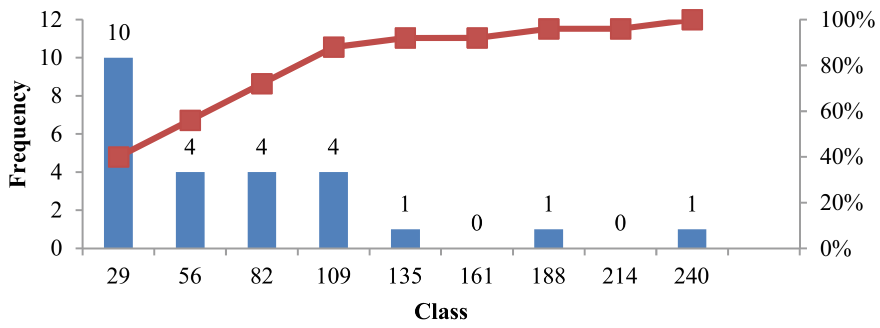

Fig. 13.5 Histogram of the number of boxes in the miscellaneous warehouse

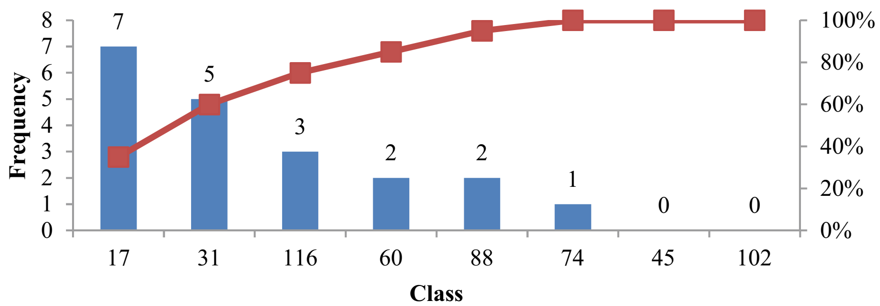

Fig. 13.6 Histogram of the number of boxes in the flammable warehouse

Table 13.10 Summary of merchandise arrival

Arrivals	Return	Import	Transfer	Plant
Times per day	3	0.33	1	5
Pallets at a time	2	32	14	19

13.2.3 Design and Analysis of the Simulation Model

The simulation model must reflect the operation as closely as possible with the information collected to understand how the processes work with available resources. The arena was used as the simulation software because it allows resource-related operations. The model of the current operation of the entire system is not shown in this document because it is very large, and only the proposed model is presented later in this paper.

The model for the current operation was run 244 times, simulating 2016. The model obtained an average of 203 WOs processed per run, with an average of 112 pallets received per day. Both values follow the reality in the previous section and are listed in Table 13.11. On average, a WO spends 10.6 h in processes until it is dispatched, while a pallet takes an average of 1.82 h to be stored, as Table 13.12 shows. The variability in the entire analysis has not been exposed (but it has been considered) because of the values of all minimum cases.

With the information obtained from Table 13.11, it is possible to project the occupation of the warehouses, intending to determine the capacity that will be required in the coming years. It is known that 112 pallets are received daily, and 203 WO are dispatched daily. In addition, a position within the warehouses stores a pallet with 220 boxes, and the WO of 110 boxes is equivalent to 0.5 pallets. The dispatch of 203 WO was equivalent to the release of 33 daily positions in the flammable warehouse and 68 in the miscellaneous warehouse, while 37 and 75 were received, respectively. Tables 13.13 and 13.14 show the 5-year projection of the occupation with a growth of 7% per year, defined by the demand planning area and the sales manager.

The storage capacity of the miscellaneous warehouse is 2,283 positions, which means that if the initial inventory is zero during the first months of the second year, the warehouses would already have storage problems. This is consistent with external warehouses and is explained by the current use of the warehouse, which does not fall below 80%.

The storage capacity of a flammable warehouse is 1,748 positions; therefore, during the first and second years, in theory, there should be no problems; however, in practice, external warehouses are already being used for accumulated products. This is because the projection considers zero as the initial inventory, which is completely different because its occupation ranges between 70 and 100%.

This is a problem that the company should address because using external warehouses is one of the most important capital leaks. In addition, the time each process takes per entity is analyzed, knowing the average waiting time of an entity. The most time-consuming process is, in the first place, picking 6.82 h to process a WO. According to the data, this is mainly explained by the time a WO must wait to be prepared. Secondly, the unloading took 1.65 h, which is explained by the accumulation of work in the process queue; that is to say, if a pallet took 2 min to be unloaded, it had to wait an average of 1.61 h for its turn. Third, there are time windows with values close to 1 h per WO, which reflect the wait for a route to be loaded owing to the non-planning of the dispatch.

Table 13.11 Average number of OT and pallets per day

Number of	Average
WO	202.64
Pallets	111.65

Table 13.12 Average processing time for OT and pallets per day

Number of	Average
WO	10.6244
Pallet	1.8292

Table 13.13 Projection of the occupation of the miscellaneous warehouse

Year	OT	Released positions	Received pallets	Stored	Accumulated
1	49,532	16,593	18,310	1717	1717
2	52,999	17,754	19,591	1837	3554
3	60,948	18,996	20,962	1966	5520
4	70,090	20,325	22,429	2104	7624
5	80,603	21,747	23,999	2552	9876

Table 13.14 Projection of the occupation of the flammable warehouse

Year	OT	Released positions	Received pallets	Stored	Accumulated
1	49,532	8173	9018	845	845
2	52,999	8744	9649	905	1750
3	60,948	9356	10,324	968	2718
4	70,090	10,010	11,046	1036	3754
5	80,603	10,710	11,819	1109	4863

Subsequently, the scheduled utilization of each resource in the model was analyzed, considering its average, half-width, minimum average, and maximum average data. It can be seen that pickers are a critical resource in this model because their scheduled utilization averages 95% on average, and all pickers have had to work up to 16% more than estimated. This happens because there are days when the workload forces DC operations to close, even after midnight, and they imply a great cost over time.

However, the data show that the efficiency of the pickers ranged from 62 to 78%. The time lost in searching, walking, ordering, and cleaning is considered within this value, so the efficiency of the pickers can be improved without modifying the picking procedure, that is, by managing work planning and using technology.

In any case, if it is decided to store with a methodology that allows knowledge of at least the positions of the products during the day, then the search time and unnecessary walks would be considerably reduced, causing the instantaneous use of the aisle to be reduced or to make it more efficient.

13.2.4 Improved Process Proposal

Because bottlenecks are generated during picking and dispatching, it was decided to design a model that shows and confirms this situation and serves as a proposal. The chosen strategy allows for improvements in the equipment investment by only two tablets. In this case, it is proposed that work orders be received at 8:15 and 14:15, corresponding to the load scheduled by the logistics planner. These are called cut-off hours. After each cut-off hour, the dispatch chief must deliver the work plan in a form to each crane. This form contains products and quantities that must be transferred from the racks to the consolidation area. In the consolidation area, at 10 a.m., all available pickers must carry out picking, leaving each finished WO in a finished WO area, which will be transferred to the dispatching area for review and subsequent loading.

Regarding consolidation, it is necessary to open a process that allows us to determine the location of each product just before starting consolidation. This process is called product recognition and takes an average of 30 min per warehouse. A picker will carry it out, and the information will be written on a tablet in an orderly and precise manner and sent to the planner. Reconnaissance must be performed in each warehouse independently, and two pickers are required in parallel.

This improvement makes it possible to eliminate the search time of each picker and the time associated with walking around, ordering and cleaning the area, and waiting for the crane to bring down a pallet, among others. It should be noted that the average preparation time of a WO is 12 min, and the average picking efficiency is 40%, which implies that the WO is ready for transfer in 30 min. It is estimated that at least 80% of the time wasted picking is explained by the search for products and associates, equivalent to 14.4 min. Therefore, the picking efficiency would increase by 44%, allowing a WO to be ready for transfer by an average of 13.6 min.

The planner must assign dispatch times for each day and arrange transport to comply with the schedule. This would facilitate complete scheduling, clarifying the priorities and achieving an early dispatch, avoiding the time window currently to carry out the load, and dissolving the problem of accumulation of work at the end of the day.

Planning would eliminate the 1 h on average time window generated today after having a route ready for the load. In this way, the consolidation strategy and use of two tablets would allow the optimization of these two processes by planning the work.

It is important to mention that this project does not propose changes in the reception of products; however, it would be very convenient to generate a reception plan because it would allow the warehouse to be organized promptly to eliminate the product recognition process. The BPMN model for the proposed method is illustrated in Fig. 13.7.

The ARENA model was run 244 times to obtain results comparable to the base model. In addition, the model presents the following considerations.

- The 10 a.m. schedule is modified by 9 a.m., maintaining the recess and lunch schedule and entering and leaving one hour earlier. This will allow the cranes a time window for free consolidation in the morning.
- The number of pickers decreases from 9 to 7. Due to the improvement, the number of pickers for this model is estimated to be 7.
- The work is divided into two batches, at 8:15 and 12:45. In the first schedule, the aim is to optimize consolidation, leaving the cranes free to carry out the consolidation without having obstacles from aisles, allowing merchandise to be

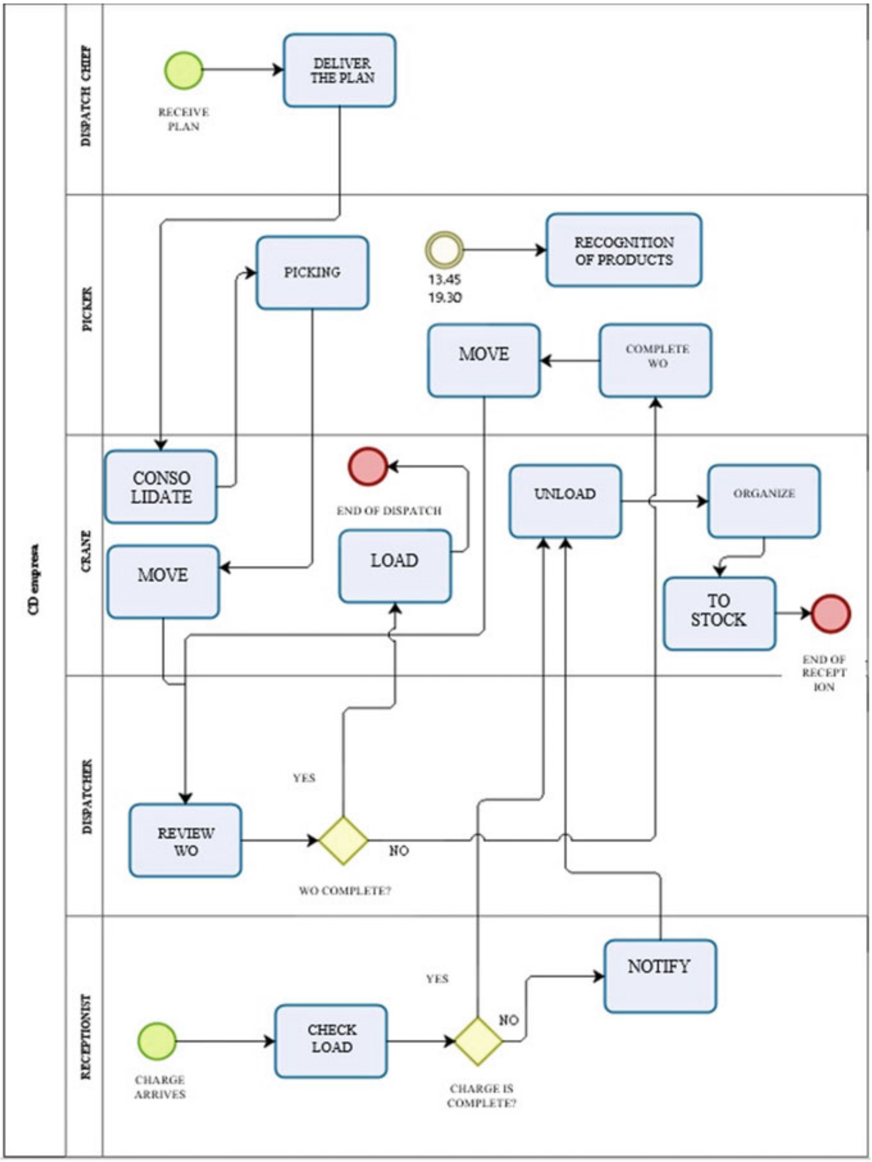

Fig. 13.7 BPMN of the proposed model

received without inconveniences. In the second round, consolidation and picking are carried out in parallel.

In the following Tables 13.15 and 13.16, you can see the results of the proposed model designed using Arena software and their corresponding analyses.

Table 13.15 New average number of OT and pallets per day

Number of	Average
WO	184.68
Pallets	109.00

Table 13.16 New average processing time for OT and pallets per day

Number of	Average
WO	6.0689
Pallet	1.8309

From Table 13.15, the amount of 185 WO is within the real, approaching the 187 registered during 2016, and the value of 109 pallets is similar to that of the original model (Table 13.11).

Comparing Table 13.16 with Table 13.12, it can be seen that the total average time that a WO takes to be ready for dispatch drops from 10.6 h to 6.1 h, that is, 4.5 h. This means that, with the proposal, a route could effectively be dispatched in 4.5 h less, estimating that the operating capacity of the DC would increase by 42.5%, thus being able to process 290 WOs per day with the same resources as the original model.

After evaluating and comparing the results of process time and waiting times of every task (loading, consolidating, downloading, flammable, miscellaneous, picking, checking, and moving) with the real operation of the system made in the former model, it can be seen the following; since the preparation now is focused on firstly dispatching a single route, the loading process is no longer divided into six routes, but instead becomes a single loading process. This increases the time in storing the merchandise in the miscellaneous warehouse. In turn, picking decreases to 28.8%.

The processes of storing miscellaneous and transferring increase their average time processing a WO due to the increase in their waiting queue. Queue time for the miscellaneous storage process skyrockets because the warehouse crane has loading, unloading, storage, and transfer functions.

Also, it was found that crane resources are the most likely to extend their working hours, becoming the new critical resource and turning the focus to optimizing crane-related processes. In addition, the number of pickers has been reduced to 7, increasing its scheduled use.

Regarding the analysis of utilization, the use of pickers decreases, and the use of cranes increases, making it clear that if the proposal is adopted, the new focus should be the resource of cranes.

13.3 Conclusion and Recommendations

Under the analysis presented, it can be said that the processes in which the bottlenecks are generated are mainly two: picking and unloading. Picking presents an average time of 6.83 h per WO and unloading 1.65 h, but the waiting explains the high time in both cases. In conclusion, the problem can be solved by generating a work plan so that all the WOs that are being prepared correspond to the route closest to the dispatch. It only needs planning so that the processes will continue to be carried out with the same current speed, but the waiting time will be reduced. However, this is not enough to eliminate overtime, so it is necessary to intervene in the processes.

On the other hand, it would be possible to obtain a notorious improvement in the use of resources, such as reducing from 9 to 7 pickers or significantly increasing the use of cranes. The planning would eliminate time losses generated by the disorder and chaos today, improving the average time in which a WO would be dispatched in 4.5 h, thereby affirming that the routes to be dispatched can be dispatched more quickly. To apply this proposal, acquiring two tablets for those who carry out the recognition of products in the warehouses and developing a plan that allows maintaining a criterion in pursuit of prompt dispatch. It is contemplated that once implemented this proposal, it is most likely that the new bottleneck will be generated by the processes related to the cranes, recommending then to carry out a new study in this regard.

In terms of cost–benefit, it can be said that the monetary costs correspond to two tablets, approximately 70,000 Chilean pesos. It should also be considered that implementing a new procedure can bring other complications that end in economic costs. In terms of benefits, in resources, it is estimated that two pickers would be expendable, equivalent to two salaries of $310,000, that is, 620,000 Chilean pesos per month. Additionally, the benefits must include the new operating capacity, corresponding to 42.5% more, equivalent to processing 290 WO, which would, in turn, imply an aid to the problem of occupation of the warehouses since 145 positions would be released each day, 43 more than in the original model.

It is also recommended to generate a merchandise reception plan according to the production and sales plans to maintain an orderly organization within the warehouses. This would help improve the efficiency of the picking process by eliminating the associated time losses, even eliminating the proposed recognition process.

Regarding the warehouse occupation, it is recommended to analyze the construction of new warehouses, according to the storage projection, reducing the cost of external warehouses and optimizing economic resources.

For those who carry out a similar study, it is recommended to recognize the operation in the plant since it provides information that allows interpreting some of the analysis results. In addition, it is recommended to investigate if there are databases with relevant information according to the investigation. All the necessary to complete a final aim: to remain competitive, especially in the current global environment plagued by the pandemic and the subsequent global inflation.

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Chapter 14
Vulnerable Regions Distribution of Packed Fresh Food Using Mobile Markets

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Abstract Disruptions in supply chains can lead to a market breakdown, and the products have different disruption sensitivities to processed food and fresh food. This work analyzes the disruptions caused in fresh food supply chains of Cochabamba's vulnerable downtown population, Bolivia. Based on the data collected, a new food kit delivery policy is proposed based on mobile market distribution. The data collected considered vulnerable areas in a region, communities' social characteristics as a typical diet, and food nutritional contribution, among others, for a week. Finally, this study identified the selected region's products, networks, and delivery routes.

Keywords Fresh food supply chain · Distribution strategies · Food security · Vulnerable regions

14.1 Introduction

The Food and Agriculture Organization of the United Nations, as well as the Organization for Economic Cooperation and Development, reported an increase in the consumption of fruits, vegetables, meat, dairy products, and fish compared to corn, rice, and beans, and an increase in crops and their assortment. In the Bolivian case, consumption of fruit, vegetables, and others increased by 22%; corn, rice, and beans

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by 6% (The Food and Agriculture Organization of the United Nations [FAO] 2019), and food purchases increased by 54% in the last ten years (2008–2018) (Los Tiempos 2019a, b), finally with energy requirements by 2371 kcal/day (Blanca Rivero Lobo 2014).

The productive capabilities and growing demand of regions have challenged the operational efficiency and productivity of the food supply chain. In 2018, Bolivia imported fruit from Chile, Argentina, and Vietnam and vegetables from the United States of America, Peru, and Brazil. By 2019, imported vegetables from the basic food basket in Bolivia, such as onions and tomatoes, had significantly increased in quantity, forcing local producers to align their supply, quality, and prices (Colaboradores de Opinión 2019; Eanzoategui 2019).

The COVID-19 pandemic and its consequences show differences between countries, communities, and people facing unexpected disruptions and uncertain environments. Supply chains worldwide have adapted their strategies to be resilient and collaborative. However, in developing countries, political, economic, social, medical, and technological factors affect the environment. Since 2019, Bolivia has experienced social disruptions, frequent mobility restrictions, social movements, and political instability. In this scenario, the global pandemic has exposed social fragility, instability, and inequality, especially in the country's food and health systems. Bolivia's food safety ranked 65th worldwide and 12th of 19 in Latin America, considering a system that guarantees community well-being and development (Clay 2018). These ranks indicate the necessity of generating initiatives and changing the scenarios.

After the 2019 social protest and 2020 quarantine for COVID-19, the food supply became vital, especially fresh food. Panic buying occurs when supply cannot satisfy demand during a crisis such as a natural or anthropogenic disaster (Lazcano 2019). In Cochabamba, as in many Bolivia regions, challenges are centered on availability, access, and purchase opportunities. The lack of facilities in Bolivia's transportation (Lazcano 2019; Rodríguez 2020), in this case, the fresh food supply chain inefficiencies and new biosecurity protocols, reduced the supply variety and increased prices. Customers had mobility restrictions, misinformation, and fear, which affected their demands. The system's lack of resilience affects food security, especially in vulnerable households.

Cochabamba agribusinesses lost 2019 around USD 57.5 MM (Lazcano 2019), and retailers' prices increased by up to 300% (Opinión 2020; Solís 2019). In the central market, tomatoes cost 1.5 USD/kilo, and potatoes cost 0.8 USD/kilo (Cossio 2019). Approximately 70% of Bolivian households have only 400 USD/month (Los Tiempos 2019a, b; CAF 2014), but their household purchases range between 130 and 230 USD/week (Colaboradores del Instituto Nacional de Estadística 2019). The Bolivian Economy's informality level, reflected in the supply chain relations, diffuse structure, lack of planning, and low productivity in their productive echelons, increases the problems. By contrast, developing countries focus on integrated supply chains, connecting producers with consumers, and generating sustainable value.

Therefore, this chapter proposes an alternative supply chain model for vulnerable regions that develops a fresh food distribution model for Bolivian families and reduces distribution costs. Consequently, it is projected to reduce the loss and waste of food in the supply chain and minimize demand uncertainty. Finally, mobile market distribution aims to improve the routing design and target demand with lower logistic costs. In this sense, the chapter seeks to increase the availability, accessibility, and opportunities to purchase fresh food.

This chapter's research revolves around three main steps: area characterization, where data from surveys are statistically analyzed using logistic regression models to determine the main factors that define each area to consider. The product design phase presents the standard fresh food product and its elements. Finally, in the distribution network design phase, the distribution routes are considered after weighing the population density of each area and the demand for fresh food to fix possible stops.

14.2 Literature Review

Petit (2008) focused on resilience in the supply chain, considering vulnerability and capability as the main factors, including assessment as disruption stages and improvement culture (Sheffi and Rice Jr., 2005). It is an important part of the research to understand the external environment (opportunities and threats) and internal environment (strengths and weaknesses) through surveys and expert interviews to propose strategies for the supply chain (Cucho et al. 2015; Medina et al. 2022). Ludowieg et al. (2021) analyzed accessibility, vulnerability, and population density indicators per area to manage public spaces considering essential goods and services in the Covid-19 pandemic. Other research includes connections between resilience and other perspectives such as ecological, logistical, and engineering (Reggiani et al. 2015), or empirical methodologies such as statistical and machine learning applied in humanitarian logistics as a framework for economic reactivation during the pandemic; spatial regression analysis provides a tool for decision-makers in disaster management (Quiliche et al. 2021).

A supply chain is a system formed by multiple entities (suppliers, producers, distributors, wholesalers, retailers) with flows (products, persons, money, information) in a complex network and echelons (Aized and Jagjit 2014). The fresh food supply chain has many particularities, such as entity fragmentation, shelf life, manipulation, and product loss and waste (van der Vorst et al. 2007). This complex system ensures food security as access (physical, social, and economic) is sufficient and nutritious for a healthy and active life (Shaw 1997). Nevertheless, approximately 17.2% of the population had moderate food insecurity, increasing to 26.4% with severe levels (FAO, IFAD, UNICEF, WFP, and WHO 2019). The panorama is worse in vulnerable populations (Alwang et al. 2001; FAO, IFAD, UNICEF, WFP, and WHO, 2019) for three exogenous and uncontrollable drivers: social conflicts, economic factors, and climate change (FAO, IFAD, UNICEF, WFP, and WHO, 2019), and endogenous as fresh products lower accessibility (Santorelli and Okeke 2017), spend more than 10% with another social-economic group (Acheson 1998), seek purchase value (processed food with higher levels of fat and sugar), and avoid fresh food (Wrigley 2002); and retailers' competitiveness factors (quality, quantity, and cost; Acheson 1998).

Purchase value has an endogenous relationship with food deserts, such as the limited provision of healthy and fresh food (Clarke et al. 2004), retailers' influence and retailers' preferences, and limited consumer choice (Clarke et al. 2004, 1994; Ghosh-Dastidar et al. 2014). Urbanization triggers food deserts in some urban regions to reduce turbulence (Vlajic et al. 2012) against agility, adaptability, capabilities, and more accessible product with affordable prices (Escamilla et al. 2020).

The transportation driver in mobile markets is fundamental because it impacts response capacity and efficiency (Chopra and Meindl 2020); also increases product variety, creates consumers trust (Zepeda et al. 2014), and brings healthier food (Robinson et al. 2016). The case study in New York shows narrow gaps (income, age, mobility) with operational improvements (Robinson et al. 2016) using a decision tree, and the logistic regression, as other techniques like agent-based modeling simulation (Hassouna et al. 2016). Direct transportation, routing, and distribution models improve network operations (Hillier and Lieberman 2010) by considering constraints (Mosquera-Recalde et al. 2022) and phases in urban areas (Merchan et al. 2016), focusing on optimal infrastructure utilization and logistics operators' flexibility. Regarding the distribution and choice of optimal distribution points, the gravity center location strategy optimizes transportation costs, considering cargo volumes, key locations, travel times, expenses, and weighting importance (Heizer and Render 2004). Other researchers added an analytical hierarchy approach (Bayu and Sawarni 2018) and facility adaptability (Troncoso et al. 2002).

14.3 Methodology

The methodology has three main phases: area characterization, product design, and distribution network design.

The area characterization phase identifies the main areas through a survey in downtown Cochabamba regarding residency area, fruit and vegetable accessibility and affordability, consumer preferences, and demand. The target population and product supply were identified by analyzing the survey's answers, considering the nutritional and cost balance. Statistical analysis determines the main variables of family monthly income, budget preferences, purchase frequency, technological factors, and availability in the market or mobile market.

The product design phase provides an optimal diet for people. This diet was designed in collaboration with Dr. Ariana Aguileras and supported by the Pennington and Fisher Food Classification by Antioxidants (2009). The product design phase defines fruit and vegetable formulas, considering the Cochabamba data, consumer preferences, and habits. The information obtained by data collection and analysis presented the characterization of downtown Cochabamba residents, economic areas, fruit and vegetable accessibility, and affordability. The product design of the box mixes fruit and vegetable preferences, product and service characteristics, and retailer relationships.

The distribution network design phase defines the boxes' optimal distribution points, product quantities, and routes, considering Bolivia's statistical information as population density data, neighbor routes, and public data as *Empresa Municipal de Servicios de Aseo* (EMSA, Municipal Cleaning Services Company).

14.4 Case Study: The Distribution of Fresh Food Kits Through Mobile Markets in Cochabamba

Cochabamba faced supply chain difficulties after March 2020 due to the COVID-19 pandemic. During this turbulent period, supply chains must refocus their value proposal and impact on communities, such as fruit and vegetable supply structures and their nutritional and dietary influence. The survey considered six communes, 15 districts, and 37 zones or sub-districts, and the influence of Tunari (30.6%), Adela Zamudio (30.6%), and Molle (23.3%).

14.4.1 Phase 1: Area Characterization

The target areas' definition constraints define high household density and family income between 650 and 720 USD/month. 34% of Bolivia's population has more than 650 USD/month, saving around 3% (Captura Consulting 2017). Specifically, approximately 28.35% of Cochabamba downtown is in this segment (El Deber 2017a, b; Captura Consulting 2017). Cochabamba represents 17.01% of the Bolivian population (El Deber 2017a, b), with 700 000 inhabitants, and is downtown with six communes: Adela Zamudio, Alejo Calatayud, Itocta, Molle, Tunari, and Valle Hermoso. The population of this study was 196 150 (see Table 14.1), and the sample consisted of 138 surveys. The pilot survey results are shown in Fig. 14.1 and Table 14.1.

The population density of the selected areas in Fig. 14.1 was found from Facebook data (Facebook Connectivity Lab and Center for International Earth Science Information Network–CIESIN–Columbia University 2016). In the first approach, 51.1% were 20–29 years old, 18.9% were 30–40 years old, 15.7% were 41–51 years old, and 6% were older than 63. Additionally, 67% of the participants were women. The downtown area of Cochabamba has economic and social differences (Cabrera et al. 2019; Antequera et al. 2008). According to the results of the surveys, 28.1% of Bolivian families earn more than USD 725 per month. In comparison, 27.6% earn less than USD 300 per month because families' budgets for fruits and vegetables are limited, and 90.6% of families are interested in buying fruits and vegetables at

Table 14.1 Population density

Area	Name	Population density (%)
12	Pukara Grande Sur	18.0
3	Alalay Norte	10.6
1	Distrito 14	9.8
11	Valle Hermoso Oeste	9.7
8	Ticti	8.1
13	Coña Coña	7.3
5	Valle Hermoso	7.1
4	Jaihuayco	6.9
2	Alalay Sud	6.8
9	Lacma	5.6
10	La Maica	3.8
6	1° de Mayo	3.2
7	Tamborada Pukarita	3.1
Total		100

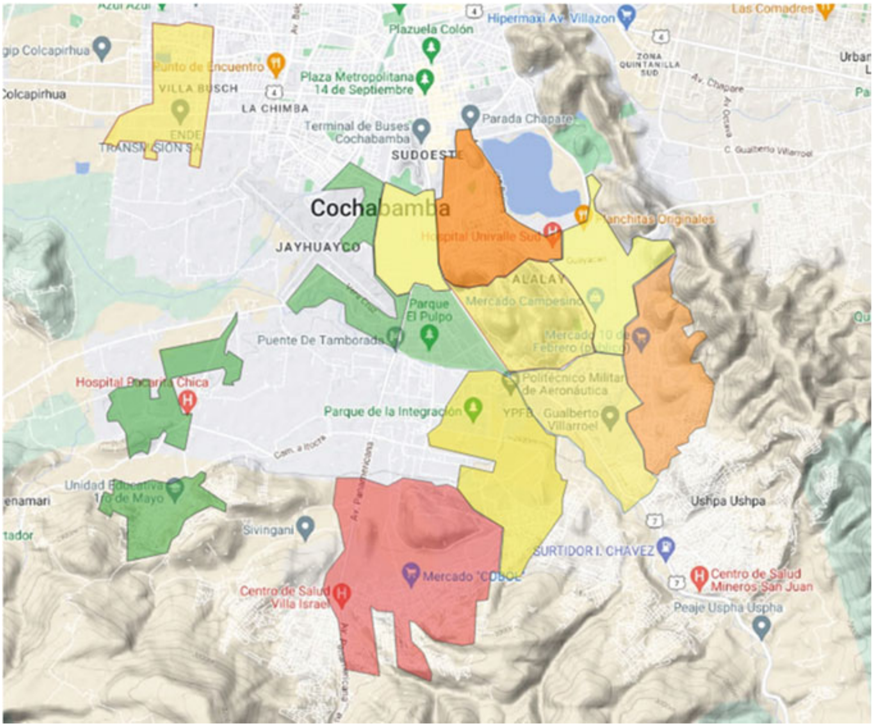


Fig. 14.1 Selected areas

a more affordable price. The number of family members is another piece of information seen in the answers to the survey, where 42% of Bolivian families had five or more members, and 39.1% had four members. Figures 14.2 and 14.3 show fruit and vegetable preferences and manners with the influence of proximity, security, and delivery against hygiene or assortment.

Equation 01 presents the logistic regression model used, and Table 14.2 the parameters obtained using Statgraphics.

According to the Bolivian Documentation and Information Center and the survey results, the fruit and vegetables higher demand in Distrito 14, Lacma, La Maica, Jaihuayco, and South Alalay; the second segment in Ticti, West Valle Hermoso, Coña Coña and Valle Hermoso and lower demand in Tamborada Pukarita, 1° de Mayo and South Pukara Grande. The fruit and vegetable preferences are shown in Figs. 14.4 and 14.5.

Table 14.4 lists fruit and vegetables as consumer preferences, carbohydrate levels, antioxidants, calories, and fiber.

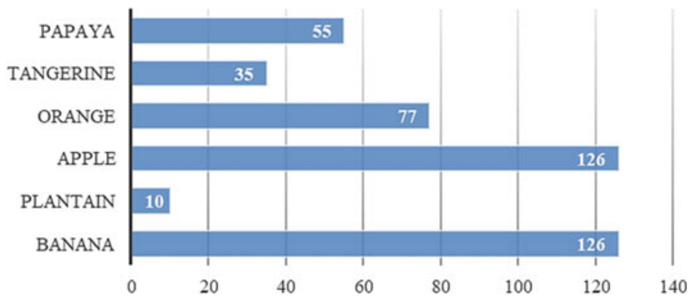


Fig. 14.2 Fruit preferences

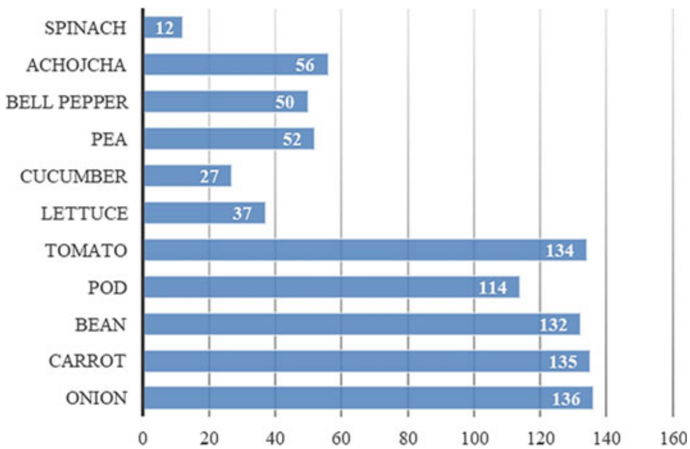


Fig. 14.3 Vegetable preferences

Table 14.2 Parameter estimates

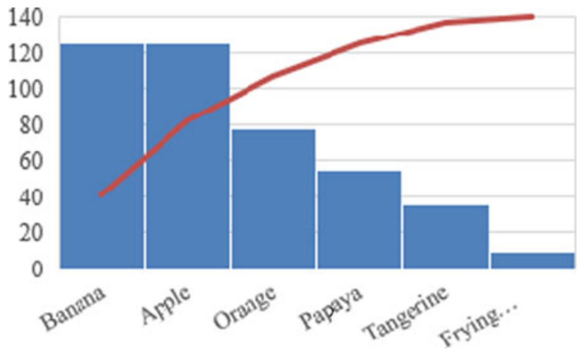
Parameter	Estimation	Standard error	T statistic	P-value
Constant	0.369653	0.0968597	3.81638	0.0002
Proximity	0.231943	0.0932935	2.48616	0.0138
Hygiene	-0.278367	0.0729603	–3.81532	0.0002
Security	0.229226	0.0748607	3.06203	0.0025
Home_delivery	0.256883	0.0829626	3.09637	0.0023
Assortment	–0.246349	0.0941338	–2.61701	0.0096

Table 14.3 Variance analysis

Source	Sum of squares	Gl	Mean square	F-Factor	P-value
Model	9.90395	5	1.98079	9.95	0.0000
Residuals	35.6312	179	0.199057		
Total (Corr.)	45.5351	184			

Mobile market choice = 0.369653 + 0.231943* Proximity – 0.278367*Hygiene + 0.229226*Security + 0.256883*Home_delivery – 0.2446349*Assortment
R-squared = 21.7501
Adjusted R-squared = 19.5644
Estimate standard error = 0.446158
Absolute mean error = 0.395192
Durbin-Watson statistic = 1.6868 (P = 0.0164)
Autocorrelation of residuals = 0.154264

Fig. 14.4 Pareto for fruit preferences



A family in Bolivia buys fruit and vegetables from USD 15 to USD 60 per month (Los Tiempos 2019a, b, 2020). In Cochabamba, a five-member family is around USD 20 per month. In the survey, 39% could buy from USD 17 to USD 22 per month, 21% from USD 23 to USD 27, 19% from USD 28 to USD 33, and 12% from 33 to USD 38. Regarding the presentation, 90% preferred a carton box.

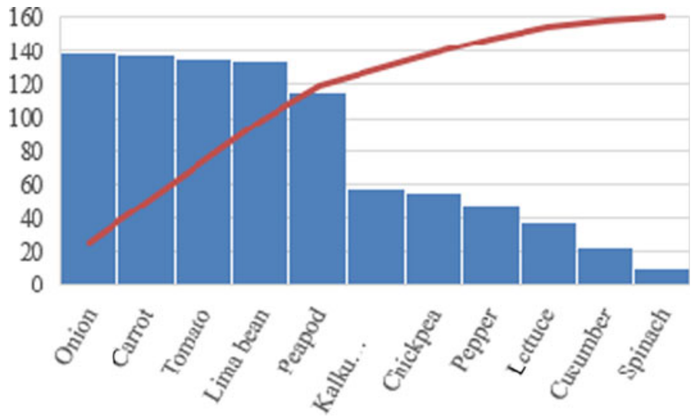


Fig. 14.5 Fruits and vegetable preferences

Table 14.4 Fruits and vegetable characterization

Food type	Selection	Carbohydrate classification	TAC (μmol TE100g)	Calories	Fiber (% Daily values)
Fruits	Melon (134 gr)	A	<500	50	4
	Red apple (242 gr)	B	>3000, <6000	130	20
	Peach (147 gr)	B	>1000, <3000	60	8
	Lemon (58 gr)	C	>1000, <3000	15	8
Vegetables	Pepper (148 gr)	A	>500, <1000	25	8
	Spinach (100 gr)	A	>1000, <3000	23	8
	Celery (110 gr)	A	>500, <1000	15	8
	Coriander (1.8 gr)	A	Unclassified	5	1
	Parsley (1.6 gr)	A	>6000, <9000	5	2
	Peapod (100 gr)	A	>500, <1000	42	9
	Kaiku cucumber	A	<500	15	6
	Tomato (148 gr)	B	<500	25	4
	Onion (148 gr)	B	>1000, <3000	45	12
	Carrot (78 gr)	C	>1000, <3000	30	8

Source Developed according to Aguileras (2020), Pennington and Fisher (2009), Munteanu and Apetrei (2021)

14.4.2 Phase 2: Product Design

The product design has three inputs: food fresh preferences survey, diet nutritional balance, and retailer interviews; Table 14.5 shows the list of products in 8.11 kg or 17.90 pounds. Packaging selection focuses on biosecurity, preventing cross-contamination, and controlling ethylene emissions. Table 14.6 shows the selected products' quantity, types, and ethylene emissions (Levi et al. 2011), which will be placed and packed in a corrugated carton box. The box dimensions were 24 cm high, 35 cm wide, and 45 cm long, with an estimated cost of 9 Bs. or $1.32.

Table 14.5 Fruits and vegetable list

Description	Amount	Unit	Unit cost
Peppers	2	Unit	2.5
Spinach	1	Bunch	1.3
Vanilla	0.5	Pound	1.0
Achojcha	0.5	Pound	1.9
Celery	1	Tied	0.4
Cilantro	1	Tied	0.4
Parsley	1	Tied	0.4
Quirquiña	1	Tied	0.4
Tomato	0.5	Pastern	1.9
Onion	0.5	Pastern	2.4
Locoto	1	Lot	1.0
Orange	6	Unit	1.6
Lemon	1	Lot	2.0
Total			17.05

Table 14.6 Fruits and vegetable packaging list

Product	Size	Unit	Weight (g)	Ethylene		Classification
				Emission	Sensitivity	
Tomato	½	Cuartilla (≈ 2.9 kg)	1462.79	High	High	HH
Spinach	1	Bunch	310.115	Low	High	LH
Peapod	½	Pound	226.80	Low	High	LH
Achojcha	½	Pound	445.63	Low	High	LH
Parsley	1	Bunch	213.71	Low	High	LH
Quilquiña	1	Bunch	53.5	Low	High	LH
Pepper	2	Unit	241.63	Low	Low	LL
Celery	1	Bunch	365.75	Low	Low	LL
Cilantro	1	Bunch	110.7	Low	Low	LL
Onion	½	Cuartilla (≈ 2.9 kg)	1473.92	Low	Low	LL
Locoto	1	Bunch	259.23	Low	Low	LL
Lemon	1	Bunch	50.95	Low	Low	LL
Orange	6	Unit	1685.6	Low	Medium	LM

Source Own elaboration based on (Levi et al. 2011)

14.4.3 Phase 3: Distribution Network Design

The dataset contained seven maps/datasets for the distribution of various populations in Bolivia: Overall population density, Women, Men, Children (ages 0–5) (5), youth (ages 15–24), elderly (ages 60+), and women of reproductive age (ages 15–49) (Facebook Connectivity Lab and Center for International Earth Science Information Network–CIESIN–Columbia University 2016). Additionally, the Humanitarian Data Exchange (HDE) supports market areas.

Figure 14.6 shows the coverage: location, market influence (red points), and influence zone (800 m). The centroid (green points) represents demand points by region.

The primary downtown market is near the influence zone; however, influential markets are currently not strategically distributed and have access problems. SENASAG controls the fruit and vegetable conditions. The mobile market model reduces the customer's distance to the retail market, eliminates intermediaries, and optimizes the last-mile costs. Furthermore, this model would decrease the cost of installation and inventory on the intermediary.

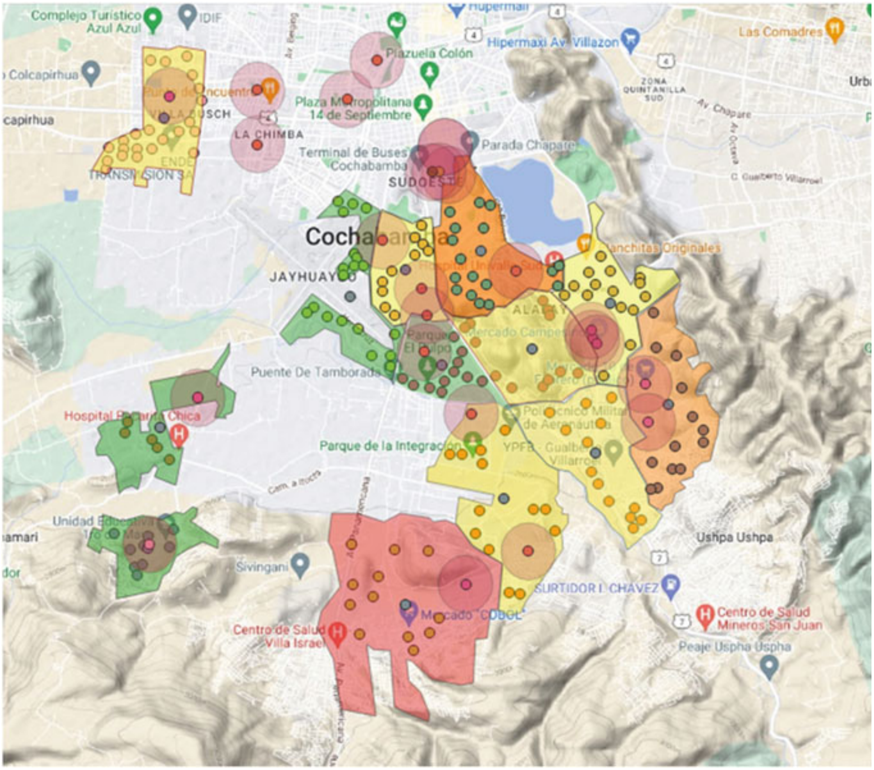


Fig. 14.6 Market coverage

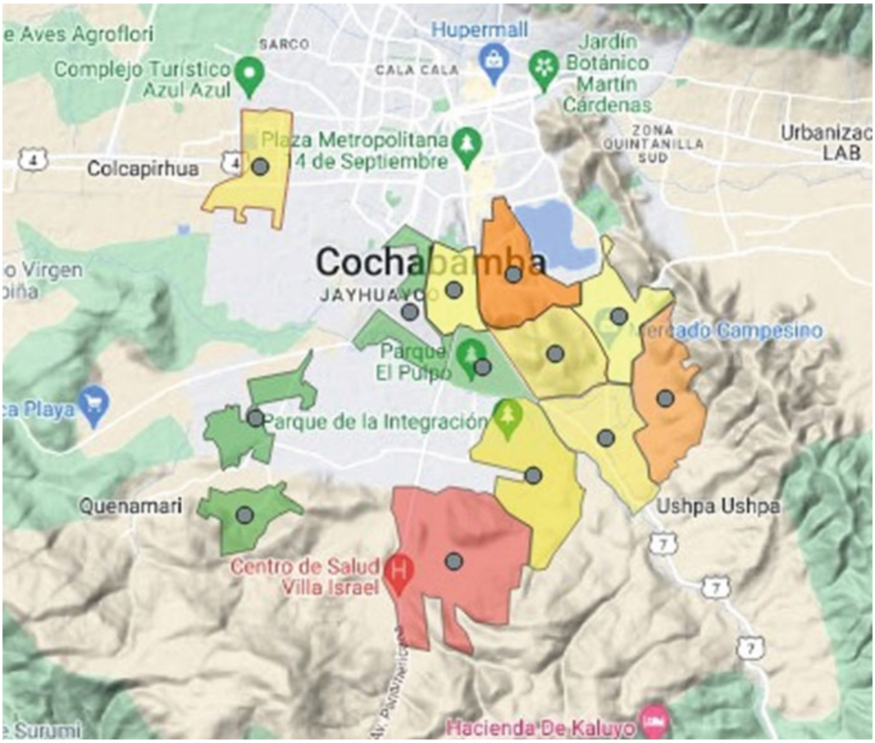


Fig. 14.7 Region centroids

To define the distribution center's location, all selected regions were considered; therefore, a geographical centroid for each was determined (see Fig. 14.7), which was later weighted with the average demand per region.

In Table 14.7, the distribution center should be located at X: −66.15 y Y: −17.43, focusing on the network distribution structure, response time, product variety, product disposition, client experience, time to the market, order visibility, and return.

As a result, the location of the distribution center was determined, as shown in Fig. 14.8.

Through QGIS and the Humanitarian Data Exchange, a dataset named Bolivia: High-Resolution Population Density Maps + Demographic Estimates from Facebook, it was possible to identify the areas where the population density was heavy through a heat map. These points were set as potential stops and critical indicators to build the corresponding route for each zone (See Fig. 14.9). This information was important because most of the selected regions were in peripheral communities with difficult access.

Google defines routes and validates the official data of the Municipal Cleaning Services Company, which regulates the cleaning of public and private spaces and the final disposal of solid waste. Finally, Table 14.8 presents the routes considering 5-ton trucks.

Table 14.7 Average Demand and coordinates per Zone

Zone	Average Demand (Boxes)	Coordinates	
		X	Y
Alalay Norte	32.013	−66.15	−17.42
La Maica	10.364	−66.17	−17.42
Jaihuayco	9.068	−66.16	−17.42
Lacma	9.068	−66.15	−17.44
Alalay Sud	8.810	−66.12	−17.43
Distrito 14	9.90	−66.11	−17.44
Valle Hermoso Oeste	6.477	−66.14	−17.46
Valle Hermoso	5.702	−66.13	−17.45
Ticti	5.193	−66.14	−17.43
Coña Coña	5.182	−66.20	−17.39
Tamborada Pukarita	3.421	−66.21	−17.45
1° de Mayo	3.421	−66.21	−17.47
Pukara Grande Sur	3.421	−66.16	−17.48
Total	111.230		

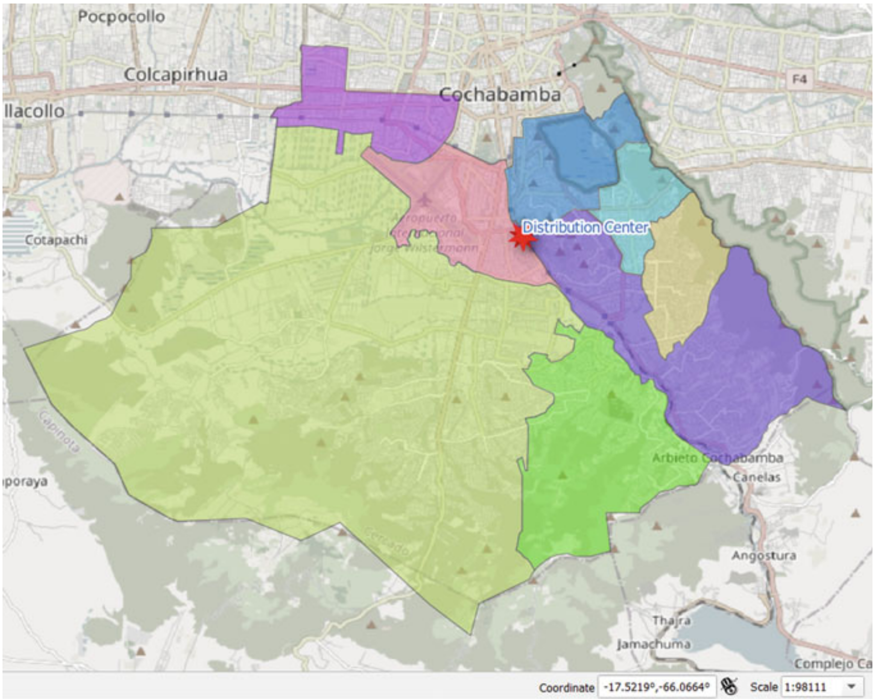


Fig. 14.8 Distribution center location

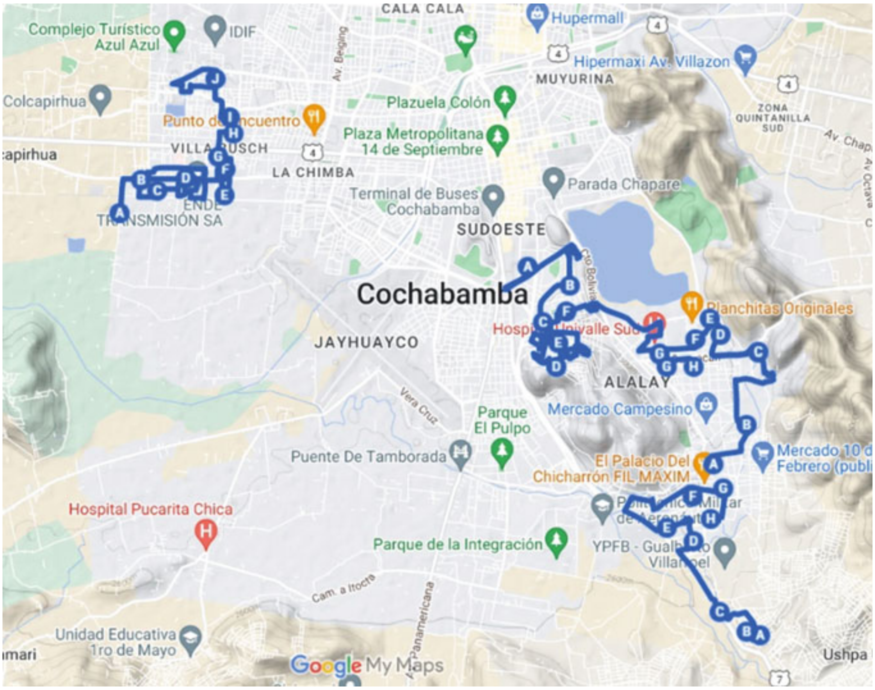


Fig. 14.9 Terrain layer in Google Maps and reference regions

The final routing constraints are the demand, schedule, and distance of the inner circuits in downtown Cochabamba.

14.5 Conclusions and Future Research

14.5.1 Conclusions

Bolivian food safety and nutritional problems are directly related to the fruit and vegetable supply and consumption value chain.

Due to the disruptions caused by the conflicts of October 2019 and the beginning of the COVID-19 quarantine of 2020, some social groups in Cochabamba needed more availability of fruits and vegetables, and the opportunity to acquire them was somehow restricted. The analysis of the consumer's context showed that Cochabamba has approximately 196,150 citizens with a limited budget for acquiring perishable products, incomes of less than USD 700, modest jobs, and household size of four or five members per family. It accurately indicates that the target audience is south of Cercado of Cochabamba, a region with challenging access routes and precarious public transportation systems.

Table 14.8 Distribution scheduling

Zone	Preferred delivery time					No clients (%)	Total monthly demand (boxes)	Visit day	Visit hour
	08:00–08:30 (%)	09:00–09:30 (%)	10:00–10:30 (%)	11:00–11:30 (%)	12:00–12:30 (%)				
Jaihuayco	12.5	37.5	37.5	0	0	12.5	321	Mon	10:00–10:30
Maica	12.5	50.0	37.5	0	0	0	366	Mon	09:00–09:30
Lacma	12.5	50.0	25.0	0	0	12.5	321	Tue	09:00–09:30
Ticti	37.5	0	0	0	25.0	37.5	229	Wed	12:00–12:30
Alalay Sud	45.4	18.2	9.1	0	0	27.3	312	Thurs	08:00–08:30
Distrito 14	33.3	26.7	6.7	0	0	33.3	443	Thurs	09:00–09:30
Tamborada Pukarita	0	60.0	0	0	0	40.0	121	Fri	09:00–09:30
Valle Hermoso	37.50	0	0	0	12.50	50.00	183	Wed	08:00–08:30
Valle Hermoso Oeste	60.00	40.00	0	0	0	0.00	202	Wed	09:00–09:30
Pukara Grande Sur	0	60.00	0	0	0	40.00	399	Sat	09:00–09:30
Coña Coña	44.00	0	0	0	0	56.00	182	Sat	08:00–08:30
1° de Mayo	20.00	40.00	0	0	0	40.00	399	Fri	09:00–09:30
Alalay Norte	40.46	11.90	2.38	2.38	2.38	40.50	1131	Mon-Tue	08:00–08:30

There were many difficulties in gathering data that could provide a complete panorama of the consumption landscape in poorer regions of Cochabamba. Therefore, many of the tools and information obtained in this study can be used for future research projects on a greater scale. This study made it possible to locate and identify the characteristics of these communities, evaluate their access routes, and generate alternative solutions to enhance accessibility. Although this is a very early and theoretical approach, the perspective provided by this study will allow further studies to seek feasible implementation.

In conclusion, two critical approaches were proposed. First, understanding the customer culture as the core analysis for the surveys and evaluating some essential factors involved in the correct evaluation and development of the supply chain to prepare both the producer and customer for future scenarios. This work was the first to understand how fresh fruits and vegetables can be delivered to peripheral and vulnerable regions in Cochabamba, Bolivia. At first glance, potential consumers are willing to purchase these products. However, in the case of disruptions and limited market access, these regions may be the first to affect food security.

14.5.2 Future Research

Future research could focus on using more sources of official historical data from Bolivia, such as the INE databases in Bolivia with social and economic metrics. This study estimates supply and demand with non-structural primary data. Thus, official data would reinforce the results and increase Bolivian supply chain competitiveness through multilevel echelons from producers to consumers, with a substantial impact on small and medium producers and vulnerable communities.

Research projects need building blocks to reinforce the productivity of fresh and sustainable vegetable supply chains with reasonable transaction costs and fair prices. As an outcome, Bolivian decision makers must focus their public policy on improving their logistics drivers and optimizing their food and agricultural production systems.

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Part IV
Miscellaneous in the Supply Chain

Chapter 15
Towards the Development of Sustainable Supply Chains for the End-of-Life Tires Management: Insights from a Literature Approach

Ignacio Castañeda Rodríguez and Andrea Teresa Espinoza Pérez

Abstract Growing environmental concerns regarding pollution have led to legislation toughening worldwide to achieve mitigation. For example, in Chile, the extended producer responsibility (EPR) law makes producers responsible for waste management of the goods they market within the country. One of these goods is end-of-life tires (ELT) because of their high pollution potential. The EPR law establishes the goal of collecting 50% of common tires and a valorization of 25% by 2023, gradually increasing over the years. Thus, there is an opportunity to implement an ELT supply chain with valorization technologies to explore new energy alternatives and value-added products. This would contribute to a circular economy and national energy matrix decarbonization. Therefore, through a comprehensive literature review, this study aimed to identify the principal supply chain design challenges for ELT treatment through a sustainable approach. Twenty-five articles were reviewed and analyzed considering the sustainability dimensions addressed, the decision-making levels assessed, the type of ELT treatment, the network structure, the country of study, the inclusion of uncertainty, the optimization model proposed objective functions number, the solution method used, and authors' analysis. The conclusions highlight the current research contributions and shortcomings and suggest possible directions for future work.

Keywords End-of-life tire · Sustainability · Optimization

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15.1 Introduction

Due to the growing environmental concerns over resource scarcity, landfill capacity depletion, and danger to human health, the "green growth" philosophy was a central point in recent discussions at the United Nations Conference COP21 in Paris (Saxena et al. 2018a). As a result, laws and policies in different countries have increased, specifically focusing on reducing the environmental impact of products at the end of their useful life (EOL) (Gupt and Sahay 2015). Most of these policies introduce the principle of "extended producer responsibility" (EPR), where producers have significant financial and physical responsibility in the treatment or disposal throughout the life cycle of the products (OECD 2001).

One of these products is tires because the constant growth of the vehicle fleet and poor waste management have made end-of-life tires (ELT) one of the most polluting agents (Ministerio del Medio Ambiente 2021a). For example, Chilean Law 20.920, known as the EPR Law, establishes ELTs' collection and recovery goals and other obligations (Ministerio del Medio Ambiente 2021a). Specifically, producers of common tires must collect at least 50% of the tires introduced by them in the national market and value 25% by the year 2023. These ratios gradually increased over time to reach the goal of 90% collection and recovery in the eighth year of application. Thus, the EPR Law generates a global opportunity to implement tire recovery technologies that explore new energy alternatives and allow the generation of value-added products, contributing to the circular economy and providing a sustainable approach to energy matrix decarbonization.

In searching for the optimal ELT treatment process, the current literature assesses different technologies, such as recycling, retreading, pyrolysis, and energy recovery. Among these, pyrolysis has been the most studied and corresponds to a thermochemical treatment that separates natural rubber, synthetic rubber, and the different types of carbon black used in the manufacture of tires when heat is applied in the absence of oxygen (Martínez 2020). The three main products are tire pyrolysis oil (TPO), carbon black (char), and steel. Furthermore, tire rubber has a higher calorific value than coal and a considerable amount of carbon black (Martínez et al. 2013). Consequently, various studies have shown pyrolysis's environmental and economic benefits (Dabic-Miletic et al. 2021). These characteristics render pyrolysis the most promising ELT treatment technology. However, there is still insufficient experience to face the different challenges that the process entails on an industrial scale (Martínez 2020).

Finally, implementing a pyrolysis plant for ELT treatment requires an appropriate supply chain design under a sustainable framework. Hence, a comprehensive review of the scientific literature is required to study the state of supply chain design for ELT treatment using pyrolysis as a valorization technology.

This study comprises two literature reviews. First, research on supply chain design for ELT using pyrolysis was conducted to determine how advanced this technology's development is on a large scale. The second research aims to review ELT supply chain design models considering different valorization technologies to complement the results of the first literature research, highlighting the specifications of a sustainable supply chain under a more comprehensive framework.

For both literature reviews, the search strategy included the following steps:

1. We defined keywords to perform an advanced search of different databases.
2. Select appropriate databases. For both cases, the selected databases were "Web of Science" and "Scopus."
3. The search fields and specifications needed to filter the results are determined.
4. Documents were initially selected. It includes a title and abstract lecture to select articles related to the research topic.
5. Final document selection. An in-depth lecture to select documents effectively related to the research topic. These documents can be reviewed in detail and classified for critical analysis.

15.2 Pyrolysis in Supply Chain Design for ELT Valorization

According to the search strategy described above, the keywords defined for this first search can be divided into three groups:

- Keywords related to the supply chain: ("Supply chain" OR "Distribution chain" OR "Delivery chain" OR "Supply network" OR "Supply line").
- Keywords related to pyrolysis: (pyrolysis OR gasification OR carbonization OR carbonization OR graphitization).
- Tires and their synonyms: (Tire OR Tyre OR Pneumatic).

The search fields were the title (TI), abstract (AB), and author keywords (AK). The search was conducted on March 10, 2022, finding 16 scientific publications, and the Web of Science and Scopus databases produced similar results.

15.2.1 Descriptive Analysis

Among the 16 scientific publications found, 13 publications assessed ELT treatment, while the remaining three focused on the treatment of natural rubber extracted from crops or by other non-tire means. Among these 13 publications, only nine documents study pyrolysis as a technology to treat ELTs. The latter included eight research articles and a literature review. A literature review presents a critical assessment of ELT management, considering pyrolysis as an increasingly common type of ELT treatment (Dabic-Miletic et al. 2021). None of the eight research articles studied the supply chain's design or management for treating ELT by pyrolysis. All of these articles are related to the study of the production process, such as the analysis of product properties under certain circumstances (Ivanov and Mihaylov 2011; Yu et al. 2022; Pakdel and Roy 1994; Seljak et al. 2014; Zhao et al. 2021), and yield optimization of the final products (Ding et al. 2015; Deng et al. 2019; Dong et al. 2019). Both cases were studied using a chemical framework, which is beyond the scope of this study. Figure 15.1 shows a summary of this analysis.

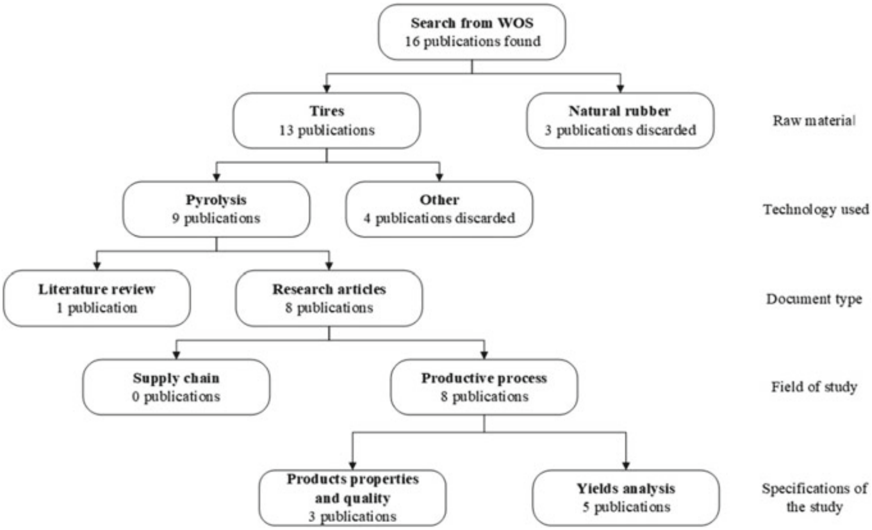

Fig. 15.1 Summary of the search results analysis "Pyrolysis in supply chain design for ELT valorization"

Based on the analysis of the results obtained, it is evident that, at present, there is still no research related to the supply chain design for ELT using pyrolysis as a valorization technology. This is mainly because tire pyrolysis technology is still at an early stage of development. Although it has proven to be fully scientifically achievable, it is yet to be economically affordable (Yadollahinia et al. 2018). Nevertheless, as reported by Dabic-Miletic et al. (2021), there is growing interest in this technology, mainly for ELT treatment, as it can contribute to the circular economy and engineering applications owing to the characteristics of pyrolytic products such as TPO and char. However, the predominant technologies used for ELT supply chain design are remanufacturing technologies such as retreading.

15.3 Supply Chain Design for ELT Treatment

The keywords defined in the previous search were utilized for this search, excluding words related to pyrolysis. Furthermore, the keywords "Logistics network" and "Network design" were added to broaden the search for supply chain design models. Thus, the keywords were defined as follows:

- Keywords related to the supply chain: ("Supply chain" OR "Distribution chain" OR "Delivery chain" OR "Supply network" OR "Supply line" OR "Logistics network" OR "Network design").
- Tires and their synonyms: (Tire OR Tyre OR Pneumatic).

The search fields were the title (TI), abstract (AB), and author keywords (AK). This research resulted in 105 scientific publications published on April 21, 2022. The relevant documentation selection then considers the following criteria:

1. Among the 105 publications, only 34 assessed supply chain design using optimization. Therefore, 71 documents were excluded.
2. These 34 documents include two literature reviews and 32 research articles.
3. Among the 32 research articles, 26 assessed supply chain design for ELT treatment. Thus, six publications related to non-ELT supply chains were excluded.
4. Finally, one article related to the design of a forward supply chain was discarded because this study focused on circular economy principles. In conclusion, 25 documents are analyzed in the following section.

15.3.1 Descriptive Analysis

The twenty-five articles' analysis covered the dimensions of sustainability, decision-making levels, type of ELT valorization employed, country of study, network structure, number of objectives, uncertainty, optimization model and solution method, and author analysis.

Studies on supply chain models for ELT valorization began in 2010 and have experienced gradual growth throughout the decade, as shown in Fig. 15.2. Only five publications between 2010 and 2017 were related to the search topic (16% of the total), whereas the maximum was in 2018. Notably, 80% of the research was conducted from 2018 to 2021. This research topic is considered to be increasingly relevant in the scientific community.

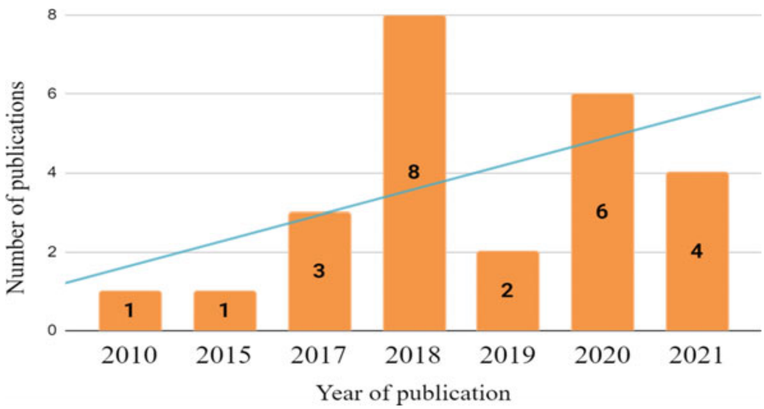

Fig. 15.2 Trend on supply chain models for ELT valorization

15.3.1.1 Dimensions of Sustainability

To analyze the sustainability aspects incorporated in the supply chain design, we followed the classification described by Bautista et al. (2016). It includes five sustainability dimensions instead of the three classical ones: economic, environmental, social, political, and technological. According to Espinoza Pérez et al. (2017), these dimensions are as follows:

- **Economic**: The main objective is to design a self-sustaining supply chain; that is, it does not need government assistance or reinvestments because it has the necessary profitability to be self-sustaining. It is necessary to evaluate indicators such as "Maximizing Profit" or "Net Present Value" because minimized costs metrics are not helpful since the high production cost of the reprocessing plants.
- **Environmental**: Seeks to adopt principles of natural resource management. Related indicators measure the environmental impact generated, such as greenhouse gas emissions, water, soil, and air quality, and the impact on human health and the ecosystem.
- **Social**: The objective is to promote social equity. Supply chain design is sought primarily through the generation of jobs and the maximization of social welfare.
- **Political**: This refers to promotion or restriction policies promulgated by the government or multilateral organizations, in addition to subsidies and tax reductions to stimulate market development.
- **Technological**: This dimension refers to the available production technologies, their readiness level, learning curve, and production level effects. It also assesses technological trends in product use and production.

Figure 15.3 represents the distribution of the reviewed publications according to the sustainability dimensions and supply chain decision-making levels.

All studies (25) included the economic dimension, among which nine research articles considered only economic objectives, while six documents assessed environmental and economic aspects. Otherwise, the technological perspective is the least incorporated, assessed in a single article, followed by the political (five) and social (six) dimensions. Furthermore, no study has considered these five sustainability dimensions.

In addition, achieving profitability is the main economic objective, which seeks to minimize the total costs and maximize profits by considering the total revenues depending on the sale of final products from reprocessing and new processed products in closed-loop supply chains (CLSC). The total costs consider the fixed and operating costs of the installed plants, transportation, and production costs, such as raw material acquisition, reprocessing, and collection. However, some authors have considered additional costs, such as adding capacity to installed plants (Subulan et al. 2015; Ghasemzadeh et al. 2021), inventory costs (Sasikumar et al. 2010; Subulan et al. 2015; Pedram et al. 2017; Saxena et al. 2018a, b; Yadollahinia et al. 2018; Yuchi et al. 2019; Ghasemzadeh et al. 2020; Kumar et al. 2020; Gholizadeh et al. 2021), losses from infrastructure malfunction (Khan et al. 2020), and costs from environmental and collection policies (Banguera et al. 2018; Yuchi et al. 2019). In

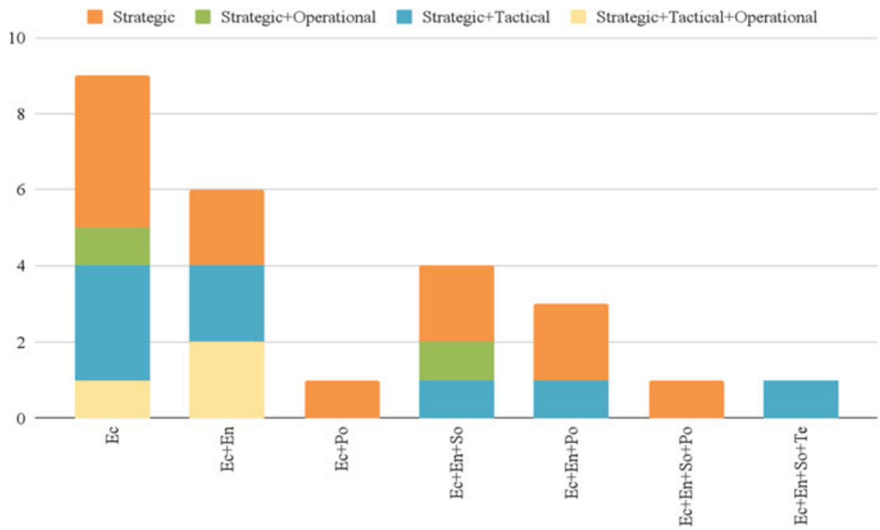

Fig. 15.3 Publication distribution according to the dimensions of sustainability (Ec = Economic, En = Environmental, So = Social, Po = Political, Te = Technological) and decision-making levels

addition to these objectives, other authors have proposed minimizing the financial risk (Hajiaghaei-Keshteli et al. 2018), maximizing customer satisfaction (Yadollahinia et al. 2018), minimizing transportation distances (Yadollahinia et al. 2018), maximizing coverage, that is, the number of used products collected from a supplier to a collection center (Saxena et al. 2018b; Kumar et al. 2020), and minimizing the time delivery of purchased products from plants to the supplier (Abdolazimi et al. 2020; Khan et al. 2020).

Concerning the environmental dimension, the most common objective function in the publications reviewed was environmental impact minimization along the supply chain. There are different ways to measure this impact, such as CO_2 emissions, measured by most authors in kg of CO_2 or CO_2 equivalents emitted or by assigning a cost to these emissions (Saxena et al. 2018a, b; Kumar et al. 2020). Life cycle analysis methodology has been applied in some studies (Sahebjamnia et al. 2018), where the environmental impact of facilities, transport, and tire disposition in nature or clandestine landfills are optimized. Subulan et al. (2015) and Ghasemzadeh et al. (2021) summarize these impacts in an eco-indicator.

The principal social objective function assessed was the maximization of social welfare, and the most commonly used indicator to represent this is the maximization of job opportunities. In addition, some authors include indicators such as the minimization of fixed lost days for work during the establishment of facilities or the loss of days caused by work damage during supply chain processes (Sahebjamnia et al. 2018) and prevention of immigration (Fazli-Khalaf et al. 2020).

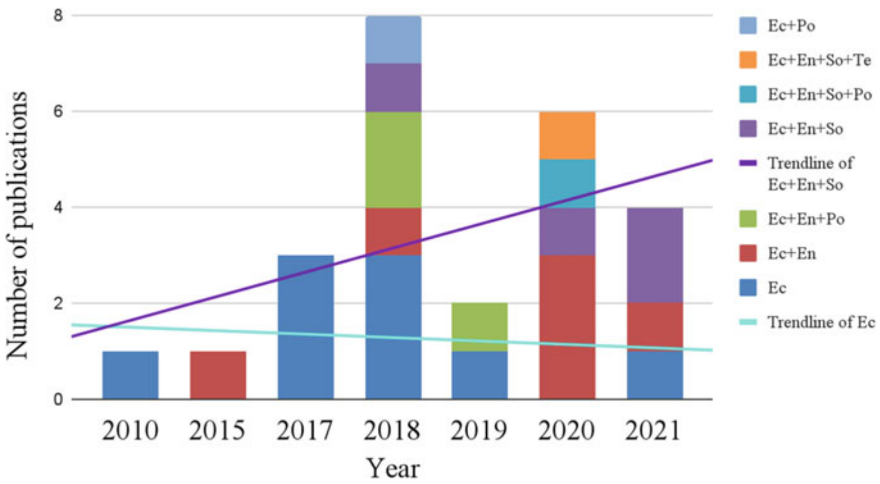

Fig. 15.4 Trend on sustainability dimensions inclusion in ELT supply chain models

For the political dimension, there were no articles with objectives classified within this dimension. However, within the economic and environmental dimensions, some authors include political considerations, such as the development of carbon tax policies (Saxena et al. 2018a, b; Kumar et al. 2020), policies of penalties for not meeting a defined ratio of ELT collection goals (Banguera et al. 2018), and the implementation of emissions trading schemes (Yuchi et al. 2019).

Fazli-Khalaf et al. (2020) presented the only publication that considered a technological objective that maximizes the reliability of installations with technologies with low failure probabilities.

Finally, the sustainability analysis also shows a trend toward an increase in the integration of the sustainability dimensions considered. Although the economic dimension is the most integrated, its individual study presents a downward trend over time, as Fig. 15.4 shows. On the other hand, since 2018, studies that integrate economic, environmental, and social dimensions have shown an upward trend.

15.3.1.2 Decision-Making Levels

Supply chain decision-making levels cover strategic, tactical, and operational perspectives (Mortazavi et al. 2015).

- **Strategic**: These decisions form the basis of tactical and operational decisions (Espinoza Pérez et al. 2017). It covers long-term decisions such as target market selection, plant location, capacity, and production technology selection (Espinoza Pérez et al. 2019).

- **Tactical**: This includes the management of medium-term decisions such as inventory planning, raw material collection planning, storage site selection, transport mode selection, and shipment sizing (Espinoza Pérez et al. 2019).
- **Operational**: This corresponds to short-term decisions concerning inventory planning (daily inventory control, lack of inventory at distribution points) and programming vehicles (Espinoza Pérez et al. 2019).

Figure 15.3 shows that only 12% of the publications (3) consider all decision-making levels. Furthermore, most publications studied only the strategic level, reaching 48% (12). The main strategic decisions considered in the reviewed publications are related to flows within the chain, facility capacity, and location. Most studies consider the location of distribution centers, collection centers, remanufacturing plants, recycling plants, and manufacturing centers in the CLSC. In addition, some authors consider cross-docking centers (Saxena et al. 2018a, b; Khan et al. 2020; Kumar et al. 2020), centralized return points (Subulan et al. 2015; Yuchi et al. 2019; Ghasemzadeh et al. 2021), hybrid centers combining collection and distribution (Yadollahinia et al. 2018; Gao and Cao 2020), manufacturing and remanufacturing (Gao and Cao 2020), tire-cutting centers (Oyola-Cervantes and Amaya-Mier 2019), storage centers (Ebrahimi 2018; Khan et al. 2020; Gholizadeh et al. 2021), energy recovery plants (Simić et al. 2017; Oyola-Cervantes and Amaya-Mier 2019; Tehrani and Gupta 2021), and landfill locations for disposal (Gao and Cao 2020; Gholizadeh et al. 2021).

Regarding the 11 publications that considered tactical decision levels, inventory planning (9) dominated vehicle fleet management (5). The authors integrated inventory management (IM) within manufacturing plants for new tires in the CLSC (Subulan et al. 2015; Saxena et al. 2018a; Yadollahinia et al. 2018; Ghasemzadeh et al. 2021), IM for ELT and remanufactured products within remanufacturing plants (Simić et al. 2017; Saxena et al. 2018a), distribution centers for new tires remanufactured products (Subulan et al. 2015; Saxena et al. 2018a; Ghasemzadeh et al. 2021), ELT within centralized return centers (Subulan et al. 2015; Ghasemzadeh et al. 2021), cross-docking (Saxena et al. 2018a), collection centers (Sasikumar et al. 2010; Saxena et al. 2018a; Oyola-Cervantes and Amaya-Mier 2019; Gholizadeh et al. 2021), and inputs for manufacturing production (Subulan et al. 2015; Ghasemzadeh et al. 2021).

However, the authors include fleet management in their models to define different types of vehicles for transportation with different capacities (Subulan et al. 2015; Saxena et al. 2018a; Gao and Cao 2020; Gholizadeh et al. 2021) and fleet size within a given period (Subulan et al. 2015; Ebrahimi 2018; Gao and Cao 2020). Furthermore, Gao and Cao (2020) included the order transported size by vehicle and transportation speed. In addition, Fazli-Khalaf et al. (2020) considered tactical decisions by determining the number of processes performed at each facility in the supply chain.

The operational level was the least considered, and it was in only five articles, equivalent to 20% of the total. Within short-term inventory management, some authors integrate daily inventory maintenance in facilities (Gholizadeh et al. 2021) and the use of safety stock (Simić et al. 2017; Fathollahi-Fard et al. 2018). Regarding the operational aspects of vehicle fleet management, Ebrahimi (2018) and Tehrani and Gupta (2021) include vehicle scheduling and routing.

15.3.1.3 Type of ELT Valorization

ELT-type valorization can be classified into four types: reuse, remanufacturing, recycling, and energy recovery. Each type of valorization is described below according to the REP Law published by the Chilean Ministry of Environment (2016).

- **Reuse**: The action of discarded products or components being reused without involving a production process.
- **Remanufacturing**: Repairing used products (Banguera et al. 2018). In the case of ELT, retreading is considered a form of remanufacturing.
- **Recycling**: Waste is the input or raw material in a productive process, including co-processing and composting, excluding energy recovery. The ELT recycling options include mechanical shredding, thermolysis, pyrolysis, pyrolysis, incineration, and cryogenic shredding (Banguera et al., 2018).
- **Energy recovery**: Waste is used to exploit its calorific value.

Figure 15.5 shows that the most common type of ELT valorization is remanufacturing, covering 20 of the 25 articles analyzed. 60% of these publications specified retreading as remanufacturing technology. Recycling was performed in 16 publications, representing 36.36% of the total. However, most studies do not specify the technology used.

15.3.1.4 Country of Study

Figure 15.6 presents the number of countries that have served as case studies for the investigations. It shows the preponderant participation of Iran, which accounts for 40% of the total, followed distantly by India, which has 16% of the case studies in its publications. Furthermore, only one study corresponded to each of the other countries. It is also worth noting that a large number of articles did not present a country as a case study, reaching 20% of the total. For these cases, it is common to define the case study only as the tire industry or not to use a case study but to use a random instance to obtain the model results.

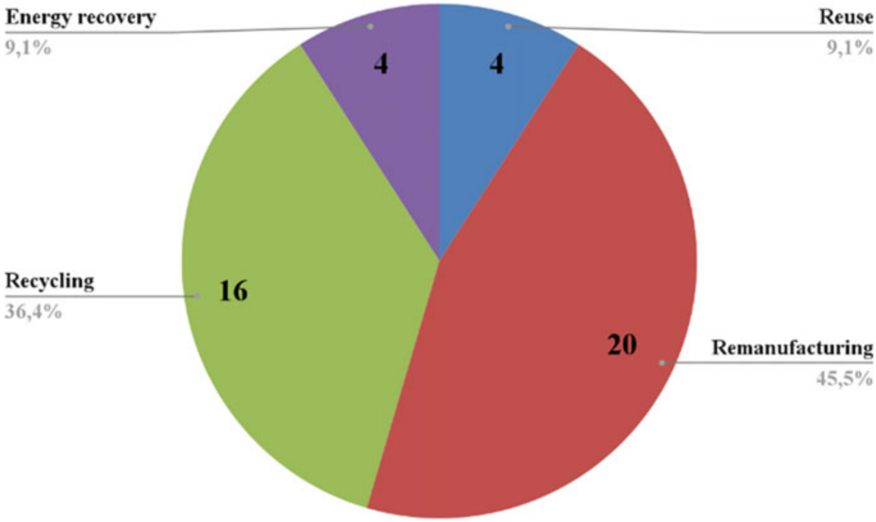

Fig. 15.5 Publication distribution according to the type of ELT valorization

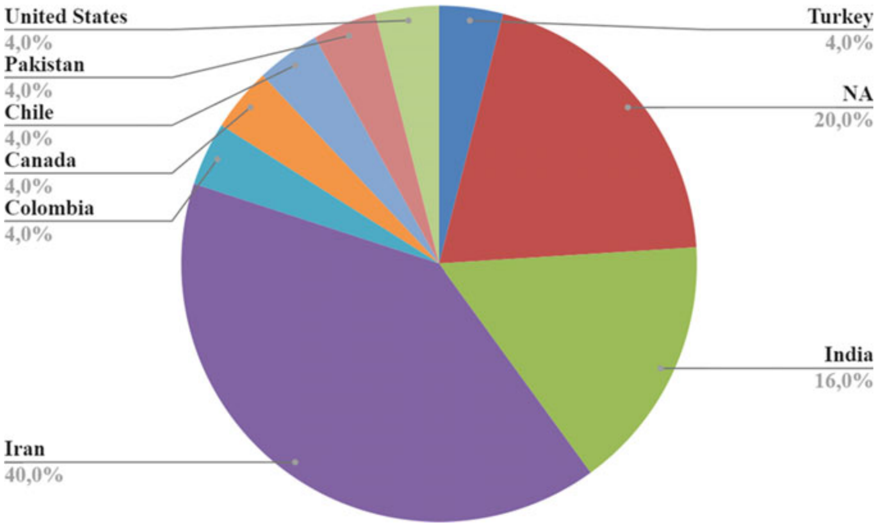

Fig. 15.6 Publication distribution according to the country of study

15.3.1.5 Network Structure

Regarding the network structure, we can distinguish between reverse logistics (RL) and the closed-loop supply chain (CLSC). Furthermore, since this study focuses on assessing supply chains that include circular economy principles, it excludes forward supply chains (FSC).

- **Reverse Logistics (RL)**: It starts from end users (first customers), where used products are collected (return products), and then attempts to manage EOL products through different decisions undertaken, including recycling, remanufacturing, repairing, and finally, disposing of some used parts (Govindan et al. 2015).
- **Closed-Loop Supply Chain (CLSC)**: This is the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with the dynamic recovery of value from different types and volumes of returns over time. If we consider the FSC and RL simultaneously, the resulting network will construct a CLSC (Govindan et al. 2015).

Figure 15.7 shows the publication distribution according to the network structure. Sixteen publications developed CLSC, corresponding to 64% of the total. Eleven researchers designed a network specifically for ELT (68.75%). The remaining 31.25% (5) assessed waste in general and then applied the model to a case study referring to the tire industry. The remaining nine publications (36%) designed RL; eight articles presented networks designed specifically for ELT, and only one focused on waste in general.

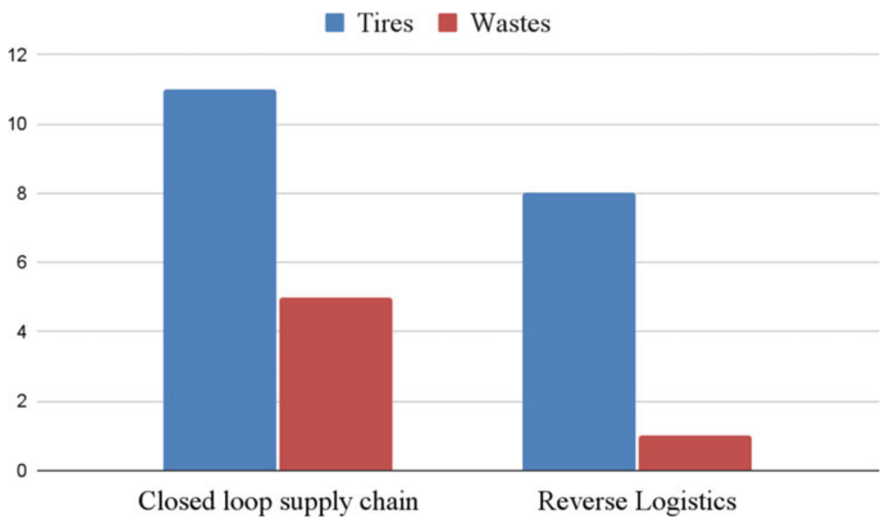

Fig. 15.7 Publication distribution according to the network structure

15.3.1.6 Uncertainty

The uncertainty classification depends on the model characteristics. For example, its classification is deterministic if the model does not consider uncertainty, stochastic if discrete or continuous probability functions represent any parameter, or the study assesses multiple scenarios, and fuzzy if fuzzy numbers represent any imprecise parameters. Ten articles introduced deterministic models, ten documents developed stochastic models, and five publications integrated fuzzy models.

Among the stochastic models, all authors consider demand uncertainty. Eight articles also integrated it into return production rates, such as retreading (Simić et al. 2017; Tehrani and Gupta 2021) and recycling rates (Tehrani and Gupta 2021). Additionally, all associated costs incorporate uncertainty in Simić et al. (2017) and Mehrjerdi and Shafiee (2021), while Abdolazimi et al. (2020) and Tehrani and Gupta (2021) consider uncertainty only in production. In addition, Mehrjerdi and Shafiee (2021) modeled parameters under uncertainty, such as pollution emitted within the network, variable labor opportunities, availability of raw materials from suppliers, and information sharing among supply chain members.

Regarding fuzzy models, most authors have considered fuzzy uncertainty in demand (Saxena et al. 2018b; Fazli-Khalaf et al. 2020; Kumar et al. 2020; Fathollahi-Fard et al. 2021). Regarding costs, the raw material purchase and ELT collection costs incorporate uncertainty (Saxena et al. 2018b; Kumar et al. 2020; Fathollahi-Fard et al. 2021); however, Fazli-Khalaf et al. (2020) considered the uncertainty in all associated costs. In addition, other parameters incorporating uncertainty include the amount of ELT collected (Kumar et al. 2020; Fathollahi-Fard et al. 2021), environmental parameters such as carbon emission costs (Saxena et al. 2018b; Fazli-Khalaf et al. 2020; Kumar et al. 2020), number of vehicles used, rate of tires destined for disposal (Subulan et al. 2015), and social parameters such as variable job opportunities and immigration rates (Fazli-Khalaf et al. 2020).

15.3.1.7 Number of Objectives

It is possible to distinguish between single and multi-objective models, depending on the number of objective functions integrated into the mathematical model.

Figure 15.8 shows seven publications with single-objective optimization, while the remaining 18 presents a multi-objective model. Multi-objective models with three objective functions predominate (9), followed by models with two objectives (6). In addition, from three objective functions onwards, publications are scarce because only two articles incorporate four objectives, and only one investigation considers six objective functions.

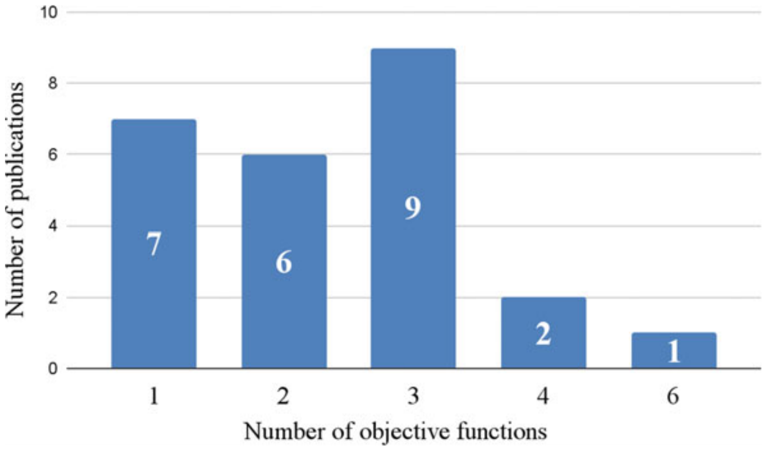

Fig. 15.8 Publication distribution according to the number of objective functions considered in the model

Regarding articles with more than one objective per sustainability dimension, we can observe that all focus on including more economic objectives, for example, by including profits, costs, network coverage, financial risk, delivery times, and customer satisfaction.

15.3.1.8 Optimization Models and Solution Methods

This section analyzes the optimization model used and its corresponding solution method. In this case, the following methods are considered: "Mixed-Integer Programming" (MIP), "Mixed-Integer Linear Programming" (MILP), "Mixed Integer Nonlinear Programming" (MINLP), "Stochastic Mixed Integer Programming" (SMIP), "Fuzzy Mixed-Integer Linear Programming" (FMIP). For the case of solution methodologies, methods such as "ε-constraint" (EC), "Improved Augmented Augmented ε-constraint" (AUGMECON2), "Branch-and-Bound" (BandB), "Lagrangian Relaxation" (LR), "Heuristics" (H), "Meta-Heuristics" (M), "Hybrid Metaheuristics" (HM), "Interactive Fuzzy Solution Approach" (IFSA) are covered.

First, more than half (56%) of the articles used linear models (MILP). Among these MILP models, there are single- and multi-objective optimizations. Single-objective optimization comprised 43% of the articles (Sasikumar et al. 2010; Amin et al. 2017; Banguera et al. 2018; Hajiaghaei-Keshteli et al. 2018; Yadollahinia et al. 2018; Oyola-Cervantes and Amaya-Mier 2019), while multi-target ones reach the majority, with 57% of the total (Pedram et al. 2017; Sahebjamnia et al. 2018; Saxena et al. 2018a; Abdolazimi et al. 2020; Ghasemzadeh et al. 2021; Khan et al. 2020; Gholizadeh et al. 2021; Tehrani and Gupta 2021).

Four articles used nonlinear models (MINLP). Fathollahi-Fard et al. (2018) included nonlinearity in their single-objective model, both in the objective function and constraint, to determine the safety stock. Yuchi et al. (2019) include nonlinearity in the environmental objective function of their multi-objective model. Simić et al. (2017) defined their model as an "interval-parameter semi-infinite programming model" (IPSIP), which includes nonlinearity in constraints to measure operational efficiency. Gao and Cao (2020) designed a SMIP model, but the vehicle scheduling constraints were nonlinear functions.

Five articles introduced FMIP models that considered uncertainty by employing fuzzy parameters. The most commonly used software to solve these models was GAMS (28%) and LINGO (32%). However, the remaining studies did not specify this information. The programming environment most frequently applied was CPLEX (44%). Finally, 73% of the articles corresponded to multi-objective models, and only three included single-objective models. About the multi-objective models, 37.5% integrated the functions. The use of methodologies such as EC (Khan et al. 2020; Fathollahi-Fard et al. 2018; Sahebjamnia et al. 2018) and AUGMECON2 (Mehrjerdi and Shafiee 2021; Gao and Cao 2020; Ghasemzadeh et al. 2021; Ebrahimi 2018), WSM (Abdolazimi et al. 2020; Gao and Cao 2020). The remaining 62.5% analyzed the objective functions independently using algorithms such as the IFSA (Tehrani and Gupta 2021; Kumar et al. 2020; Subulan et al. 2015), different H (Gholizadeh et al. 2021; Khan et al. 2020), M (Fathollahi-Fard et al. 2021, 2018; Hajiaghaei-Keshteli et al. 2018), and HM (Fathollahi-Fard et al. 2021; Sahebjamnia et al. 2018). It is worth noting that many of these studies apply heuristic algorithms, followed by a check of these results through exact methods.

15.3.1.9 Authors

To analyze the authors' relationships, Fig. 15.9 shows a relationship diagram according to the works carried out jointly by the authors. It should be noted that most of the clusters were composed of the authors of one publication, and only two were composed of more than one.

On the one hand, the works of Fathollahi-Fard et al. (2021), Fathollahi-Fard et al. (2018), Hajiaghaei-Keshteli et al. (2018), Sahebjamnia et al. (2018) are grouped. Here, the most involved authors are "Fathollahi-Fard, AM" and "Hajiaghaei-Keshteli, M" because they are in all cluster articles. These authors came from Iran, and their research has mainly studied single-objective models focusing only on the economic dimension of the tire industry, except for the study by Sahebjamnia et al. (2018), which includes more sustainability dimensions. They proposed remanufacturing and recycling as the main types of valorization. Finally, most of this research considers only the strategic decision-making levels.

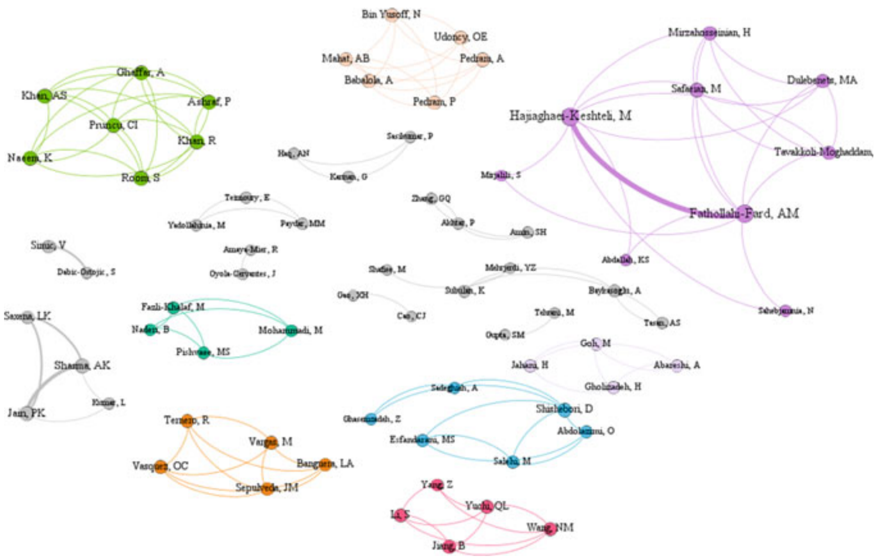

Fig. 15.9 Publication distribution according to the relations of the authors

Secondly, in the cluster associating the works of Saxena et al. (2018a), Saxena et al. (2018b), and Kumar et al. (2020), the authors "Sharma, AK" and "Jain, PK" have participated in all three works. These authors come from India and have studied only multi-objective models, including three or more dimensions of sustainability, where the political dimension is always present, addressed through carbon tax policy. They analyzed only retreading as a technology, and except for the work of Saxena et al. (2018a), they only considered strategic decision-making levels.

Appendix 1 Summarizes the Results of Each Classification.

15.4 Conclusions

Sustainability analysis shows that although most publications consider only the economic dimension, an upward trend exists in including more and different dimensions. Therefore, one of the challenges is to incorporate the five sustainability dimensions.

Regarding the other aspects evaluated, there was no notable trend over the years analyzed. The decision-making level analysis showed that only 12% of the total publications covered the three decision-making levels. The operational level was the least considered, accounting for only 20% of the total. Therefore, it is necessary to develop future research that integrates these three decision-making levels.

Regardless of the various technologies used for ELT treatment, remanufacturing is predominant, especially retreading. Furthermore, considering that the least included sustainability dimension is the technological dimension, there is a need to develop a greater inclusion of technologies in ELT supply chain models to generate a more significant value-added product variety.

The inclusion of uncertainty in the models was present in 60% of the publications, employing either a stochastic or fuzzy model. In the case of stochastic and deterministic models, the most commonly used are MILP models, whereas, for fuzzy models, all studies applied the FMIP.

Finally, regarding the country of study, the predominance of research in Iran and India was evident. The authors' analysis showed that the only significant clusters came from research in these countries. In contrast, only two Latin American studies have been conducted. Therefore, promoting this type of research with applications in a greater diversity of emerging and developing countries is necessary, considering their territorial uniqueness conditions, to establish guidelines for building sustainable development pathways globally.

The results showed that although there is a contribution to the development and modeling of ELT supply chains, there still needs to be more research concerning the edges of analysis. There is a need to increase the number of studies that consider the five dimensions of sustainability, emphasizing the implementation of political and technological considerations, the inclusion of the three decision-making levels, more significant application of recovery technologies, and more remarkable development of research in Latin American countries.

Finally, this study's reduced number of research articles shows the need to promote end-of-life tire assessment globally.

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Appendix 1: Summary of the Publications Reviewed According to Network Structure, Uncertainty

Reference	Network structure	Uncertainty	Decision-making level			Type of valorization					Dimension of sustainability				Number of objectives	Optimization model	Solution method	Country of study
			STR	TAC	OP	RU	RM	RE	WE	EC	EN	SO	PO	TE				
Sasikumar et al. (2010)	RL	DT	x	x			x			x					1	MILP	LINGO	India
Subulan et al. (2015)	CLSC	F	x	x			x	x	x	x	x				2	FMIP	IFSA	Turkey
Pedram et al. (2017)	CLSC	ST	x				x	x		x					1	MILP	CPLEX	Iran
Amin et al. (2017)	CLSC	ST	x					x		x					1	MILP	GAMS	Canada
Simić et al. (2017)	RL	ST	x	x	x	x	x			x					1	MINLP	LINGO	NA
Hajiaghaei-Keshteli et al. (2018)	CLSC	ST	x				x	x		x					2	MILP	M	NA
Sahebjamnia et al. (2018)	CLSC	DT	x				x	x		x	x	x			3	MILP	EC, HM	NA
Saxena et al. (2018a)	RL	DT	x	x			x			x	x		x		3	MILP	LINGO	India
Yadollahinia et al. (2018)	RL	DT	x	x			x	x		x					3	MILP	B&B	Iran
Saxena et al. (2018b)	RL	F	x							x	x		x		6	FMIP	LINGO	India
Fathollahi-Fard et al. (2018)	CLSC	DT	x		x		x	x		x					3	MINLP	M, EC	Iran
Ebrahimi (2018)	CLSC	ST	x	x	x		x	x		x	x				2	SMIP	AUGMECON2	Iran
Banguera et al. (2018)	RL	DT	x			x	x	x	x	x			x		1	MILP	CPLEX	Chile
Oyola-Cervantes and Amaya-Mier (2019)	RL	DT	x	x					x	x					1	MILP	CPLEX	Colombia
Yuchi et al. (2019)	RL	DT	x				x			x	x		x		2	MINLP	NSGA-II	NA

(continued)

(continued)

Reference	Network structure	Uncertainty	Decision-making level			Type of valorization					Dimension of sustainability				Number of objectives	Optimization model	Solution method	Country of study
			STR	TAC	OP	RU	RM	RE	WE	EC	EN	SO	PO	TE				
Kumar et al. (2020)	RL	F	x				x			x	x	x	x		4	FMIP	IFSA	India
Ghasemzadeh et al. (2021)	CLSC	ST	x	x			x	x		x	x				2	MILP	AUGMECON2	Iran
Fazli-Khalaf et al. (2021)	CLSC	F	x	x			x	x		x	x	x		x	4	FMIP	IFSA	Iran
Abdolazimi et al. (2020)	CLSC	ST	x				x	x		x	x				3	MILP	WSM, EC	Iran
Khan et al. (2020)	CLSC	DT	x				x			x	x				3	MILP	EC, H, NSGA-II	Pakistan
Gao and Cao (2020)	CLSC	ST	x	x		x	x			x	x	x			3	SMIP	AUGEMCON2	NA
Fathollahi-Fard et al. (2021)	CLSC	F	x			x	x	x		x					1	FMIP	HM, M, CPLEX	Iran
Mehrjerdi and Shafiee (2021)	CLSC	ST	x					x		x	x	x			3	MIP	AUGEMCON2	Iran
Gholizadeh et al. (2021)	CLSC	DT	x	x	x			x		x	x				2	MILP	EC, H	Iran
Tehrani and Gupta (2021)	CLSC	ST/F	x		x		x	x	x	x	x	x			3	MILP	IFSA	USA
Total	-	-	26	11	5	4	20	16	4	25	15	6	5	1	-	-	-	-

(DT = Deterministic, ST = Stochastic, F = Fuzzy), decision-making level (STR = Strategic, TACT = Tactical, OP = Operational), type of ELT valorization (RU = Reuse, RM = Remanufacturing, RE = Recycling, WE = Energy recovery), sustainability dimension (Ec = Economic, En = Environmental, So = Social, Po = Political, Te = Technological), number of objectives, optimization model, solution method, and country of study

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Chapter 16
Battery Recovery Supply Chain Design. A Literature Review

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Abstract Batteries are products of many devices, especially electronic ones. The rapid development of electronic devices has reduced the effective life span of these products. As a result, these products end up in landfills and cannot be valorized or used again, causing environmental pollution by the hazardous substances they contain. Currently, it is possible to find different policies and initiatives to increase the percentage of recovered batteries. However, this is a complex process because of its different formats and components. In addition, recovery systems must be developed from a sustainability perspective, which increases their complexity from the perspective of evaluation and implementation. This study presents a literature review to map how the design and implementation of battery recovery supply chains have been addressed in the literature. Fourteen journal articles were selected and analyzed considering the type of problem addressed, the variety of batteries and sustainability dimensions considered, the supply chain studied, the optimization model approach, and the geographical location of the case studies. The main findings are the lack of consideration of social, political, and technological aspects in the sustainability assessment and the lack of consideration of domestic-use batteries.

Keywords Batteries · Supply chain design · Sustainability

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16.1 Introduction

The development of new technologies not only allows us to meet the needs of our society but also causes new consumption products to be manufactured. For example, electronic devices, whose rapid development has reduced the effective life span of these products (Rautela et al. 2021). These products end up in landfills and cannot be valorized or used again, causing environmental pollution by the hazardous substances they contain (Yu and Wu 2010). The above, together with climate change, the depletion of raw materials, and human health problems, have led to the point of no return (Cardoso et al. 2013). For this reason, these elements' management, recycling, and valorization are relevant worldwide.

Batteries are essential for the operation of electronic devices. Every year, approximately 800,000 tons of automotive batteries, 190,000 tons of industrial batteries, and 160,000 tons of consumer batteries enter the European Union (EU) (Batteries and Accumulators 2020). For this reason, Directive 2006/66/EC legislated waste batteries in 2006. This directive sets targets for battery collection rates of 25% by weight of the amount placed on the market in 2012 and 45% by 2016 (European Commission 2019).

In the South American context, in Colombia, the management and handling of solid waste are included in environmental legislation, considering two main frameworks. The first seeks to prevent risks to health and the environment that could arise due to the operation of poor waste management systems. The second seeks to ensure the financial sustainability of companies and their responsibility for managing this type of waste (Naciones Unidas 2017). In Uruguay, the management and handling of solid waste are regulated under legal and fiscal regulations through environmental codes, laws, and decrees. Even so, there is no general or specific law for the sector, although there is a draft general law on solid waste (Naciones Unidas 2017). In Chile, to reduce waste generation and encourage reuse, recycling, and any other type of recovery, the Extended Producer Responsibility (EPR) law was enacted in 2016. This law makes producers responsible for the organization and financing of waste management derived from recovering their products (Ministerio De Medio Ambiente 2016). This law also defines priority products to recover, including batteries for domestic use, are one of them. In addition to defining priority products, the Chilean EPR law defines waste recovery and valorization goals for each product. Batteries have been proposed as a goal to recover and valorize 3% of these products from the first year of enactment and reach 45% by the tenth year (Ministerio de Medio Ambiente 2022).

Despite worldwide political efforts to promote waste management, particularly that of batteries, the development of waste recovery technologies and systems is essential to achieve defined goals. However, the development and implementation of these recovery systems is a challenge because of (1) the different formats (vehicle batteries, AA, AAA, C, D, 9V, button cells) and compositions (lithium, alkaline, carbon zinc) in which batteries are present in the world, and (2) the need to carry out recovery activities taking into consideration a sustainability perspective, which increases its complexity from the point of view of its evaluation and implementation.

Several studies have been conducted on battery recovery. However, they have focused only on technological development (Zhang et al. 2021; Hua et al. 2021), not addressing aspects related to the design of supply chains for battery recovery, which is an important aspect considering the implementation of these recovery systems. To address this issue, this study aims to map how the design and implementation of battery recovery supply chains have been addressed in the literature.

The remainder of this paper is organized as follows. Section 16.2 presents the methodology used to select the documents to be analyzed, and Sect. 16.3 analyzes the main results obtained from the documents related to the research topic. Finally, Sect. 16.4 concludes the paper with bibliographic search results and defines the research contribution.

16.2 Methodology and Data Selection

In this study, a systematic literature review was carried out based on the guidelines presented by Siddaway et al. (2019), which consisted of two stages, as shown in Table 16.1.

First, the strategic search includes the definition of the following aspects: (1) the keywords associated with the research topic, (2) the search equation to be used in the different databases, (3) the search period, and (4) the databases used to obtain the research documents.

Table 16.1 Procedures and criteria

Stage	Principle	Description
Search strategy	Document types	Journal articles
	Keywords	Closed-loop supply chains, reverse logistics, reverse supply chain, batteries, waste batteries, domestic batteries, household batteries
	Search equation	(“Batteries” OR “Battery” OR “Waste Batteries” OR “Domestic batteries” OR “Household batteries”) AND (“Closed-loop supply chains” OR “CLSC” OR “Reverse logistics” OR “RL” OR “Reverse supply chain” OR “RSC”)
	Period of time	Until August 10, 2022
	Database	Scopus and web of science
Study selection	Criteria	Articles related to supply chain design for battery recovery
	Procedures	Review of title and abstract related to the topic of interest
		In-depth article review
		Title, abstract, and keywords are screened The full article is reviewed Selection is made based on selection criteria

In the second stage, studies were selected by adopting criteria related to the research topic and using review procedures, such as abstract and full-text reading, to select the most relevant results.

Figure 16.1 presents the results for each stage. As can be observed, the first inputs used for the search were the keywords categorized into two groups. The first group corresponds to "Batteries" OR "Battery," OR "Waste Batteries," OR "Domestic batteries" OR "Household batteries," which are related to the types of products to be recovered (batteries), taking into consideration the different ways in which this element is referenced in the literature. The second group of keywords correspond to "Closed-loop supply chains" OR "CLSC" OR "Reverse logistics" OR "RL" OR "Reverse supply chain" OR "RSC," which are related to the different type of supply chains considering their structure. On the one hand, reverse supply chains are all those recovery activities from when the user discards the products until the products are reusable in the market (Fleischmann et al. 1997), including collection, sorting, transportation, treatment, and storage (Hevia and Urquiaga 2006). On the other hand, closed-loop supply chains involve not only reverse flows of materials/goods from end users to manufacturers or related facilities, such as collection centers, disposal sites, and recovery centers but also direct flows of raw materials/goods from suppliers to manufacturers and then to customers (Subulan et al. 2015a). Therefore, considering the databases, Web of Science and Scopus were selected, where the search equation indicated in Table 16.2 was searched on the Title, Abstract, and Keywords.

The Web of Science database generates 145 results. The Scopus search generated 809 results, filtered according to the document type "Article," to obtain 474 documents in this database. Considering both databases, 619 documents were obtained, of which 92 were duplicates, leaving 527 documents for analysis. Subsequently, the titles and abstracts were reviewed to verify that they were related to the studied topic, leaving a total of 45 documents. After a complete reading of these articles, 14 papers were selected.

16.3 Results

Table 16.2 presents a detailed description of the 14 studies considered in this review. As can be observed, the articles were classified according to the following:

- Type of problem: The papers were classified according to the level of decision-making modeled, considering whether it was a supply chain design problem or a vehicle routing problem. Supply chain design problems are responsible for evaluating a combination of *processes to fulfill customer requests, including all possible entities such as suppliers, manufacturers, transporters, warehouses, warehouses, retailers, and the customers themselves* (Chopra and Meindl 2010). On the other hand, vehicle routing problems are *those in the logistics and transportation domain, assisting customers geographically dispersed around the central warehouse using a fleet of trucks with different capacities* (Braekers et al. 2016).

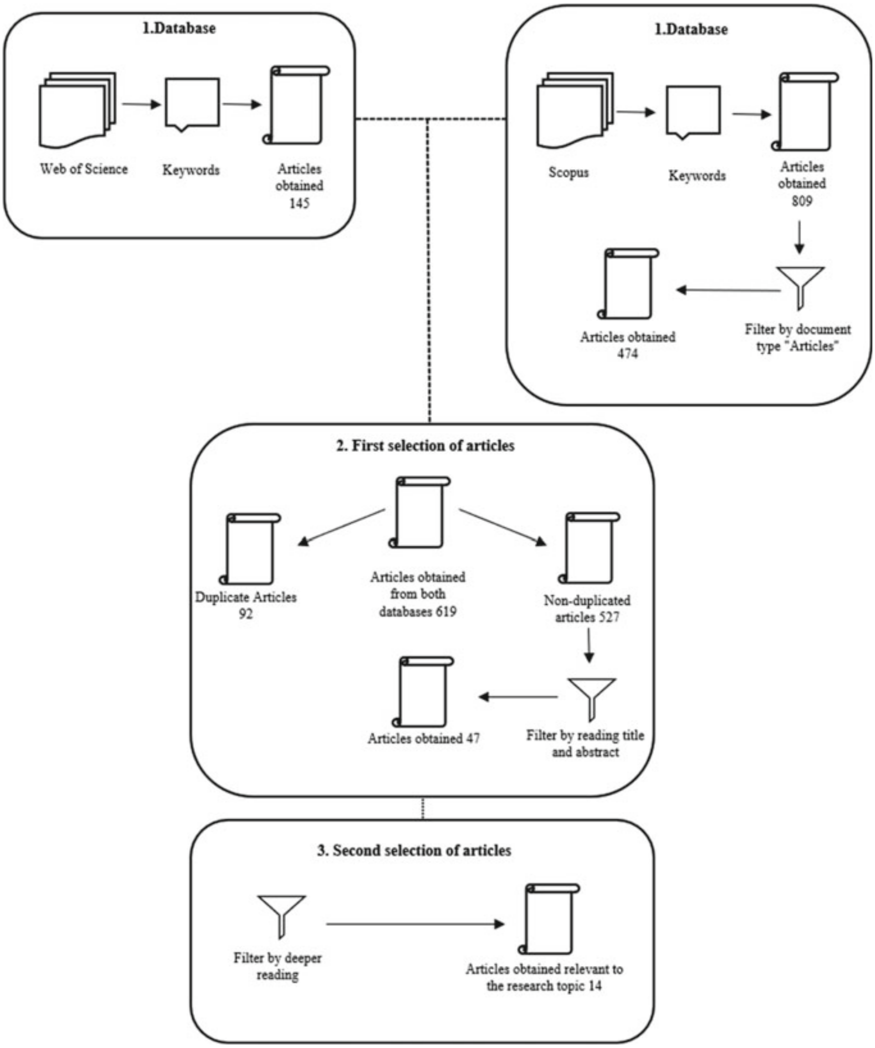

Fig. 16.1 Search methodology

- Type of batteries: This classification identifies the different types of batteries studied in the literature.
- Sustainability dimensions: This classification identifies the sustainability dimensions considered in the literature (economic, environmental, social, political, and technological) (Bautista et al. 2016; Espinoza Pérez et al. 2017).
- Type of supply chain: This classification identifies the types of supply chains (closed-loop or reverse) considered in the literature on battery recovery supply chains.

Table 16.2 Classification of articles

	Type of Problem		Type of batteries			Sustainability dimensions					Type of supply chain			
References	Design	Routing	Electric vehicle batteries/lithium batteries lead	Lead acid batteries	Alkaline batteries	Economic	Environmental	Social	Political	Technological	RL	CLSC	Optimization model	Case study
Hao et al. (2021)	x		x			x	x	x			x		MINLP	China
Tosarkani and Amin (2019)	x			x		x	x		x			x	FFSP	Canada
Mota et al. (2015)	x			x		x	x	x	x			x	MILP	Portugal
Subulan et al. (2015a)	x			x		x						x	HMOLP	Turkey
Hoyer et al. (2014)	x		x			x	x		x	x	x		MILP	Germany
Yu and Wu (2010)	x			x		x	x				x		N/A	Taiwan
Tadaros et al. (2020)	x		x			x	x				x		MILP	Sweden
Masudin et al. (2019)	x		General Batteries	x	x				x				MILP	Indonesia
Subulan et al. (2015b)	x			x		x						x	FMOLP	Turkey
Yu et al. (2020)		x	x			x					x		MILP	China

(continued)

Table 16.2 (continued)

	Type of Problem		Type of batteries			Sustainability dimensions					Type of supply chain			
References	Design	Routing	Electric vehicle batteries/lithium batteries lead	Lead acid batteries	Alkaline batteries	Economic	Environmental	Social	Political	Technological	RL	CLSC	Optimization model	Case study
Shen (2020)	x		Button Cell Batteries	x	x				x				MILP	China
Li et al. (2018)	x		x			x	x					x	MILP	United States
Hendrickson et al. (2015)	x		x			x	x		x		x		MINLP	United States
Wang et al. (2020)	x		x			x	x		x		x		MILP	China

MILP (Mixed-Integer Linear Programming), MINLP (Mixed Integer Non-Linear Programming), FFSP (Fully fuzzy stochastic Programming), FMOLP (fuzzy multi-objective linear programming), HMOLP (hybrid stochastic and possibilistic multi-objective linear programming)

- Optimization model: This classification was conducted to identify the main optimization models developed in the literature on battery recovery supply chains.
- Case Study: This analysis was conducted to determine the prominent geographical locations where the research topic was developed or applied.

Considering the type of problem addressed in each paper, 13 articles aimed to develop a supply chain design (see Fig. 16.2). Only one of the studies focused on the vehicle routing problem for transferring waste batteries (Yu et al. 2020). Studies that address the design of supply chains consider decisions related to the location of collection and reprocessing centers for the treatment of batteries, taking into consideration the coverage that each facility has, their capacities, the different technologies present, the operational costs for their operation, and the sale of the generated products. For example, Hao et al. (2021) evaluated different configurations related to environmental risks for installing recovery centers for electric vehicle batteries in China. Subulan et al. (2015a) incorporated the facility location decision in their model to maximize the battery collection coverage, subsequently considering the sale of the produced material. Hendrickson et al. (2015) evaluated various scenarios regarding different recycling processes, using economic and environmental criteria for the optimal location of facilities within California, USA. However, studies addressing vehicle routing problems consider variables such as the number of vehicles available, their maximum loading capacity, and the distance between different collection nodes to be traveled. For example, Yu et al. (2020) developed an optimization model for routing problems related to battery transport based on the ant colony algorithm, considering battery transport distribution's cost, speed, and efficiency.

Regarding the types of batteries studied in each article (see Fig. 16.3), 58% of these analyzed Lithium Batteries for Electric Vehicles and 42% Lead Acid Batteries (traditional vehicles). In other words, no study has used alkaline or household batteries as the elements for analysis.

Fig. 16.2 Type of problem

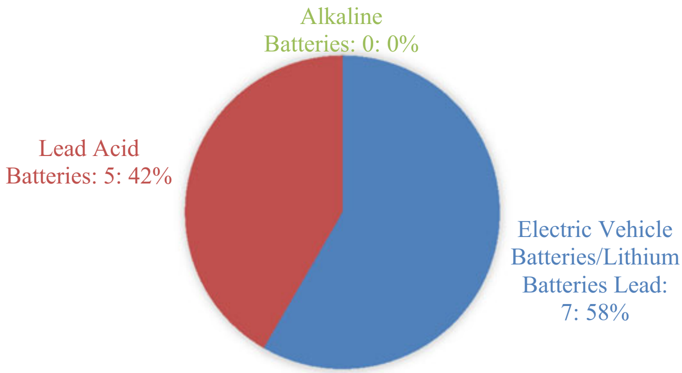

Fig. 16.3 Type of batteries

Considering the sustainability dimensions (see Fig. 16.4), no study has considered all of these. Only two articles studied four of the five dimensions. For example, Mota et al. (2015) considered the economic, environmental, social, and political aspects for the development of a generic multi-objective mathematical programming model for the design and planning of a closed-loop supply chain, considering the policies imposed by the European Commission regarding sustainable development under the Lisbon Treaty, which is still being updated. They used the life cycle assessment (LCA) method to measure environmental aspects. Economic parameters, such as production costs, were considered for economic dimensions. Variables, such as job creation, were included for the social dimension. Hoyer et al. (2014) considered the economic, environmental, political, and technological aspects and developed a mathematical optimization model to maximize cash flows. The optimization model developed allows the selection of technology for battery recovery, considering the political measures and environmental care imposed in the EU Directive 2006/66/EC. The model was applied to the German research project, LithoRec.

Considering the sustainability dimensions separately, the articles analyzed mainly considered the economic, environmental, and political aspects (see Fig. 16.5). By contrast, issues related to social and technological aspects were addressed in only three articles.

Economic indicators such as profit maximization related to sales of raw materials in secondary markets, transportation, and reprocessing costs are the most considered. Concerning the environmental dimension, the most commonly used indicators are the number of emissions produced in the transportation of batteries from different points and those generated in treatment plants. Finally, political aspects are mainly related to national regulations, international recommendations on treating these elements, and expected recycling goals.

As shown in Fig. 16.4, one of the least evaluated dimensions is social, which was considered in only two articles. One of these was in the previously noted research by Mota et al. (2015), and the second article was by Hao et al. (2021). The latter

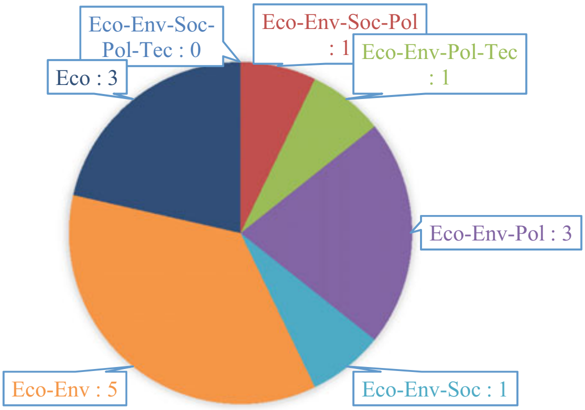

Fig. 16.4 Set of dimensions evaluated

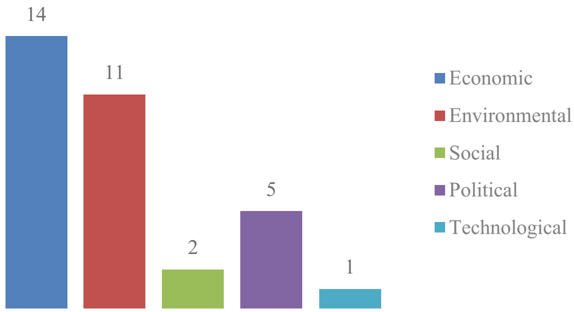

Fig. 16.5 Sustainability dimensions

developed a multi-objective, multi-period recovery reverse logistics network model through a mixed-integer non-linear linear programming (MINLP) model to minimize environmental and safety risks and maximize social responsibility, such as employment opportunities and economic benefits. Hoyer et al. (2014) is the only research assessing technological aspects based on the development of the German research project LithoRec.

Regarding the type of supply chain, nine articles analyzed a reverse supply chain (see Fig. 16.6). The stages considered address the disposal of the product at collection points at the end of its useful life, its transfer to reprocessing centers, and the physical/chemical processes of material recovery. Although Closed-loop supply chains have been studied in five articles, in contrast to RSC structures, they also consider direct flows of raw materials to manufacturers or suppliers, creating various secondary markets. For example, Subulan et al. (2015a) considered using lead and plastic parts (after the recycling process) to manufacture new batteries or sell sulfuric acid to third parties for chemical, fertilizer, pigment production, and the pesticide industry.

Considering the types of programming used to solve optimization problems (see Fig. 16.7), eight of the analyzed articles used Mixed-Integer Linear Programming

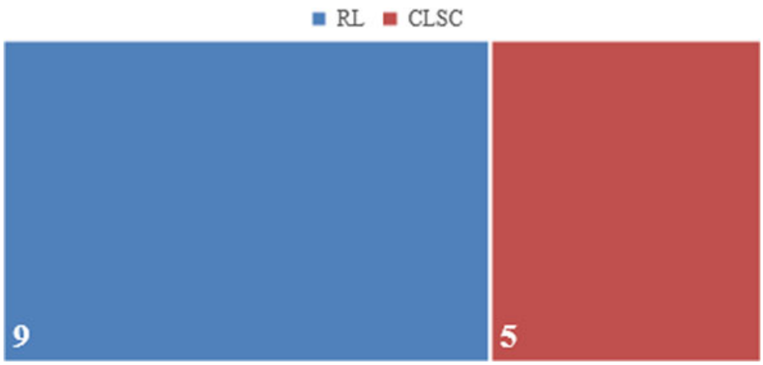

Fig. 16.6 Types of supply chain

(MILP), followed by two articles that used mixed integer non-linear programming (MINLP). The rest of the analyzed research used different programming methods. For example, Tosarkani and Amin (2019) applied a multi-objective FFSP (Fully fuzzy stochastic programming) approach to consider non-deterministic variables and decision parameters concerning environmental compliance. Subulan et al. (2015b) used FMOLP (fuzzy multi-objective linear programming) to consider diffuse objectives with different importance. Subulan et al. (2015a) applied HMOLP (hybrid stochastic & possibilistic multi-objective linear programming) to consider the uncertainties of the parameters.

Finally, regarding the geographical location of the case studies in the research articles, Fig. 16.8 shows that the most significant number of case studies come from the Asian continent, where four articles correspond to China, one to Indonesia, and one to Taiwan. Two case studies have been conducted in Europe, one from Turkey, one from Germany, one from Sweden, and one from Portugal. The lowest number of cases corresponds to North America, with two cases in the United States and one in Canada. No research articles have been found in the South American context.

Fig. 16.7 Optimization models

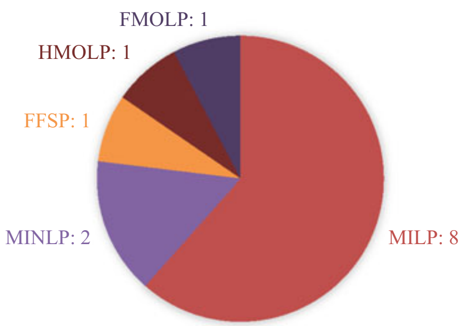

Fig. 16.8 Case study

16.4 Conclusions

This document presents a systematic literature review to understand how the design and implementation of battery recovery supply chains have been addressed in the literature. Concerning the queries made in the Scopus and Web of Science databases, a total of 619 articles were obtained. Most of the articles were mainly related to the element of interest, the batteries, but focused on the manufacturing processes related to the optimization of chemical processes and the demand for their raw materials (Lithium and Carbon). In addition, some articles have studied the element during its useful life, mainly focusing on the implementation of new technologies for electric vehicles from a sustainability perspective. Only 14 articles considered the post-life stage of this element, mainly developing the financial aspect, such as pricing or subsidies required for a competitive and sustainable supply chain. These articles were analyzed considering the type of problem addressed (supply chain design or vehicle routing problem), type of batteries and sustainability dimensions considered, type of supply chain studied, optimization model approach, and geographical location of the case studies. The main findings and conclusions are as follows.

- Regarding the type of supply chain problem addressed, most of the articles analyzed aimed at supply chain design, where the installation of collection points and treatment plants for battery recovery are the most considered decisions; only one case considers a vehicle routing system, which has the objective of optimizing route planning, considering elements such as the capacity of each vehicle and the distance to recycling points, among other variables.

- Supply chain design can address different sustainability dimensions, such as economic, environmental, social, political, and technological. However, most of the analyzed documents focused on the first two, highlighting maximizing economic benefits and reducing the environmental emissions produced during the transformation and transportation processes.
- Regarding the type of batteries, most of the analyzed articles considered Electric Vehicle Batteries or Lead Acid Batteries, which are batteries of a larger size and a higher economic value, taking into consideration the elements that can be recovered at the end of their useful life. However, no document for reduced-size domestic batteries, such as double A, triple A, and button cells, requires further investigation. Thus, waste management of these types of batteries is an open topic for future research.
- Finally, considering the geographical location of the case studies, most articles related to the supply chain for the recovery of batteries were developed in Europe and Asia. In the first case, due to the numerous legislations imposed by the European Commission since the beginning of the 2000 decade, giving great importance to the pollution produced by battery waste was discarded, and the regulations related to the treatments and collection percentages of these elements were strengthened. In the case of the Asian continent, the most significant number of articles corresponds to China. This may be due to the constant development of new technologies in this country and its vast population, which makes waste management an indispensable topic for the correct functioning of society. In the case of the Americas, only two countries were found to have developed supply chains for batteries: the United States and Canada, both in the northern hemisphere, which can be considered highly developed countries with a high technological capacity. In Latin American countries, no research related to supply chains for battery recovery was found, but this does not mean that this is not a topic of interest for this part of the continent. As described at the beginning of this literature review, countries such as Colombia and Uruguay are already implementing regulations for the management of these wastes, seeking to prevent the risks to health and the environment that could arise from poor management of these elements. In the particular case of Chile, the roadmap for achieving a circular economy by 2040 has already been published, focusing on sustainable development and the responsible and efficient management of natural resources. In the case of waste generated by batteries, a preliminary project related to managing this element is currently being developed, considering the collection goals that are expected to be reached within ten years.

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Chapter 17
Urban Logistic Analysis in the Commercial Area and Proposal of a Policy for Loading and Unloading of Goods in Popayán City

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Abstract The last two decades have witnessed significant growth in Latin American cities, with 81% of the region's inhabitants living in urban areas. This tendency affects the quality of citizens' lives and produces greater demand for resources and services. This study aims to provide alternative solutions to improve the problems of vehicular congestion and logistics processes in one of the most congested sectors of Popayán. First, logistics operations were characterized in the city center using the last mile/km^2-MIT methodology. This methodology allowed us to identify areas with the greater vehicular flow and a higher density of economic activities. Subsequently, two scenarios were evaluated with discrete simulations to determine the loading and unloading zones and schedules for loading and unloading times to suggest improvements in vehicular flow. The results showed an 8% improvement in loading and unloading zones, a 12% increase in the pedestrian/vehicle ratio, an 18% improvement in pedestrian trips, and a 16% reduction in vehicle flow disruptions. Finally, the chapter provides a proactive tool for decision-makers to guide public policies aimed at improving urban-to-last-mile freight distribution in Popayán.

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Keywords Traffic flow · Public policy · Last mile · Simulation

17.1 Introduction

In 2012, 52.6% of the world's population lived in urban areas. Projections suggest that by 2030, cities will be home to approximately 66% of Earth's inhabitants (United Nations 2015). The population of urban areas grows at a rate of 65 million people annually. Rapid urban growth in emerging economies is incredibly complex. In 2012, urban areas accounted for 79% of the world's inhabitants, which is projected to increase to approximately 85% by 2030 (BID 2019). These increases in population density generate an increase in commercial activity, such as urban transportation, which is a critical factor in the supply of goods in stores (Blanco and Fransoo 2013). Latin America has no stranger to this trend; currently, 82% of the region's population lives in urban areas. The cities with the highest populations are São Paulo, Mexico City, Buenos Aires, Rio de Janeiro, Lima, and Bogotá (United Nations 2016).

As a multidisciplinary field, urban logistics aims to understand, study, and analyze the different organizations, logistics systems, stakeholders, and planning actions related to improving the different urban freight transport systems and linking them collaboratively (Gonzalez-Feliu and Routhier 2015).

Cities in Asia, Latin America, Europe, Beijing, Kuala Lumpur, Madrid, Mexico City, Sao Paulo, Rio de Janeiro, Bogota, and Santiago have begun to understand and address the challenges and problems associated with loading and unloading in urban areas (Ambra et al. 2019). However, these cities are also facing other challenges, such as urbanization trends, e-commerce, and increasing fragmentation of freight transportation. These changes negatively impact congestion, safety, the environment, and the overall quality of life (Steg and Gifford 2005). The most studied transport branches are long distances, leaving urban transport in the background (García 2015). To date, authorities and decision-makers have attempted to implement policies and regulations to address these issues. However, these have been disjointed and have often had negligible or counterproductive effects (Nocera et al. 2021; Comi and Savchenko 2021).

Different studies (Arvidsson and Pazirandeh 2017; Ambra et al. 2019; Lauenstein and Schank 2022; Wang et al. 2020) have estimated that between 28 and 75% of total supply chain costs are incurred in the loading and delivery of goods, reflecting both system inefficiency and poor operational performance. However, infrastructural development and transport planning are not balanced by the number of vehicles in circulation (Kin et al. 2018). This is because some city areas are not easily accessible to large commercial vehicles or even cars (Blanco and Fransoo 2013).

The development process of Latin American cities has been characterized by uncontrolled and dispersed growth in vulnerable ecological zones, environmental deterioration, depletion of food production areas, and increased social and territorial inequalities (Piña 2014). Therefore, cities must implement public policies for sustainable urban development (Bruzzone et al. 2021).

This study analyzed the area of the city of Popayán. According to data from Colombia's Departamento Administrativo Nacional de Estadística (DANE) for 2022, the city has a population density of 49.97 inhabitants/km^2 and a population of 330,750, which is predicted to increase to 559,084 by 2050 (41%). As a clear sign of urban growth in Popayán, the total number of registered vehicles increased by 44%, from 29,297 in 2020 to 66,192 in the following year, with repercussions for mobility in the city (Alcaldía Municipal de Popayán 2020).

According to a study by Chará Ordóñez et al. (2017), 85% of Popayán residents have a negative perception of mobility in the city, reflecting the need to consider additional transportation and logistics strategies to improve traffic congestion, with current average speeds of approximately 20 km/h. The problem faced by urban freight transport policymakers is the lack of the necessary instruments, techniques, and knowledge to deploy adequate measures and address such urban logistics problems (Kin et al. 2018). Therefore, in the present study, we apply the MIT Megacity Logistics Lab's km^2 methodology (Merchán et al. 2015) to improve the loading and unloading of goods and propose urban freight transport policies that facilitate the circulation of goods in the city. To this end, we contextualize the environment in which logistics operations are conducted and review the specialized literature on urban logistics. In doing so, we seek to better understand the area's characteristics and support future public policies to improve transportation systems, create a smooth traffic flow, and generate the optimal distribution of resources.

The rest of this article is organized as follows: Sect. 1.1 presents the literature review, Sect. 17.2 explains the methodology, Sect. 17.3 sets out the main results, and Sect. 17.4 concludes the paper.

17.1.1 Literature Review

The literature demonstrates that urban logistics is a rapidly growing academic research area encompassing various methodologies. The following section presents the themes found in the literature and the methodologies and theories used.

17.1.2 Urban Logistics

Despite the growing literature on urban logistics, much research and innovation have been conducted in developed countries. The freight transport landscape differs significantly between emerging markets and developing countries (Mareï and Savy 2021). In recent years, urban planners in these environments have paid more attention to urban logistical challenges (Holguín-Veras et al. 2016). Although urban logistics seems to be an excellent approach to the problems of freight transport activities, two main factors hinder its implementation. First, the logistics branch is highly dynamic because of the interaction of multiple actors. Second, there is a lack of knowledge and methods to solve prevailing urban logistics problems (Kin et al. 2018).

Urban logistics must be safe and cost-effective because goods deliveries are time sensitive and must be carried out expeditiously. However, these processes are often characterized by high costs and other critical problems that make them fragmented, uncoordinated, and unappealing. For instance, conflicts between good vehicles and congestion seriously threaten the punctuality of deliveries and lead to high costs (Vasiutina et al. 2021).

To address these issues, several case studies have been conducted to characterize cities in which different methodologies are applied for data collection, improving the delivery of goods (Lagorio et al. 2016), and a review of regional experience in freight management by analyzing freight distribution, regional logistics constraints, strategies, and implications for policy and planning (Castro et al. 2016), or preparing studies that serve as a reference for developing comprehensive cargo mobility policies (Hesse 2004). Similarly, several studies have addressed analytical techniques for analyzing urban logistics solutions. For example, Holguín-Veras et al. (2016) produced a report that consolidated available freight generation models into an electronic database to help professionals use these models. The report also identified the most appropriate approaches for developing and applying freight generation models. In addition, a series of studies have synthesized good practices and recommendations for public policies (Doblanc 2009; Holguín-Veras et al. 2016).

However, several studies have explored and proposed improvements to the last-mile distribution. Thomas (2009) examined the effects of customer density and length and their relationships with delivery route efficiency in the delivery window. Greasley and Assi (2012) analyzed the last-mile distribution link between a specific industry and its customers by simulating changes in delivery policies. Greasley and Assi (2012) proposed a logistics model to increase the efficiency of urban distribution by introducing innovative contracts to improve the logistics chain as multimodal distributions. Bierwirth et al. (2019) found that the costs associated with the last mile contribute significantly to total supply chain costs by as much as 75%. Kin et al. (2017) estimated that up to 28% of the costs related to the transportation sector are incurred in the last mile. Such high estimates necessarily reflect system inefficiencies and poor operational and environmental performances.

These operational offerings are in addition to the study of distribution in the last mile (or last kilometer) owing to the rapid growth of urban areas. Some studies analyzed the densest area, such as Merchán et al. (2015), who focused on Bogotá's T Zone with its hotels, restaurants, cafes, bars, and shopping malls, using the MIT km^2 methodology. Other authors have centered on the impact of nano-stores: small retailers in emerging economies that one person usually manages with direct contact with the end user (Blanco and Fransoo 2013).

17.1.3 Use of the km² Methodology for the Analysis of Urban Logistics

The km² methodology implements logistics indicators representing and characterizing the selected areas (Gutierrez et al. 2021). This methodology is applied in two stages. The first was to collect and specify store inventory information, road policies, and parking restrictions within the selected km². In the second phase, delivery times are recorded, along with the products, quantities, and equipment used in product delivery (Gutierrez et al. 2021).

One of the most notable characteristics of the km² methodology is that it is applied through observation, which simplifies the procedure and allows the collection of a large amount of information that can be used in policies or improvement models. For example, the km² was applied to downtown Bogotá to generate strategies for mobility, logistics, and urban planning (Hidalgo and Chicaiza 2018).

Various models have been proposed to improve mobility efficiency in specific sectors; for instance, one study sought to increase the fluidity of delivery distribution (Gutierrez et al. 2021). Other studies have focused on reducing the negative impact of city overgrowth and promoting the efficient distribution of goods (Chong 2005). For logistics improvement, others have characterized areas according to demographic, economic, and road infrastructure variables (Merchán et al. 2015). The km² methodology has also been used to determine the optimal location of distribution points to improve city mobility (Montesdeoca et al. 2012).

17.1.4 Optimization of Transport by Discrete Event Simulation

Simulation has proven to be a valuable tool for planning, designing, and evaluating the contribution of urban freight transport to urban mobility and the environment (Greasley and Assi 2019). Our literature review shows that most of the literature is centered on local authorities (75%). In contrast, others focused on private actors, such as carriers (50%), shippers, and receivers (35%), and a few studied residents (10%). We also found that discrete event simulation is the most frequently used simulation technique to address urban logistics problems, a technique that discrete state models characterize (as opposed to continuous state models), in which systems evolve in a discrete space where events drive time.

In addition, investigations have proposed distribution improvements using simulations (Elbert and Friedrich 2020), implemented a microsimulation model to evaluate a logistics platform in the agri-food sector (Fatnassi and Chaouachi 2016), utilized an intermodal transport tool to simulate loading and unloading operations and the planned flow of goods and commercial transactions between ports (Fanti et al. 2015), and studied the organization of urban distribution based on consolidation (Makhloufi et al. 2015). Hosoya et al. (2003) developed a micro-simulation model for the Tokyo metropolitan area (Japan) to evaluate four logistics policies in terms of vehicle kilometers traveled (VKT) and costs, considering individual company behavior and characteristics. Their evaluation concluded that road pricing was the most effective measure in the simulation.

Simulations have also been used to propose solutions for transportation problems such as rail yards (Fatnassi and Chaouachi 2016), urban rail freight (Motraghi and Marinov 2012), passenger transport (Wu and Guan 2013), and real-time dispatch and fleet management. Parola and Sciomachen (2005) analyzed the impact of new road and rail networks on intermodal transportation systems. Finally, Delaitre (2009) simulated the delivery area distribution scenarios within a medium-sized city. This study focuses on Popayán, a fast-growing city contributing to decision-makers implementing mature public policies and preparing for the near future.

17.2 Methods and Procedures

In this study, we developed a comprehensive methodology to identify urban freight transport solutions adapted to the needs of Popayán in Colombia (see Fig. 17.1). This methodology was designed to reflect the reality from the perspective of the main actors facing the challenges of daily urban freight transport and the specific characteristics of the city. The following section introduces each phase of the methodological structure (Merchán et al. 2015).

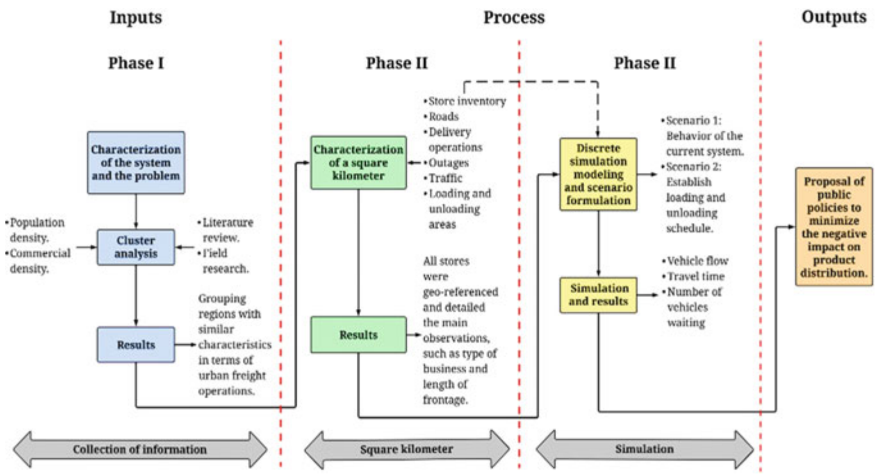


Fig. 17.1 Methodological framework

17.2.1 Phase 1: Cluster Analysis

The comprehensive method we propose is intended to meet the challenges of urban freight transportation in addition to the specific characteristics of Popayán. Thus, it was possible to evaluate the adequacy of practices and regulations contributing to solving the problems involved in this activity. After defining the relevant variables from a research perspective, we selected the following variables: population density and retail density.

Population density is a measure of the population distribution in each segment and is equivalent to the number of inhabitants divided by the area in which they reside. Therefore, it indicates the number of people in each unit area and is usually expressed as inhabitants per km^2. Finally, we established the store density (supermarkets, grocery stores, and small stores) in each area, that is, the number of these types of businesses per square kilometer.

We identified trade activities, types of commercial premises, and associated sizes through fieldwork and area analysis. For information about the facilities, we applied the MIT km^2 method (Merchán et al. 2015; Tanco and Escuder 2021). We then completed an inventory of commercial premises using the "Shop Inventory Collection Form" to collect information on the number of stores, their size, and the availability of loading and unloading areas.

17.2.2 Phase 2: Characterization of One Square Kilometer

In the second stage, we selected a method created by the MIT Megacity Logistics Lab to characterize a km^2 of the city, a cluster of the previous phase. To this end, we drew on Merchán et al. (2015), who identified five categories of information collected during fieldwork: store inventory, roads, delivery operations, disruptions, and traffic. For the first two, we collected data at the square kilometer level and the remaining three at a representative street segment. MIT Megacity Logistics Lab provided manuals and templates for the data. Instead of using GPS devices, we used smartphones to georeference each store, as suggested by the km^2 method. Merchán et al. (2015) described these categories as follows:

- Inventory of establishments: Basic characteristics of the shops located within km^2 identified by name, type, size, and geographical reference.
- Streets: Characteristics and regulations of the streets in the area, such as addresses, sizes, parking lots, bus stops, and loading and unloading areas.
- Delivery operations: Analysis of all deliveries along each selected street.
- Traffic count: Estimating traffic congestion, identification of peak hours and periods of free movement, and types of vehicles used.
- Interruptions: Identification of the causes of noncompliance with the Law, rules that resulted in traffic congestion, and the type of vehicle involved.

Data collection required five weeks of full-time fieldwork. We georeferenced all stores and detailed the main observations, such as the type of business and the length of frontage. In addition, we identified and recorded the existing road network, regulations, and parking infrastructure (including the loading and unloading zones). Simultaneously, we tracked all store deliveries on the selected streets and identified all lane-blocking actions while observing the street segment. Finally, an estimate of the traffic flow within the street was recorded over a wide range of hours.

17.2.3 Phase 3: Discrete Event Simulation

The above steps helped us understand some of the challenges facing urban freight transport in Popayán through objective data. We proposed simulating discrete events to inform measures to alleviate this problem (Gutierrez-Franco et al. 2021). In addition to basing our work on assumptions about how things work, this approach could help us find the root of the many problems we identified in the previous phases and detect even more. Likewise, this method enables the identification of the location of loading and unloading zones, the best schedule, and the proposal of public policies to improve mobility in the urban area (Holguín-Veras et al. 2016).

17.3 Results

17.3.1 Phase 1: Characterization of the Study Area

Within each city, there were areas with different characteristics. Therefore, each regulation or best practice to be implemented will have different impacts depending on the characteristics of the selected area. Consequently, following the study by Bruzzone et al. (2021), we recommend using cluster analysis or clustering theory as a first step: a method for grouping regions with similar characteristics in urban freight operations.

Popayán is divided into nine communes that account for 295 neighborhoods, according to its territorial planning plan (Alcaldía Municipal de Popayán 2020). The city's economy is primarily based on the service sector, mainly in the fields of commerce, education, and tourism, followed by the financial sector (Alcaldía Municipal de Popayán 2020). A representative sample of the commercial distribution in Popayán can be found in the historic center, where 53% of the 320 establishments are represented by commerce (Cámara de Comercio Del Cauca 2020) (see Fig. 17.2). The historic center has an area of 2.74 km^2, comprising 359 blocks, 6,530 dwellings, and approximately 31,149 inhabitants.

In 2019, 27,988 productive units were recorded in the historic center, an increase of 2.7% from the 27,257 units identified in the previous year. This exceeds the

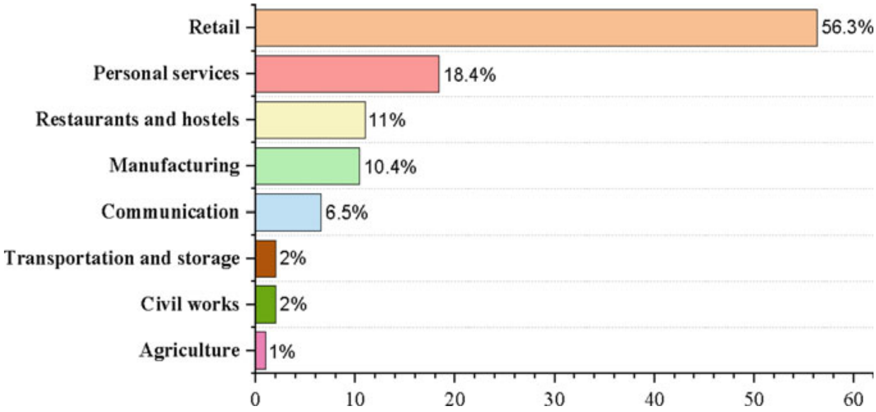


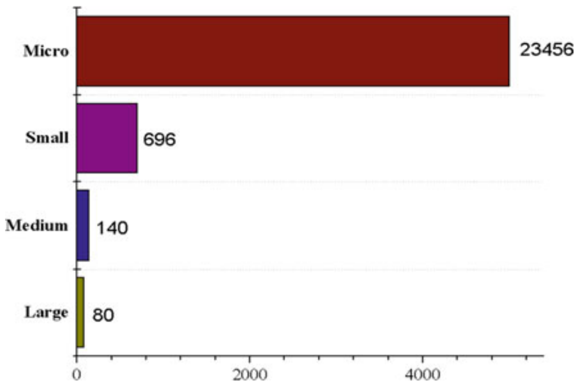
Fig. 17.2 Economic activity in the historic center

national total by 0.6 percentage points, showing that the commercial distribution of the area generates new markets and production niches among the 21,105 individuals, 3,022 simplified joint stock companies (SAS), 2,762 associations and foundations, 359 limited companies, and 337 cooperatives operating there. In terms of company size, there are 23,456 micro-enterprises, 696 small companies, 140 medium-sized companies, and 80 large companies (see Fig. 17.3) (Cámara de Comercio del Cauca 2020).

The results show that 4.2% of the companies affiliated with Cámara de Comercio del Cauca reported growth in sales value during the second half of 2019. However, given the impact of the COVID-19 health crisis, this was not repeated in the previous six months (27.4%).

These results indicate that urban centers, such as densely populated residential areas, are known for their complexity, as reported in the literature. Although urban centers are often the most constrained, this is true for densely populated residential

Fig. 17.3 Size and number of companies registered with the Cámara de Comercio del Cauca–2019



areas. In addition, the nuisance impact of last-mile deliveries in historical centers is more significant because loading and unloading activities hinder vehicular traffic.

17.3.2 Phase 2. Application of the km² Methodology

First, we selected a representative area of the city based on the density of retail trade, the area's relevance, and the feasibility of data collection. In this case, we selected an area in the historic center of Popayán, one of the most critical areas (see Fig. 17.4). We then characterized the specific area and collected data on the number of stores, roads, delivery operations, disruptions, and traffic.

We observed that the characteristics of the km² studied are similar to those of the Lince area in Lima, Peru, which combines areas of significant commercial activities and residential neighborhoods. In our selected area, the available parking space represents 35% of the total curb space. However, the entire space for loading and unloading was smaller than that in other major cities, accounting for only 10% of the total space. Figure 17.5 presents the results.

We found 1,787 businesses in the selected square kilometer, noting the predominance of retail stores, which accounted for 39% of the total, clothing and footwear establishments, with an 18% share, followed by food and beverage establishments (15%). This is followed by public agencies and services (14%) (see Fig. 17.6), which is small compared with other cities where this methodology has been applied (Beijing, Bogota, Kuala Lumpur, Madrid, Mexico City, Montevideo, Quito, Rio de Janeiro,

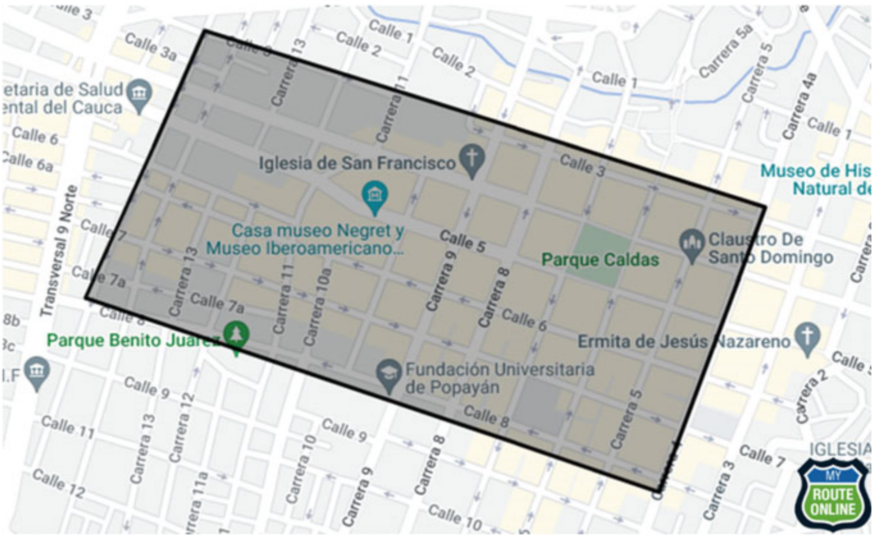
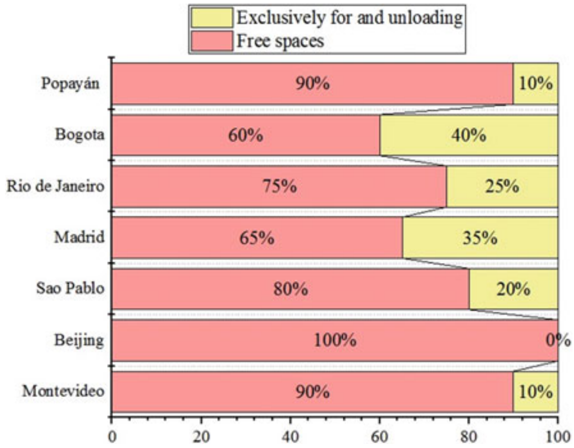


Fig. 17.4 The area selected to apply the km² methodology. *Source* My routeonline 2013

Fig. 17.5 Comparison of parking areas. *Source* Adapted from Tanco and Escuder (2021)



Santiago, and São Paulo) (Merchán et al. 2015). These data provide insights into urban freight logistics activities for different types of km^2 stores and are the key to possible solutions that can help improve the distribution system.

The analysis of vehicular traffic on the street shows that it is mainly composed of cars and that the use of bicycles is almost nonexistent, as shown in Fig. 17.7. This result is not unexpected, given the lack of bicycle lanes in the area.

In addition, we found that traffic congestion was low in the early morning, increased steadily as the day progressed, and was low again in the evening. However, when cross-checking this result with delivery frequency, shippers do not take advantage of the less-congested hours to perform their activities (see Fig. 17.8). However, if different companies consolidate and transport their goods, this could reduce the overall waiting time.

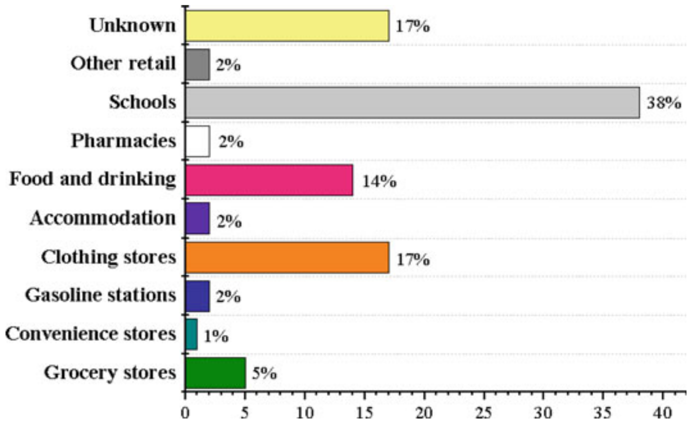


Fig. 17.6 Characterization of establishments

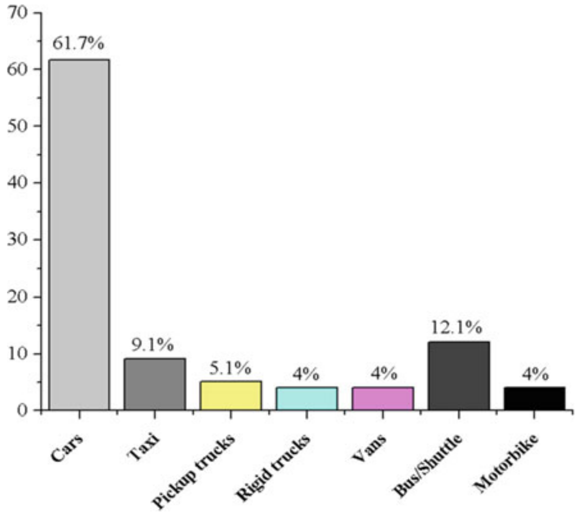


Fig. 17.7 Vehicle characterization

Fig. 17.8 Characterization of the study area. *Source* Corporación Universitaria Comfacauca 2022

Figure 17.9 shows the results for the time it takes companies to carry out distribution during weekdays, which shows that most of the time is spent waiting (64%), followed by driving (21%), leaving only limited time for unloading and checking activities (15%). Moreover, given the lack of loading and unloading areas, when shippers go to lengths to avoid committing any traffic violations and parks in spaces reserved for this purpose, the entire process can take longer. Almost half of the time (53%), shippers commit parking violations when making deliveries.

These data shed light on logistics activities in the urban transportation of goods for different stores within km^2. These can provide possible solutions for improving the distribution system.

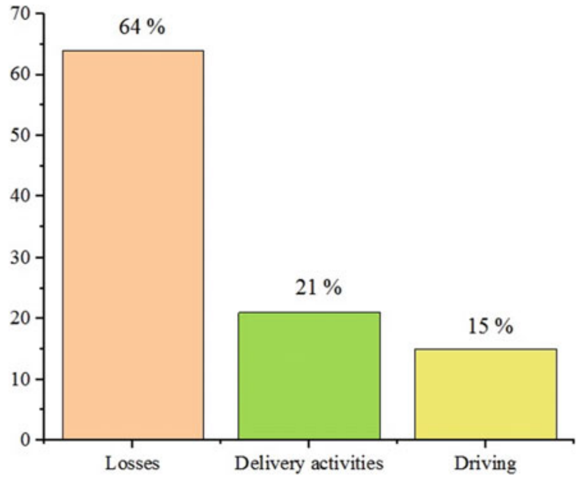


Fig. 17.9 Distribution of delivery times

17.3.3 Phase 3—Simulation of Discrete Events

The simulation model was used to evaluate the effectiveness of the loading and unloading operations in reducing traffic congestion. To develop a simulation model capable of meeting the needs of this study, facility inventory, delivery operations, traffic counts, and interruptions were used as input data.

17.3.4 Construction of the Conceptual Model

The simulation model compared the actual behavior of vehicular flow in a highly congested area (study area), which we evaluated using a time allocation policy for freight vehicles given that there are currently no controls to regulate the parking of this type of vehicle, causing congestion.

We propose a discrete simulation model to represent the random behavior between the arrival times of cargo vehicles. To this end, we employed the FlexSim software. This program allows us to build and use a simple system in a virtual environment, study different scenarios and conditions, and obtain satisfactory results through 3D modeling (Anacona et al. 2022). Figure 17.10 shows a simplified process map that illustrates the basic structure of the simulation model.

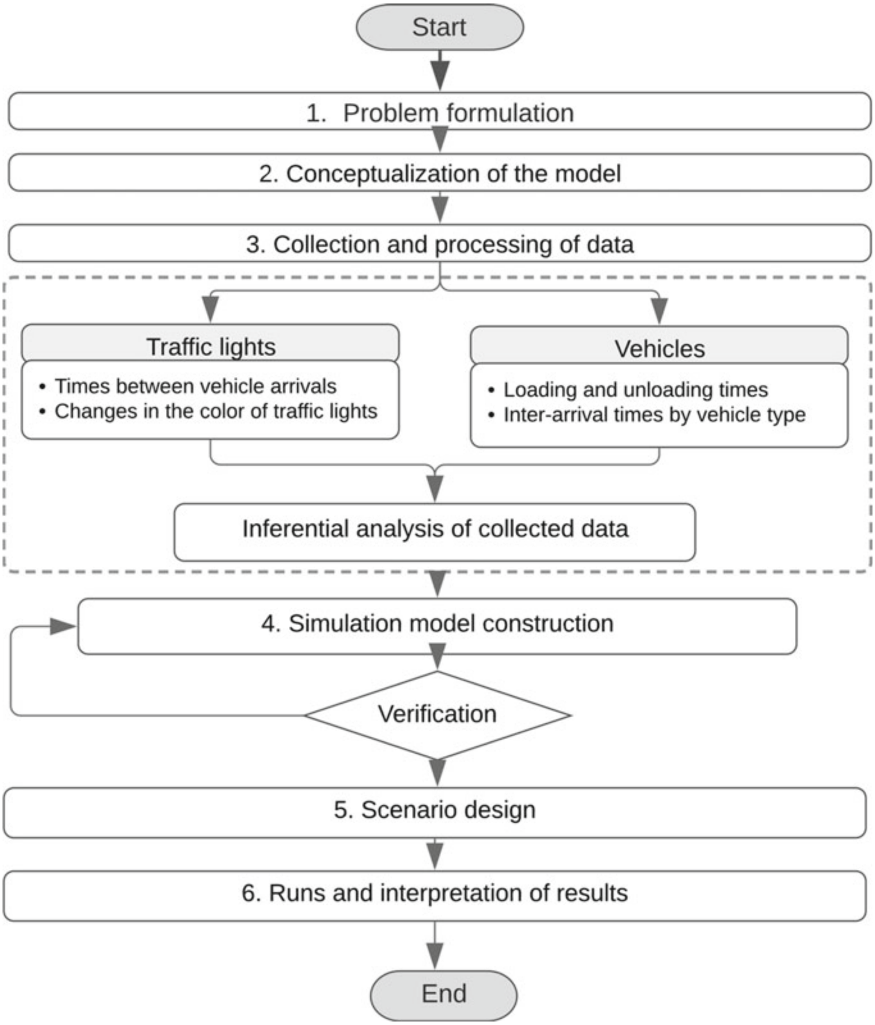


Fig. 17.10 Simulation model process map

17.3.5 Data Analysis

According to Altiok and Melamed (2007), two errors commonly made in simulation research are related to the input data. The first error refers to substituting a probability distribution for the mean of the data; this practice can produce incorrect results that lead to inappropriate decisions. The second is to use an incorrect distribution. In the literature review, we frequently found studies that widely used the normal distribution of an input source. However, from the experience of Law (2011), this is usually not appropriate for modeling a source of normalized randomness in arrival times.

Table 17.1 Probability distributions according to the schedule

Time	Distribution	Parameters
06:00–07:59 am	Johnson SB (Theta, Sigma, Gamma, Delta)	(0.8, 71.13, 1.48, 0.58)
08:00–11:59 am	Beta (Min, Max, Alpha, Beta)	0.005, 59.19, 0.88, 1.11
12:00–02:59 pm	Inverse Gaussian (Location, scale, shape)	0.78, 9.73, 5.66
03:00–05:59 pm	Beta (Min, max, shape1, shape2)	0.005, 59.19, 0.88, 1.11
06:00–07:59 pm	Johnson SB (Min, max, shape1, shape2)	0.84, 71.13, 1.48, 0.57

The importance of adequately simulating the random components present in the current process lies in analyzing the arrival of cargo vehicles at different times. Five samples were collected and distributed as follows: the first from 6:00 to 8:00 am, the second from 8:00 to 12:00 pm, the third from 12:00 pm to 3:00 pm, the fourth from 3:00 to 6:00 pm, and the last from 6:00 to 8:00 pm.

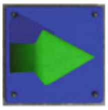
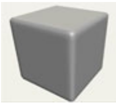
For the data analysis, we used Expertfit software, which evaluates and finds the best fit for the distribution of data collected in a time study. The expert fit was developed by Simón-Marmolejo et al. (2013) and is now used by analysts such as Patella et al. (2021), Bruzzone et al. (2021), and Law (2011), who studied real-world systems through a discrete event simulation model in different areas, such as transportation, manufacturing, logistics, traffic control, supply chains, and others. The results of the data analysis showed that the probability distribution of *Johnson SB* was adjusted to represent the inter-arrival times of vehicles from 6:00 am to 8:00 am. From 6:00 to 8:00 am, the *Beta* distribution for the 8:00 am to 12:00 pm period and the *Inverse Gaussian* distribution for the 12:00 to 3:00 pm period are shown in Table 17.1.

17.3.6 Model Construction

To construct the simulation model, a new worksheet (new model) was created using the FlexSim software. The necessary resources were selected from the libraries, and the objects used were dragged to the work area, as shown in Table 17.2.

The following data were added to the selected objects: traffic light cycle times, vehicle capacity on the road, vehicle speed, routing logic, probability distribution types (distribution type), and 3D graphic options. Subsequently, the simulation was

Table 17.2 Simulator elements used to structure the simulation model

Icono	Element	Quantity	Description
	Source	1	Used to create the vehicles that circulate in the study area
	Flow items	8	Represent the vehicles flowing on the road
	Queue	2	In which the vehicles that are waiting for the change of the traffic light to continue with the route accumulate
	Network node	4	It is used to trace the routes along which vehicles travel
	Traffic control	2	It emulated the cycle times of traffic lights
	Background	1	Used to import the drawing into AutoCAD with the scale measurements of the study area
	Sink	1	Stands for the output of vehicles from the modeled system

started by conditioning to the time range of this research, the results of which can be visualized graphically in Fig. 17.11.

17.3.7 *Analysis of Simulation Model Results*

The results obtained from the simulation were presented according to the two scenarios developed in this study. The first scenario corresponds to the construction of the behavior of the current process, and the second scenario is an improvement

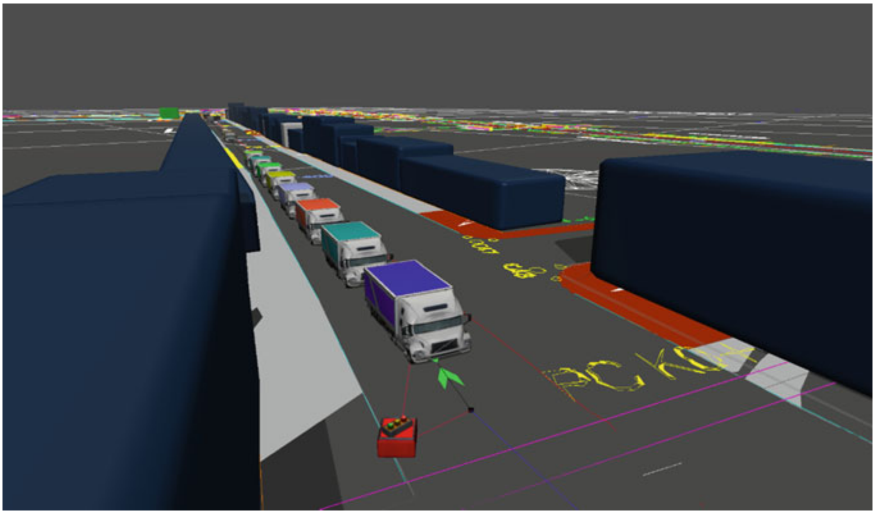


Fig. 17.11 Pilot model

proposal based on the problems identified in the sector, the objective of which is to adjust the vehicle loading and unloading schedule to improve vehicular mobility.

Thus, to measure the behavior of each scenario, three performance indicators were proposed to evaluate the differential impact of each scenario. The first indicator refers to the intensity of vehicular flow per hour, which allows visualization of the peaks that represent the most significant vehicular congestion; the second determines the permanence in the system, that is, the time it takes vehicles to travel the route; and the third represents the number of vehicles waiting, considering the cycle times at traffic lights.

The results of the current and proposed scenarios are shown in Figs. 17.12 and 17.13. Figure 17.12 shows three peaks whose amplitude corresponds to the time slot with the highest vehicle flow, with the highest intensity between 1:00 and 2:00 pm, reaching a maximum of 390 vehicles per hour. However, there are also some flat hours, with a lower vehicle flow of approximately 150 vehicles per hour, between 9:00 and 12:00 pm and 3:00 and 6:00 pm. The proposed scenario distributes flat hours for vehicle loading and unloading operations. Figure 17.13 shows that adopting a load control policy makes the peaks between flat hours smoother, making the effect of high traffic less noticeable to users and gaining a more strategic and competitive advantage for businesses in the sector.

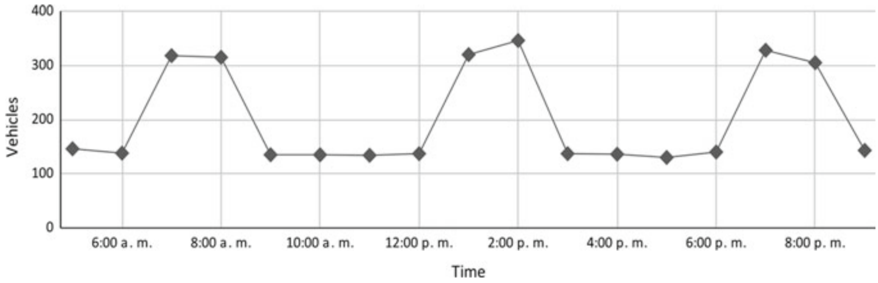


Fig. 17.12 Vehicle intensity current scenario

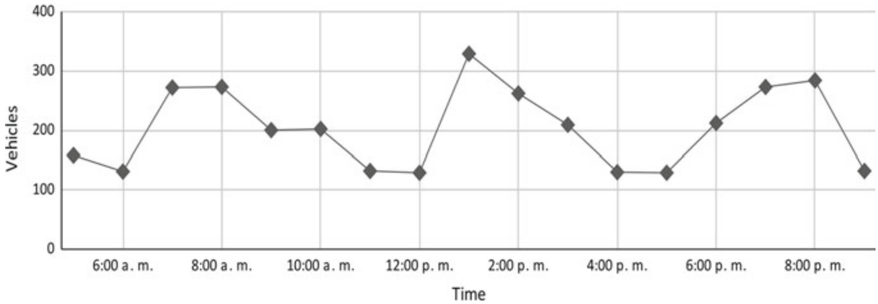


Fig. 17.13 Vehicle intensity proposal scenario

17.3.8 Vehicle Dwell Time in the System

Vehicle dwell time refers to the time taken by a user to travel through the study area. Figure 17.14 shows that the average travel time per vehicle is 90 s to travel to 260 m. In the proposed scenario (Fig. 17.15), this time is reduced by 40%, indicating that the vehicle loading control policy reduces travel times in the sector and speeds up the goods delivery process.

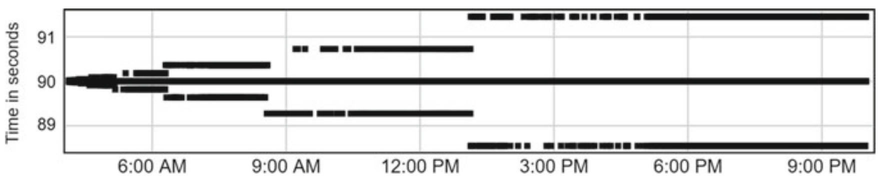


Fig. 17.14 Time spent in the system by the author—current scenario

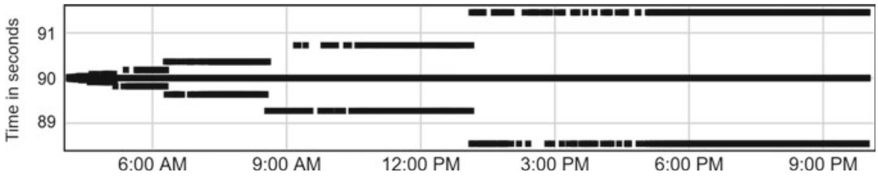


Fig. 17.15 Time spent in the system by the author—proposal scenario

17.3.9 Vehicle Content Versus Time

Figure 17.16 shows that the most significant accumulation of vehicles coincides with the peaks shown in Fig. 17.13. This behavior is the cause of traffic jams generated at each peak, which generates queues of up to twenty-seven vehicles. Figure 17.17 shows that, with the proposed loading control policy, the accumulation is reduced to a maximum of 15 vehicles in the midday peak; in the morning and afternoon peaks, it is reduced to 12 vehicles.

The results of the simulation are satisfactory because the three proposed indicators suggest that the adoption of a policy to control loading and unloading during flat hours relieves users of the effect of traffic congestion because it reduces travel times, fuel savings, timely delivery of goods, safety in delivery, control of loading and unloading vehicles, and the use of a more efficient system of loading and unloading.

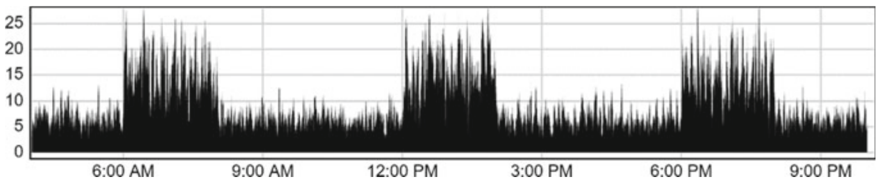


Fig. 17.16 Vehicles waiting for the current scenario

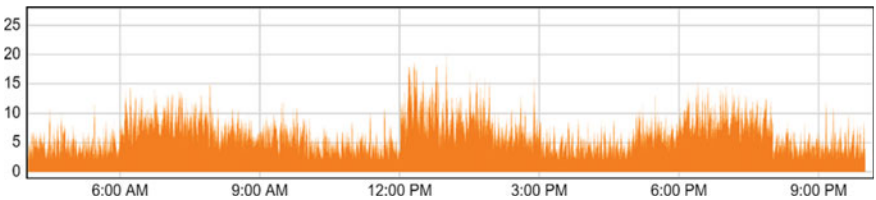


Fig. 17.17 Vehicles waiting for proposal scenario

17.4 Conclusions and Future Research

Owing to the difficulties in finding solutions for urban freight transport, we developed and applied this method. This methodology considers not only the characteristics of the city but also the reality from the perspective of the main actors. They face challenges in terms of daily urban freight transport. The choice of a multi-perspective study seemed convenient for addressing the complexity of these processes, allowing for a global vision.

The lack of urban planning increases the distance and time to products and community mobility. Accurate urban development with well-established policies will help improve distribution planning. Population density played an essential role in the analysis of this scale. Vehicle flow, loading, and unloading spaces highlight the challenges of sourcing activities and loading and unloading operations at retail outlets. This is related to the variety of establishment types, sizes, and locations.

One factor for the sustainability of Popayán is to improve last-mile delivery logistics, for which four actions are proposed. First, knowing how the logistics network is designed to develop an efficient and flexible fast network and to face new challenges related to infrastructure management and the strategy of vehicles to be used. Second, the implementation of public policies that help to create them according to the reality of the city, working on access or vehicle restrictions, timetable policies, incentives for the use of low-emission vehicles, and taxes that help to improve traffic management. Third, simulation improves the distribution network, obtains information for decision-making, and ensures adequate product demand management. Finally, with all the information generated daily, a data observatory should be created with the help of the central government to monitor the city environment, control the parameters, and visualize all the results obtained for the exchange of information with other cities, looking for better logistics practices. Through this study, we have been able to identify opportunities for improvement.

Finally, this study describes the logistics profile of the city's historic center, analyzes the indicators that provide relevant information on logistics performance, and presents a characterization for decision-makers in the public and private sectors. The main contribution of this research to the urbanization and growth of Popayán is to establish a positive impact on the quality of life with policies based on the improvement of loading and unloading zones by 8%, considering a pedestrian/vehicle ratio of 12%, pedestrian mobility of 18%, alternative mobility of 14%, and signaling of 15%. In contrast, vehicle flow interruptions were reduced by 16%. The research group proposed to continue this project in Popayan and implement a permanent observatory in the community.

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Chapter 18
Characterization of Hydrogen Supply Chain Design

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Abstract Due to the constant growth in our need for energy and the search through international agreements to reduce the use of fossil fuels to reduce carbon emissions, the promotion and use of renewable energy sources have increased. The increased use of renewable energies, mainly wind and solar, has also increased the interest in energy carriers such as hydrogen, mainly the so-called green hydrogen, because, in addition to storing energy, it also offers the possibility of using hydrogen as a fuel with low environmental impact, giving a possibility to indirectly electrify some industries that are difficult to electrify. That is why the correct planning and design of the hydrogen supply chain (HSC) are necessary. This study seeks to identify and describe the actors involved in the operation of the HSC, the decisions each actor must make and the relationships that may exist with other actors in the supply chain. Next, the strengths and weaknesses concerning the aspects identified are analyzed in Colombia. Subsequently, the problem types, modeling techniques and solution methods applied in the design of the HSC are identified and analyzed, with greater emphasis on optimization techniques. Finally, some challenges and proposals for future research in HSC design are presented.

Keywords Hydrogen · Supply chain design · HSC · Optimization

18.1 Introduction

Most of the primary energy worldwide is produced from fossil fuels such as coal (27%), oil (33.1%) and natural gas (24.3%) (Ritchie and Roser 2020); however, the

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use of these types of fuels generates approximately 66% of global CO_2 emissions (Foster and Elzinga 2020) contributing to the problem of global warming and air pollution, which causes approximately 7 million deaths per year worldwide (WHO 2018). In addition to the above, if the current level of consumption of these fuels is maintained, some of them, such as oil and natural gas, will only have a reserve for about 50 years (BP 2020), which makes it necessary to transition to clean and renewable energy sources.

According to the IEA (2021a, b), the main types of renewable energy are biomass, wind, solar, geothermal, and hydroelectric. This type of energy has less impact on the environment than conventional methods of energy production. However, although its share in the world energy matrix has increased, it currently does not exceed 6% (not including hydroelectric power). However, it is expected to continue increasing its share at the same time as the share of oil, coal and nuclear energy decreases (BP 2021).

This increasing generation of energy from renewable sources, mainly sunlight and wind, has led the industry to face the challenge of seasonal intermittency in energy production caused by the inherent nature of the resources used (Dawood et al. 2020). To mitigate the impact of this problem on energy production and to think of a sustainable energy system, the use of efficient energy storage systems or energy carriers is vital (Tian 2018; Wang et al. 2022; Kebede et al. 2022). One of the most attractive energy carriers to solve this problem is hydrogen (Visintin et al. 2017; Reuß et al. 2017). From this and the possibility of being used as a replacement for fossil fuels due to its high energy content and lower environmental impact when consumed, creating the possibility of indirectly electrifying some industries (IEA 2019), hydrogen has increased its popularity in recent years, evidencing greater research and investment in its supply chain (Liu and Ma 2020; Dawood et al. 2020).

The growing interest in hydrogen is caused by the factors mentioned above and, in addition, the increase in demand for hydrogen in recent years accompanied by projections of an increase in demand that would reach up to 18% of global energy demand by 2050 (Hydrogen Council 2017; IEA 2021a) makes decisions about the design of its supply chain more important, as it charts a path for efficient investment in infrastructure (for production, storage, transportation and end uses) and provides clarity on the relationships between them. The infrastructure dedicated to meeting hydrogen demand and its interrelationships is what is called the hydrogen supply chain (HSC).

In the following, we first identify the actors on the HSC and their respective decisions. Then, the relevant aspects of HSC and its actors are analyzed in Colombia. In the next step, we identify some problem types, modeling techniques and solution methods applied. In the last section, we present proposals for future research identified in the literature.

Based on the study of Li et al. (2019), it is identified that the main echelons addressed in the literature in the Hydrogen Supply Chain Network Design (HSCND) are feedstock, production, transportation, storage and refueling stations, at the same time some of the main decisions associated to each echelon are presented in Table 18.1. A brief description of each of these echelons will be given in the

Table 18.1 Strategic decision in HSCND models

	Feedstock	Production	Transportation	Storage	Refueling station
Decisions	Type	Number	The flow rate of the product	Number	Number
		Production rate	Type	Inventory	Type
		Type	Number	Type	Size
		Physical form	Existence	Size	
		Size	Direction		
			The flow rate of the energy source		

Source Adapted from Li et al. (2019)

following sessions. The decisions associated with each will be deepened depending on the cases found in the literature.

18.1.1 Primary Energy Sources (Feedstock)

It is important to clarify that hydrogen is not a primary energy source but a carrier produced from different primary energy sources. The energy sources most commonly used in research projects are natural gas, coal, biomass, water, and electricity from the local power grid (Almansoori and Shah 2009, 2012). International agreements aimed at reducing CO_2 emissions have led to an increase in consideration of renewable energy sources in the process of hydrogen production through electrolysis, for example, the use of solar and wind energy, hydroelectric energy, and geothermal energy to feed the electrolyzers (Güler et al. 2021; Karayel et al. 2021).

It is evident the importance of explicitly integrating the raw material problems into the SCND; however, this aspect has not received sufficient attention. In several HSCND models, the feedstock type is preselected according to the production technology examined. According to Li et al. (2019), there are different aspects related to feedstock that has not been widely considered in the literature; for example, in addition to the feedstock purchase cost, availability, storage and transportation should be taken into account, in addition. In the production of hydrogen from electrolysis, very few studies explicitly represent aspects such as the availability or the cost of water in the model. The works of Ogumerem et al. (2018) and Won et al. (2017) are examples of the inclusion of these aspects in their models. Lastly, Almansoori and Shah (2009) mention that some of the important decisions to be made regarding primary energy sources are geographical location, availability, and quantity, as well as the decision of whether or not to import resources from elsewhere and how much of that resource will be used to produce hydrogen.

18.1.2 Production

Different sources have been considered for hydrogen production, determining the production plant to use. Currently, most of the hydrogen (96%) is obtained from fossil sources using natural gas steam reforming plants, partial methane oxidation, coal gasification, and only 4% from water electrolysis. However, most of the electricity is obtained from the grid. Thanks to international agreements, such as the Paris Agreement (UN 2015) or the Glasgow Climate Pact (UNFCCC 2021), to reduce the emission of greenhouse gases, there has been an increase in the production of hydrogen using electrolysis powered by renewable energy sources or the so-called green hydrogen (Yukesh Kannah et al. 2021) and biomass gasification (Liu and Ma 2020). Figure 18.1 shows the summary of the hydrogen production methods.

Different decisions are taken based on the production plants, evidencing works that seek to optimize the location of several of these plants (Thor Ingason et al. 2008), others where, in addition to the location, they seek to determine the quantity of hydrogen, production rate and type of technology with which it will be produced (Han et al. 2012) and others where economies of scale are taken into account when modeling the cost of capital and operating costs (Murthy Konda et al. 2011). Below is a brief description of the main hydrogen production methods discussed in the literature.

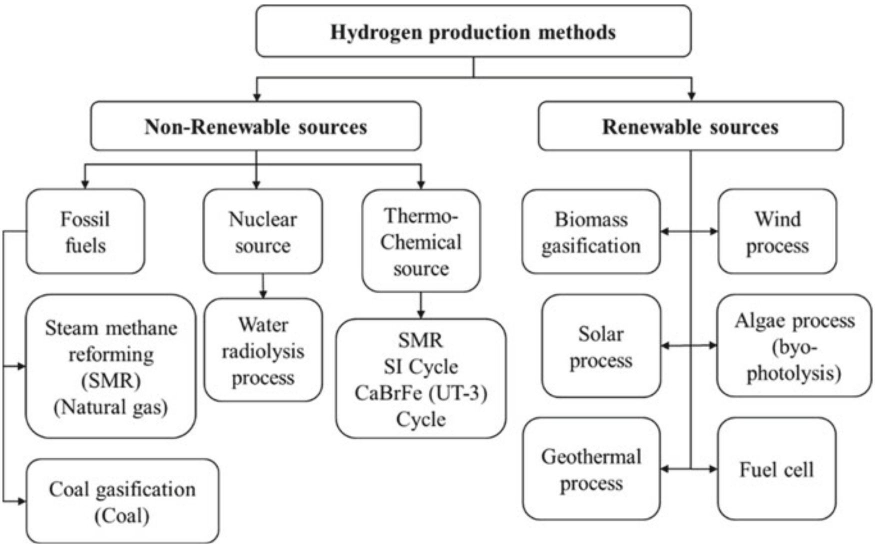

Fig. 18.1 Hydrogen production methods. *Source* Adapted from Amin et al. (2022)

18.1.3 Steam Methane Reforming (SMR)

According to Timmerberg et al. (2020), steam methane reforming (SMR) is the globally dominant hydrogen production process and consists of the application of the following four steps:

- Contaminants such as Sulphur or chloride compounds are removed.
- Methane reacts with water steam yielding carbon monoxide and hydrogen.
- The hydrogen yield is increased through the reaction between carbon monoxide and additional water steam to carbon dioxide and additional hydrogen (water gas shift reaction).
- The raw hydrogen is purified typically through pressure swing absorption (PSA).

This method is the most extended for producing hydrogen from natural gas, contributing approximately three-quarters of all the hydrogen produced today (Amin et al. 2022). Countries like the USA are frequently practicing this technique for hydrogen production. This method can produce hydrogen with a cost between 2.33 and 4.00 USD per kgH2. It is important to note that in this process, the cost of hydrogen production depends mainly on the cost of natural gas, since depending on the size of the facility, this can contribute between 40 and 68% of the production cost (Yukesh Kannah et al. 2021).

18.1.4 Pyrolysis

This process decomposes the energy source (methane, biomass) by applying high temperatures. Hydrogen in the gaseous state and carbon in the solid state or bio-oil is obtained, and oxygen is not involved in this process. The quantity and quality of hydrogen obtained will depend on different factors of the process. If high-purity hydrogen is required, an additional purification process will be necessary, whereas if the hydrogen is required to be used as a gas for combustion, this additional process may not be necessary (Timmerberg et al. 2020; Yukesh Kannah et al. 2021).

Two types of pyrolysis (slow and fast) are frequently used for H_2 production. Among the two, fast pyrolysis with high temperature is the preferable method for H_2 production. This is because fast pyrolysis favors higher hydrogen production in less time at the same temperature (Al Arni 2018). Additionally, based on Parkinson et al. (2018), methane pyrolysis is the hydrogen technology with the lowest CO_2 abatement cost among all investigated alternatives. This same study shows that under certain conditions, it is possible to produce hydrogen by methane pyrolysis at a low cost and lower cost than by SMR with CO_2 capture and storage (CCS).

18.1.5 Gasification

This process is traditionally used to produce hydrogen from the thermal decomposition of coal or biomass. This method consists of applying temperature to the energy source (above 750 °C) under a reactive oxygen environment, which causes partial oxidation of the feedstock. Between coal gasification and biomass gasification, the latter has become more prominent, mainly due to the high level of CO_2 emissions per ton of hydrogen produced, which are approximately double those generated by SMR (Parkinson et al. 2018); however, many chemical fertilizer companies use coal gasification to produce ammonia which is another useful by-product of hydrogen gas (Amin et al. 2022).

Due to the high CO_2 emissions generated by coal gasification, this method requires using Carbon Capture Utilization and Storage (CCUS) technologies to produce low carbon hydrogen and relatively low emissions. If coal is used as feedstock, the cost of hydrogen production can vary between 0.36 USD and 1.83 USD depending on the plant configuration and H_2 yield level. It is observed that when using CCUS technologies, the cost is approximately 22% higher than if they were not used. If biomass is used as feedstock, the production cost can reach between 1.69 USD per kgH2 and 2.11 USD per kgH2 (Yukesh Kannah et al. 2021; Nikolaidis and Poullikkas 2017).

18.1.6 Water Electrolysis

This process consists of splitting water into hydrogen and oxygen through an electrochemical reaction that uses an electricity-powered electrolyzer. The fastest and cheapest way to use this method is by using grid electricity but depending on the source used to produce the electricity, which may not be the best from an environmental point of view (Yukesh Kannah et al. 2021). However, suppose renewable energy sources such as hydro, solar or wind are used. In that case, the hydrogen produced becomes the cleanest energy carrier, which can be used to mitigate the effects of the intermittency of solar and wind energy production (Nikolaidis and Poullikkas 2017).

For the application of this method, it is important to decide the type of electrolyzer to be used and its capacity, having that the most commonly used are alkaline (AEC), proton exchange membrane (PEM) and solid oxide electrolysis cells (SOEC). Among the three, AEC and PEM are relatively mature and have entered the commercial application stage, while SOEC is still in the laboratory research and development stage. The costs of hydrogen production using this technology vary between 3.85 USD and 7.49 USD depending on the energy source and the type of electrolyzer used (Fan et al. 2022; Nikolaidis and Poullikkas 2017).

Around 80% of the low-carbon hydrogen produced in 2050 uses electrolysis, reflecting the significant policy support for electrolytic hydrogen in various regions (IEA 2021b).

18.1.7 Terminal Facilities

The terminal facility is an intermediate facility for hydrogen delivery to the end user and is used mainly in the case of centralized hydrogen production. The terminal for hydrogen is similar to current gasoline terminals, where the gasoline is stored, loaded onto trailers, and delivered to stations. For liquid hydrogen, a terminal should include liquid hydrogen storage, high-pressure cryogenic pumps, and equipment for loading liquid hydrogen onto trucks. For gaseous hydrogen, a terminal comprises compressed gas storage, compressors, and equipment for loading the hydrogen onto tube trailers (Li et al. 2019). Decisions related to these facilities include determining the number of hydrogen terminals, allowing for optimization of the amount of hydrogen transported and stored (Kim and Kim 2017), the determination of the terminal's mode, location and capacity (Mula et al. 2010) and the inclusion of different facilities into a central production plant (Talebian et al. 2019).

A hydrogen terminal plays a vital role in the hydrogen delivery pathway; however, several studies about hydrogen supply chain design (HSCD) do not consider hydrogen distribution. In these models that do not consider transmission and distribution, storage facilities are used as terminals without considering the other characteristics of a terminal, so it is suggested that terminals be explicitly included in HSCD models (Li et al. 2019).

18.1.8 Storage Facilities

In hydrogen storage, there is evidence of the use of mainly two technologies, compressed hydrogen gas storage (CH_2S) and liquid hydrogen storage (LH_2S), there are also solid-state hydrogen storage methods, but the latter is still under development and could be more widely used in the future (Tarhan and Ali Çil 2021). By 2010, more than 80% of hydrogen refueling stations used compressed gas as a storage method (Zheng et al. 2012). It is also known that hydrogen stored as a liquid has a higher density than hydrogen stored as compressed gas; at the same time, in its liquid form, it stores more energy per unit volume (Zhang et al. 2016), although it needs to be stored at −253 °C, while in gas form it can be kept at room temperature, this due to the low boiling point in its liquid form, having a continuous risk of evaporation (Tarhan and Ali Çil 2021).

For this type of facility, aspects such as uncertainty in power generation, especially from renewable sources, have been considered in the literature (Reuß et al. 2017). Also, the design and economic feasibility of using hydrogen subsystems in a hybrid energy storage system (Mohseni and Brent 2020) and, lastly, decisions on the location and size of the facilities and the amount of energy generated and converted (Samsatli and Samsatli 2015), in addition to the consideration of time-lapse inventory holding to meet local hydrogen requirements (Han et al. 2012).

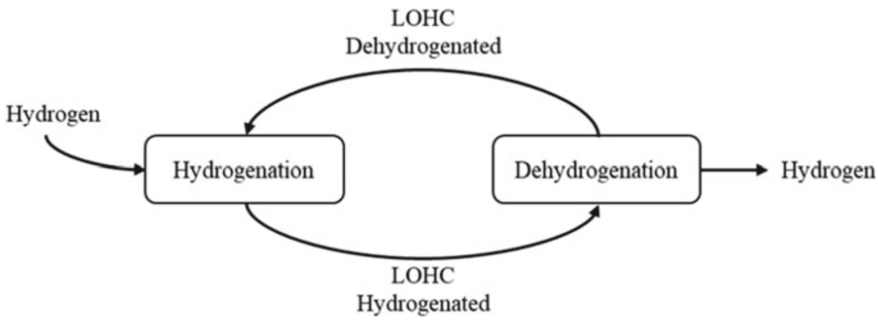

Fig. 18.2 Graphical representation of the LOHC concept

A new technology that is becoming relevant in the storage of hydrogen in its liquid form is Liquid Organic Hydrogen Carriers (LOHC), which are chemical compounds that can be loaded with hydrogen at the production site (hydrogenation) and unloaded at the demand site (dehydrogenation). Some of the main advantages of using LOHCs are as follows (Niermann et al. 2019; Tarhan and Ali Çil 2021; Kwak et al. 2021):

- Storage cost is reduced since no high pressures, low process temperatures or specialized materials are required to withstand these conditions.
- LOHCs exhibit similar properties to crude oil-based liquids (e.g., diesel, gasoline).
- LOHCs can be easily handled, transported and stored; therefore, a gradual implementation using existing crude oil-based infrastructure would be possible.

Some studies show that the use of LOHCs proves to be more efficient than other methods for hydrogen supply chains with low to medium-scale demands (Reuß et al. 2017) and for distances to the customer differing between 150 km (Hurskainen and Ihonen 2020) and 365 km (Bano et al. 2018). However, these LOHCs are more likely for storage and especially for energy transport, but not in direct application in mobility because of certain conditions necessary for dehydrogenation (Niermann et al. 2019). Figure 18.2 shows a graphical representation of the LOHC concept.

18.1.9 Transportation Methods

Hydrogen transportation has been mainly considered as a liquid or compressed gas. Liquefied hydrogen can be transported in tankers via railways, roads (trucks), or ships, whereas gaseous hydrogen may be conveyed via high-pressure pipelines, tube trailers, or railway tube cars. Tanker trucks are the transportation mode most represented in literature (Li et al. 2019). In this sense, the most important decision in this echelon is to choose the appropriate mode of transport for the system under evaluation; this decision is mainly affected by the demand profile and the distance from the production site to delivery points (Lahnaoui et al. 2018), other decisions include whether to establish a link between different grids and what the flow rate of the product should be (Almansoori and Shah 2009).

Each transport method has its capacity, but it is known that methods using liquid hydrogen move approximately five times more hydrogen per trip compared to methods using hydrogen in compressed gas form, which is why the latter is often used in supply chains with low demand or smaller site capacities (Liu and Ma 2020).

Recently, it has been considered the transport of hydrogen using LOHC, which, for each run, can transport at least half the hydrogen than if cryogenic liquid hydrogen is used, but at a much lower cost, due to the physical characteristics of LOHC, allow it to make use of infrastructure used for petroleum products, in addition to being stable at room temperature and atmospheric pressure, requiring neither refrigeration nor pressurization. However, it also has some disadvantages, the first being that once the LOHC is dehydrogenated, it must be transported back to the hydrogenation site, increasing fuel consumption; another disadvantage is the degradation of the LOHC used (Roos 2021).

18.1.10 Fueling Stations

One of the main focuses of hydrogen economics research is its use to decarbonize the automobile industry by replacing combustion engines with fuel cells. This is why the consideration of fueling stations becomes relevant in the HSCND framework. Since hydrogen in its liquid and compressed gas forms are the most widely used in the literature, fueling stations for these forms of hydrogen are the most commonly considered (Liu and Ma 2020). According to the comparison made by Pan et al. (2021), it can be said that liquid hydrogen fueling stations have several advantages over compressed hydrogen fueling stations; some of these are the requirement of lower investment per ton of capacity, lower space requirements, lower operating costs, higher safety, among others.

Another important feature to note is that fueling stations can be of two types: stations where hydrogen produced at other locations is received and stations where hydrogen is produced on-site (Sinigaglia et al. 2017). Figure 18.3 shows graphically those mentioned above and the technologies and types of hydrogen used in each case.

The fueling decision includes the determination of the number of fueling stations required to be installed (Almansoori and Shah 2012) and, in addition, the location, size, and type (Liu and Ma 2020). Based on Li et al. (2019) review, less than a third of the studies reviewed considered decision variables related to refueling station problems. Only four determined the number of refueling stations, three considered the number and station type, and two included the three properties of a refueling station, i.e., number, type, and size. The IEA study argued that identifying the optimal size of a station is a critical step.

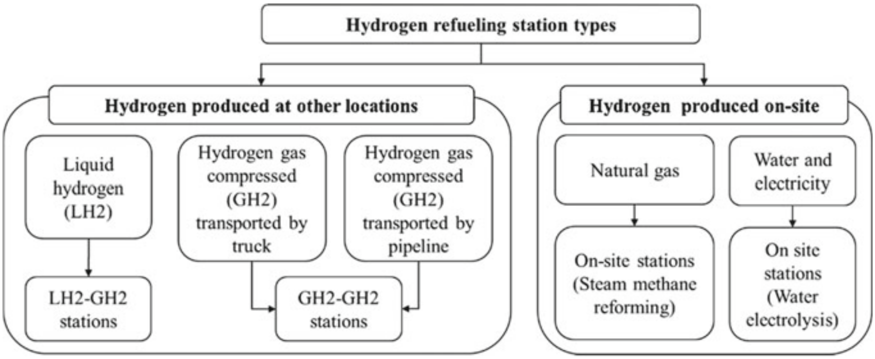

Fig. 18.3 Fueling station types. *Source* Adapted from Li et al. (2019)

18.2 Characterization of the Global HSC

According to Hydrogen Council (2021), worldwide, a favorable outlook for the so-called hydrogen economy is observed, with a greater presence at present in Europe, Asia, and the USA, as evidenced by the number of refueling stations currently in operation (328), with 139 in Europe, 119 in Asia, 68 in North America, 1 in South America, and 1 in Australia (H2stations 2022).

It can also be seen that these same places have the highest number of announced future projects related to HSC (228 projects), with Europe having the highest participation (55% of all announced projects). Of all these projects, only 38 have reached the execution stage (Hydrogen Council 2021).

These projects will help to increase hydrogen production capacity, with hydrogen production from renewable sources and low emissions as a major contributor in the future.

At the Latin American level, it is important to mention the five announced projects presented and to emphasize the Chilean production project, with a capacity of more than 1 GW. In addition, other countries such as Paraguay and Colombia have announced their respective hydrogen roadmaps, aiming to include this carrier in the decarbonization of their economy (Minenergía 2021; MOPC and VMME 2021). In this sense, given the interests of the authors, the following section delves into aspects related to hydrogen and its HSC in Colombia.

18.3 Characterization of the HSC in Colombia and Its Future Potential

In Colombia, hydrogen is concentrated in refining, fertilizers and the chemical industry. These same sectors are the most likely to use low-emission hydrogen due to the compatibility of their current infrastructure, thus minimizing the investment required. However, studies are planned in other subsectors to understand and design long-term decarbonization and carbon neutrality strategies (Minenergía 2021).

Based on the hydrogen roadmap (Minenergía 2021) in Colombia, hydrogen is expected to significantly contribute to public transport systems, heavy goods transport and light-duty vehicles such as cabs. However, the lack of infrastructure for hydrogen production, storage, transport and refueling is a barrier to deploying zero-emission mobility with hydrogen. On the other hand, the lack of hydrogen-powered vehicles discourages investment in refueling stations because of their difficult profitability.

Thanks to the significant coal reserves (more than 80 years) in the different mining zones (UPME 2022), Colombia has the potential to produce hydrogen from this resource, raising the possibility of installing gasification plants in areas close to the most important deposits of this mineral (Castiblanco and Cárdenas 2020).

Additionally, Colombia has a favorable potential for solar photovoltaic energy compared to other regions of the world. It is estimated that the country has average radiation of 4.5 kWh/m2/d, which exceeds the world average of 3.9 kWh/m2. In addition, most of the national territory has a resource of solar brightness (hours of sunshine), about 4.8 and 12 h of sunshine on an average annual daily (Valderrama Mendoza et al. 2018). According to SIEL (2021), of the initiatives filed for electricity generation through non-conventional renewable sources, approximately 75% of the current electricity generation projects are related to photovoltaic solar energy. The UPME and the Ministry of Mines and Energy estimate that by 2030 close to 10% of Colombia's energy consumption will come from photovoltaic or solar projects (Castiblanco and Cárdenas 2020).

In terms of onshore wind potential, when comparing Colombia with the rest of the world, in general, the country does not have the best winds to implement these technologies; however, La Guajira, a large part of the Caribbean region and some areas of Risaralda, Tolima, Valle del Cauca and Boyacá have the potential for their implementation (RAP-E 2020).

Although La Guajira is the region with the best renewable resource and, consequently, the most competitive levelized cost of hydrogen (LCOH), the analysis and development of the potential of other regions will allow supplying the national market and exports in the long term, in addition to reducing transportation costs by producing hydrogen in areas closer to its consumption. In this context, it is planned to promote studies to quantify the renewable potential in other regions, also considering new technologies, such as off-shore wind power, to determine the total green hydrogen production potential (Minenergía 2021).

Colombia is also one of the countries with the best water resources in Latin America and has 56 GW of potential hydroelectric projects without dams. Due to this, the roadmap proposes to analyze the feasibility of diverting part of the hydroelectric energy to produce renewable hydrogen, thus taking advantage of the country's water potential. This will be done by considering the country's electricity needs and possible future hydroelectric power plant projects (Minenergía 2021).

Despite not having large reserves of natural gas, the country has an extensive network of gas pipelines dedicated to its distribution (CREG 2016); this type of infrastructure can be important when planning a future HSC in the country since some research mentions that hydrogen can be mixed with natural gas for its final use, although with some limitations (Özçelep et al. 2021; Sun et al. 2021; Blokland et al. 2021).

18.4 Problem Types and Modeling Techniques

Within the context of HSCND, models can be divided into either single-objective or multiple-objective models; however, most papers consider multi-objective models because HSCND involves multiple factors to be optimized (Liu and Ma 2020). The main types of models evidenced in the literature are:

- ***Pathway models***: in these types of models, the aim has been to evaluate long-term approaches within the HSCND, taking into account the selection of hydrogen supply channels, technical factors and other aspects such as cost, feasibility, reliability, environmental impact, safety and social impact (Liu and Ma 2020; Qadrdan et al. 2008).
- ***Optimization models with uncertainty***: Most of the HSCND models are based on fixed values for the parameters used; under this approach, the aim is to include the uncertainty of some parameters in the modeling. In the literature, we can observe works in which the uncertainty in demand is represented (Ochoa et al. 2020), the availability of technologies and resources (Agnolucci et al. 2013) and the prices of both hydrogen and electricity to produce it (Botterud et al. 2008).
- ***Transportation models***: These models seek to minimize transportation costs while meeting customer needs. They are a means of choosing the best way to distribute products from multiple factories or warehouses to multiple destinations. With this approach, Sakurai and Ueno (2006) evaluated transportation costs of off-peak nuclear power for hydrogen production based on water electrolysis in Japan. They found that the transportation cost of the off-peak power could be 1.42 ¥/kWh (1 US$ was equivalent to 115 ¥ in 2005); Gim et al. (2012) used a transportation model to attempt to build a cost-effective central hydrogen supply system. Their results indicate that the use of pipelines can minimize transportation costs, and, in addition, they estimate that the hydrogen pipeline network in 2040 would be similar to the network of natural gas in 2005; Bin and Kim (2019) compared two types of transport modes including replenishment cycles to find the optimal configuration for HSC under different demand scenarios in Jeju Island, South Korea.
- ***Life cycle models***: These models are one of the key concepts of systems engineering. A life cycle for a system generally consists of a series of stages regulated by a set of management decisions that confirm that the system is mature enough to leave one stage and enter another (SEBoK 2022). This is why life cycle models can evaluate renewable energy optimization models. Some authors use the method to evaluate the environmental impact of the future infrastructure of an HSC (Sabio et al. 2012), while others use it within the framework of HSCND optimization.

The latter uses the life cycle costing (LCC) methodology and the life cycle assessment (LCA) approach to optimize the levelized cost of hydrogen (LCOH) and global warming potential (GWP) intensity (Li and Feng 2022). Other authors use this method to evaluate the impact of the incorporation of green hydrogen in the methanol production process from coal (Zhao et al. 2022).

- ***Forecasting models***: these types of models are used to evaluate the long-term impacts of the movement of some parameters associated with the HSC; this is the case of Krzyzanowski and Kypreos (2008), who use a MARKAL model to predict the long-term impact of increased transport demand and conclude that the greatest resource consumption and pollutant emissions come from road vehicles. At the same time, Hu et al. (2022) use a dynamic hydrogen production yield forecasting model based on the Discrete Grey Method (DGM) and the Gradient Boosting Regression Tree (GBRT) to help the biomass-based hydrogen production process to adjust the material input in time.
- ***Dynamic programming models***: The storage and transportation system is dynamic, and it is usually necessary to capture its state characteristics every hour or in even shorter intervals for accurate modeling (Samsatli and Samsatli 2015). This type of model has been used to analyze the technical and economic feasibility of large-scale hydrogen underground storage (Le Duigou et al. 2017) and also to analyze the impacts of the application of seasonal storage in HSC due to its high storage capacity and minimal annual charging (Reuß et al. 2017). On the other hand, Zhou et al. (2018) propose a unified dynamic programming model and its solution method to solve the interpolation leakage problem, the dimension disaster problem, the standardization problem and the Markov problem for fuel cell electric vehicles.

18.5 Solution Methods

18.5.1 Exact Methods

Most hydrogen supply chain system designs in small-size problems are formulated as LP or MILP (Liu and Ma 2020). These can usually be solved efficiently by commercial software such as CPLEX (Almansoori and Shah 2009, 2012; Zhang et al. 2018), GUROBI (Güler et al. 2021) and GAMS (Almansoori and Shah 2012; Han et al. 2012; Zhang et al. 2018). For some MIP problems, the decomposition method has proven applicable for obtaining satisfactory solutions with relatively small gaps (Samsatli and Samsatli 2015).

18.5.2 Heuristic and Metaheuristic Methods

Heuristic methods such as genetic algorithms are also prevalent in large-scale and complex planning problems. Some examples of the application of this type of method include Mohseni and Brent (2020), who assess the economic feasibility of sustainable hydrogen production, storage, and utilization technologies integrated into on- and off-grid micro-grids to achieve this. They use a performance comparison of different meta-heuristics. Also, Cantú et al. (2021), who present a Novel Matheuristic based on bi-level optimization for the multi-Objective design of hydrogen supply chains, found that the proposed hybrid approach produces an accurate approximation of the Pareto-optimal fronts more efficiently than the exact solution approach.

18.5.3 Simulations

Based on mathematical theory, simulation modeling compares alternatives and solutions to problems, as well as tests and hypotheses, and simulation has the potential as an effective tool for studying complex systems like HSC (Liu and Ma 2020). An exploratory study by Elvira et al. (2022) shows that environmental and economic performance are related to key processes in Supply Chain Management in which packaging and distribution are critical for achieving logistics and transportation sustainability goals. Contreras et al. simulated energy consumption in the road transport sector in Madrid from 2010 to 2050 according to vehicle fuel types and conducted a market penetration analysis of hydrogen usage (Contreras et al. 2009). Hong et al. (2021) present a holistic study of various options for transporting (not producing) hydrogen from both techno-economic and environmental perspectives; they found that the preferred transport mode depends on export location and end-use.

18.6 Future Research in HSC Design

The following are some of the challenges that some authors point out within the HSCND. More studies on logistics in emerging regions can impact environmental, social, and economic performance differently. It would also be valuable to research packaging and distribution in upstream and downstream processes (Elvira et al. 2022). Also, future work should introduce the social perspective into HSCND and consider unexpected incidents, such as geopolitical events that may change a region’s energy import, affecting hydrogen prices (Li and Feng 2022). Finally, for the hydrogen network, the models should be extended to include pipeline storage and hydrogen injection into the natural gas grid and apply techniques to heat systems to evaluate the role of thermal storage in low-carbon heat networks (Samsatli and Samsatli 2015).

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Chapter 19
Towards Cybersecure Maritime Supply Chains in Latin America and the Caribbean

Claudio Alvarez, Camila Hinojosa, Sebastián Gonzalez, and Luis Rojas

Abstract Maritime supply chains are a highly dynamic environment in which multiple public and private stakeholders interact by exchanging digital data through various systems and technologies in cyberspace. The maritime industry is immersed in a digital transformation process that is evolving to be highly dependent on cyber-physical systems composed of information and operational technologies. In the Latin American and Caribbean region, there are multiple challenges in cybersecurity of the maritime industry in general, as countries present different maturity levels in their cybersecurity capabilities, particularly in protecting critical infrastructures, including ports, terminals and intermodal connections. This chapter describes cyberthreats, vulnerabilities, risks and recent cyberattacks in maritime supply chain operations in Latin America and the Caribbean (LAC), discusses ongoing supranational initiatives towards the development of cybersecurity capabilities for maritime supply chains in the region, analyzes advances of LAC countries in developing cybersecurity capabilities and adopting best practices for maritime supply chain operations, discusses the region's prospects for development of cybersecurity policy and strategy, and provides recommendations for decision-makers and technical staff in charge of maritime supply chain operations.

Keywords Cybersecurity · LAC region · Maritime supply chains · Capabilities · Best practices

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19.1 Introduction

The maritime industry represents around 80% of the volume of international trade in goods worldwide (Sirimanne 2021). Maritime supply chains are nowadays immersed in a digital transformation process by which they are evolving to be highly dependent on Cyber-Physical Systems (CPSs) composed of Information Technology (IT) as well as Operational Technology (OT) (Kuhn et al. 2021). Digital transformation from steam-based Industry 1.0 to smart network-based Industry 4.0 has incorporated CPSs in vessels and seaports while the connectivity of cyberspace and the physical environment has grown considerately (Cheung et al. 2021; Gunes et al. 2021). Nevertheless, technological changes are being implemented by private actors more slowly than by other industries (Karamperidis et al. 2021). In addition, ports vary in structure and ownership, making standardization and regulation challenges. As a result, the maritime sector risks being the target of criminal activity not only in its physical domain and cyberspace (McGillivary 2018). These attacks generate alarming economic damage and harm corporate reputation and confidence in private companies and state-run maritime operations (Park et al. 2019).

The Latin America and Caribbean (LAC) region includes many ports and major maritime infrastructures, such as the Panama Canal, at various technological development and maturity levels from a cybersecurity standpoint (Inter-American Committee against Terrorism 2021). The region is rich in raw materials, energetic sources, mineral resources, and pharmacological potential. It depends on maritime supply chains for commercial exchange among its states and other locations worldwide. Combining these factors with the lack of a robust apparatus of regional and national cyber defense, maritime supply chains in the LAC region experience a dire vulnerability regarding cybercrime (Díaz 2021). According to the European Union Agency for Cybersecurity (ENISA), states' greatest challenge in digital transformation in ports and maritime supply chains is the effective design and implementation of policies, regulations and new maritime assets for establishing effective and secure IT and OT (Drougkas et al. 2019). States in the Western Hemisphere, and particularly in the LAC region, are beginning to take notice of the need to foster their cybersecurity capability and are rapidly developing national cybersecurity plans and increasing ways to share information and respond rapidly to cybersecurity incidents concerning critical infrastructures and supply chains, including those serving the maritime industry (Inter-American Committee against Terrorism 2021).

This chapter describes cyberthreats, vulnerabilities, risks and recent cyberattacks in maritime supply chain operations in Latin America and the Caribbean (LAC) (Sect. 19.2), discusses ongoing supranational initiatives toward the development of cybersecurity capabilities for maritime supply chains in the region (Sect. 19.3), analyzes advances of LAC countries in developing cybersecurity capabilities and adopting best practices for maritime supply chain operations (Sect. 19.4), discusses prospects for development of cybersecurity policy and strategy in the LAC region, and provides recommendations for decision-makers and technical staff in charge of maritime supply chain operations (Sect. 19.5).

19.2 Cyberthreats, Vulnerabilities and Risks in Maritime Supply Chain Operations

Maritime organizations are critical in facilitating domestic and international supply chain activities by connecting sea and inland transport services (Inter-American Committee against Terrorism 2021). Port and maritime operations are complex and involve a wide variety of fixed, technological, and communication assets that interconnect to support an array of vessel operations, cargo handling, supply chain, and governmental services (Kuhn et al. 2021). As maritime organizations in the Western Hemisphere become increasingly digitalized to improve efficiency and competitiveness and, in some cases, comply with national requirements, their operations become increasingly vulnerable to the action of cyber criminals.

Maritime supply chains have become information hubs, integrating data from terminal operators, carriers, logistics companies, and government authorities. As data and information hubs, maritime organizations create, process, transmit/receive, and store a wide variety of data and information in cyberspace (Park et al. 2019). This data is commercially valuable to many, including competitors seeking an advantage or criminals seeking to steal or compromise data to facilitate fraudulent transactions or smuggling (Inter-American Committee against Terrorism 2021). In addition to ensuring the digital security of their operations, maritime organizations must protect the confidentiality, integrity, and availability of the data on their networks and in their systems (Gunes et al. 2021).

Erstad et al. (2021) define a cyberdanger as a "threat that exploits cyberspace," while a cyberrisk is a risk generated by a cyber threat. As a result, a maritime cyber threat may result in cyberattacks against maritime supply chain operations. According to Mednikarov et al. (2020), there are two basic types of cyberattacks in the maritime field: targeted and untargeted. Targeted attacks act on specific corporate IT/OT technologies with a specific purpose of penetration, such as access to confidential information and obstruction of the normal functioning of port and vessel systems. Untargeted attacks are carried out using an Internet environment and software tools to detect unprotected communication components.

According to the Inter-American Committee against Terrorism (CICTE),[1] an entity part of the Organization of American States (OAS), maritime organizations face threats from a wide variety of cyber threat actors (Inter-American Committee against Terrorism 2021):

- **Organized crime**: By gaining access to cargo logistics and management systems, organized criminals can access, monitor, and edit critical cargo information, reducing the effectiveness of customs scrutiny on a shipment. It is possible that organized crime operations can steal entire containers.
- **Insider threats**: Current and former workers, contractors, partners, and vendors present potential cybersecurity hazards to maritime companies. These dangers are the result of both purposeful and unintended behaviors. Insider threats may come

[1] https://www.oas.org/en/sms/cicte/default.asp.

from a dissatisfied former or current employee with access to credentials that are not disabled. Employees may also be persuaded or blackmailed by outside entities for disclosing essential information, downloading malicious software, or even altering IT/OT protocols, processes, and configurations. Insiders can easily download threatening software by accident via phishing emails or corrupted websites.

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- **Terrorists**: While the maritime industry has taken tremendous precautions to protect itself from physical terrorist attacks on facilities and other crucial infrastructure, it remains exposed to the increasing threat of cyber-terrorism. For example, terrorists in the Western Hemisphere may see key ports or other essential marine infrastructure, such as the Panama Canal, as potential targets.

Attackers will generally follow a five-step methodology to perpetrate a cyberattack on the maritime supply chain (Drougkas et al. 2019). Firstly, cyberattackers conduct (1) **intelligence and planning procedures**, including investigation and surveillance of target actors, systems, networks, and other cyberphysical infrastructure. Next, attackers will (2) attempt to **exploit cybersecurity vulnerabilities and gain access** to systems or data. (3) After a security breach has been exploited, the third step is maintaining **access**. How access is maintained will depend on the characteristics of exploited vulnerabilities and the method by which it has been possible for hackers to penetrate. Later, (4) **pivot infiltration** may be accomplished by cyber attackers by interrupting ITs and OTs in vessels or systems operating in ports and terminals. The final step is (5) **trace removal**, where attackers will attempt to eliminate evidence of their intrusion, aiming to reduce the odds of success of future forensic investigations. For this, attackers can alter, edit, corrupt, or delete audit logs and records that include any information about their activity.

The maritime industry can be affected by several intentional cyber-physical attacks. According to Drougkas et al. (2019), common examples are the following:

- **Eavesdropping, interception and hijacking**: By these attacks, the attacker can intercept communication within a vessel or between a port and various stakeholders to compromise the targeted systems.
- **Nefarious activity and abuse**: This category includes attacks such as Denial of Service (DoS), malware, ransomware, brute force password or encryption cracking, identity theft, social engineering, phishing, abuse and theft of data, and data manipulation.
- **Fraud, sabotage and vandalism**: These deliberate and purposeful acts break international and civil Law and seek to weaken or damage the vessel or port systems, infrastructure, and assets. Such attacks can impact both IT and OT systems. For example, IT systems for port operation could generate errors that delay or paralyze traffic. At the same time, OTs could support automatic controls of gantry cranes with the risk of generating accidents in cargo movement on the ship or within the port Gamboa et al. (2020).
- **Fraud, sabotage and vandalism**: Attackers expect to profit from their illegal activity and obtain valuable information or money through violence or intimidation. This will involve dishonest or unlawful actions directed toward the maritime infrastructure and cyberspace.

Vulnerabilities presented by cyber-physical ship and port operations and attacks that succeed at exploiting them can lead to risks, including disruption of operations of the maritime supply, with repercussions at the port level. Such risks include (Inter-American Committee against Terrorism 2021; Drougkas et al. 2019):

- **Theft of high-value cargo or illegal trafficking**: Cyber-physical port systems are instrumental in attackers' goal to steal cargo and containers. To succeed, aggressors must have extensive knowledge of port systems, networks, processes, and infrastructure.
- **Propagation of ransomware**: These attacks typically lead to a total shutdown of port operations. Ransomware attacks can be either targeted or non-targeted. Hackers create ransomware and spread it over port networks, encrypting various systems and devices, resulting in information leaks and potential unrecoverable destruction of data stored in affected systems.
- **Compromise of Critical Systems Onboard Vessels or In-Ports**: Risks of data theft or hijacking affect systems, such as Port Community Systems (PCSs) and Terminal Operating Systems (TOSs) in ports or vessel navigation systems. After gaining illegal access to such systems, attackers may corrupt information about port services to disrupt operations or modify system processes. Results are commonly reputational, operational and financial damage to port stakeholders and operations.
- **Hijacking of OT systems**: Risks of hijacking ship and port OT systems exist, leading to significant accidents in port areas. These attacks can be perpetrated by hackers, as cyberattacks that stem from the side of IT devices and infrastructures

can pivot to the realm of cyber-physical (OT) systems, thus damaging machinery, end-devices, security monitoring capabilities and safety checks in port and ship operations.

A statistical study by the Chatham House Cyber-Security Group (Kapalidis 2019) of the Royal Institute of International Affairs identified the essential systems, both on-ship and in-port, that require cyberattack protection due to their respective vulnerabilities. Findings showed that the number of vulnerable components in-port is higher than on-ship. On the other hand, in a recent review of cybersecurity of components, systems and services within the maritime industry, Ben Farah et al. (2022) conclude that every port or vessel is at risk of cyberattacks if key information systems are not adequately protected. The challenge is increasingly complex by proliferation in the deployment of new technologies with associated increases in the scope of vulnerabilities within most operation-critical infrastructures.

A report issued in 2021 by the Economic Commission for Latin America (ECLAC) (Díaz 2021) informs that several cyberattacks have taken place in the Latin America and Caribbean (LAC) region. Some high-profile cases include DoS and ransomware attacks against companies such as Maersk (which resulted in a $300 million loss) and CMA GGM, port terminals (e.g., Terminal Pacífico Sur, Valparaiso, Chile), port authorities (e.g., Dominican Port Authority, Dominican Republic), and attacks to critical infrastructures in the energy sector affecting port operations (e.g., CPFL Energia, Brazil). Alarmingly, many of these attacks have affected several locations at once. Cyberrisk is multiplied by the connectivity of information, communication and cyber-physical systems. An isolated cyber incident in a port may have cascading effects across the global port system (Kuhn et al. 2021). That can partly explain this as with other industries, such as the banking sector, professional hackers like those in APT groups target ports in the LAC region due to the cybersecurity capability in the region is immature in comparison to other more developed regions, such as North America and Europe (Pimenta and McKenzie 2021). To be effective, cybersecurity must evolve rapidly and constantly alongside technology implemented in ports, and private actors must jointly develop cybersecurity capabilities.

19.3 Development of Cyber Security Capabilities for Maritime Supply Chains in the LAC Region

19.3.1 Oxford's Cybersecurity Capacity Maturity Model for Nations

As global trade and maritime supply chains have become more dependent on cyberspace for their operations, developing national cybersecurity capabilities has become a critical concern for sovereign states. Moreover, coordination between states and among public and private actors within them is essential for progress to be achieved.

To assess the cybersecurity capabilities of states globally, the University of Oxford's Global Cybersecurity Capacity Center (GCSCC 2021) has developed the Cybersecurity Capacity Maturity Model for Nations (CMM). The CMM model is a framework by which the maturity of the cybersecurity capabilities of a country can be measured and analyzed considering five dimensions:

1. **Cybersecurity Policy and Strategy**: This Dimension encompasses a country's capacity to develop and enact cybersecurity strategy and enhance its cybersecurity resilience by improving its incident response capabilities, cyberdefence and critical infrastructure protection capacities. This Dimension considers effective strategy and policy in delivering national cybersecurity capability while maintaining the benefits of cyberspace vital for Government, international business and society in general.
2. **Cybersecurity Culture and Society**: Includes cybersecurity culture, such as understanding of cyberrisks in society, trust in the Internet, e-government and e-commerce services, and users' understanding of personal information protection online. Moreover, this Dimension considers the existence of channels for users to report cybercrime. In addition, the Dimension includes the role of media and social media in shaping cybersecurity values, attitudes and behavior.
3. **Building Cybersecurity Knowledge and Capabilities**: Comprises the availability, quality and uptake of programs for various stakeholders, including the Government, private sector and the population, and relates to cybersecurity awareness-raising programs, formal cybersecurity educational programs, and professional training programs.
4. **Legal and Regulatory Frameworks**: Considers the Government's capacity to design and enact national legislation that directly and indirectly relates to cybersecurity, with a particular emphasis on regulatory requirements for cybersecurity, cybercrime-related legislation and related legislation. The capacity to enforce such laws is examined through law enforcement, prosecution, regulatory bodies and court capacities. Moreover, this Dimension observes issues such as formal and informal cooperation frameworks to combat cybercrime.
5. **Standards and Technologies**: This Dimension addresses the effective and widespread use of cybersecurity technology to protect individuals, organizations and national infrastructure. The Dimension specifically examines implementing cybersecurity standards and good practices, deploying processes and controls, and developing technologies and products to reduce cybersecurity risks.

Each of the above dimensions is evaluated by constituent factors that relate to the descriptions given above. In turn, each factor has multiple components called aspects. The number of aspects related to a factor depends on the themes that emerge in the content, that is, on factor complexity. The most granular measurement of CMM is indicators. Each indicator describes the steps, actions, or building blocks indicative of a specific stage of maturity in cybersecurity aspects, factors and dimensions.

Per each factor or aspect, the CMM defines stages of maturity. The most basic stage is (1) **Start-Up**, in which there is no cybersecurity maturity. This is followed by the (2) **Formative** stage, in which some characteristics of the factor or aspect have begun to be formulated in a disorganized, poorly defined, or ad-hoc way. The next level of maturity is described by the (3) **Established** stage, where there are indicators in place, demonstrable evidence, and a functional and operational definition of each aspect. Then, the (4) **Strategic** stage determines that there are decisions about the importance of prioritizing certain aspects over others. Such decisions are based on national or organizational interests. Finally, the (5) **Dynamic** stage establishes that there are well-defined mechanisms to alter the national strategy depending on the prevailing circumstances, such as the threat environment, global conflict, or changes in some area of concern. The Dynamic stage also determines that there is global leadership in cybersecurity and that there is the ability to make quick decisions, with reallocation of resources, and in response to changes in the environment.

19.3.2 Strategic, Political and Institutional Cybersecurity Capabilities for LAC's Maritime Industry

Oxford's CMM model has become influential in public policy decisions by countries in the LAC region. In an effort that began in the past decade, involving the Organization of American States (OAS), the Inter-American Development Bank (IDB), and the University of Oxford's Global Cybersecurity Capacity Centre (GCSCC), the Observatory of Cybersecurity in Latin America and the Caribbean (OCLAC)[2] has published measurements of cybersecurity capabilities in countries of the LAC region in 2016 and 2020. The 2020 measurement is based on 32 countries and is extensively documented in a public report (GCSCC 2020), hereafter referred to as the 'OCLAC 2020 report'. The report concludes that states in the LAC region are not sufficiently prepared to face cyberattacks, including the capacity to face attacks on critical infrastructures and those involved in the maritime industry and its associated supply chains.

Regarding developing national cybersecurity policies and strategies and legal and regulatory frameworks, the first global precedent has been the Budapest Convention. This agreement is the first international treaty created to protect society against computer and Internet crimes through legislating, improving investigation techniques and increasing international cooperation. Currently, 67 countries have signed the Budapest Convention (Council of Europe 2022). In the LAC region, only Argentina, Chile, Colombia, Costa Rica, Panama, Paraguay, Peru and the Dominican Republic had ratified the agreement until late 2020 (GCSCC 2020).

International maritime security and safety efforts began in the early twentieth century. The first version of the International Convention for the Safety of Life at Sea (SOLAS) treaty was signed in 1914. Later conventions modernized regulations and kept up with technical developments in the shipping industry. SOLAS conventions and amendments have set minimum standards in merchant ships' construction, equipment and operation. The International Ship and Port Facility Security (ISPS)

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[2] https://www.cybersecurityobservatory.org.

Code was an amendment to SOLAS Convention in 2002 (International Maritime Organization (IMO) n.d.-b) and defines measures to enhance maritime security both on board ships and in ports (Kuhn et al. 2021). The ISPS Code was initially based on a traditional approach to container security. However, it has recently included port cybersecurity regarding access control and authentication requirements. The ISPS Code has three security levels, ranging from low to high, in correspondence to the nature and scope of the security threat or incident. The ISPS Code requires ports and port authorities to develop and implement Port Facility Security Plans (PFSP) for multiple operational levels, outlining measures to address threats and countermeasures. PFSP is based on the Port Facility Security Assessment (PFSA) and a risk analysis scheme that governments and authorized security organizations implement to identify major assets, possible threats and countermeasures (Inter-American Committee against Terrorism 2021).

The IMO, the leading international maritime organization and the organization behind SOLAS, has significantly addressed cybersecurity considerations in the maritime area since 2017. All states in the LAC region are members of the International Maritime Organization (IMO) (n.d.-a). The IMO has developed a strategic plan for the period between 2018 and 2023 (International Maritime Organization (IMO) 2017b), where the need for an integration between the existing and new technologies in the regulatory process is recognized, aiming at balancing benefits between security, safety, and environmental protection as well as the influence on personnel both onboard and ashore (Mraković and Vojinović 2019). As part of its strategic plan, IMO passed resolution MSC.428(98) (International Maritime Organization (IMO) 2017c), which came into force on January 1st, 2021, and IMO Guidance MSC-FAL.1/Circ.3 (International Maritime Organization (IMO) 2017a). These regulations address the implementation of maritime risk management in vessels' safety management systems (SMSs) under the ISM (International Safety Management) Code objectives and requirements. MSC.428(98) and MSC-FAL.1/Circ.3 complement the IMO ISPS (International Ship and Port Facility Security) code for vessels dealing with cyber and physical port security (Progoulakis et al. 2021).

Recently, CICTE has focused on identifying threats to the Western Hemisphere's critical infrastructure. In particular, the CICTE Cybersecurity Program assists OAS member states in developing national or regional cybersecurity strategies. By the end of 2020, thirteen countries throughout the Western Hemisphere had developed national cybersecurity strategies, and seven are currently under development with support from the OAS/CICTE Inter-American Committee against Terrorism (2021). Concerning maritime security strategies, the CICTE Maritime and Port Security Program (Organization of American States (OAS) 2022) focuses on strengthening the protection and security capacities of OAS member states, from the national level to the port level, according to their needs, vulnerabilities, and regulatory and legislative frameworks. The CICTE Maritime and Port Security Program organizes regional and national activities in consultation with other organizations, authorities and key actors involved in developing maritime and port security capabilities. OAS and CICTE initiatives lay the groundwork for addressing maritime cybersecurity risks and vulnerabilities in the region (Inter-American Committee against Terrorism 2021).

19.3.3 Operational Cybersecurity Capabilities for Maritime Supply Chains in the LAC Region

After a country addresses relevant dimensions of policy, strategy and legislation for cybersecurity, it can focus on incorporating the regulatory framework that contributes to mitigating the impact of cybercrime in institutions, the economy, and citizens' lives (Díaz 2021). Local regulations on cybersecurity define how incidents are managed by bodies providing tactical and operational capacity. The objective of operating bodies in the public and private sectors is to minimize the time between the detection of incidents and the start of their management, which includes resistance, response, resilience and recovery capabilities.

'Cybersecurity Incident Response Team' (CSIRT) or 'Computer Emergency Response Team' (CERT) are names often used synonymously for key operational bodies that the public sector and private actors can count on to anticipate, resist and recover from cyberattacks (Killcrece 2004; OAS Cyber Security Program 2016). A CSIRT is a team or entity within an agency that provides services and support to a particular target community (OAS Cyber Security Program 2016). CSIRTs are multidisciplinary specialists who adopt formal procedures and policies to respond quickly and effectively to cybersecurity incidents and mitigate cyberattack risks. CSIRT services have evolved from basic functions related to incident management and response to sophisticated R&D activity for threat intelligence and security monitoring of ecosystems comprised of public and private actors (i.e., contractors and technology providers) through Security Operation Center (SOC) facilities.

While a CSIRT will respond to cybersecurity incidents, a SOC can be deployed as a unit specialized in cyberattacks preventions and data breaches (Ruefle et al. 2014). Thus, CSIRTs and SOCs play synergistic roles in the cyber defense capabilities of a country, industry, and public or private organizations. To prevent cyber threats and attacks and to protect infrastructure, applications, data and users from cybercrime, SOC staff and technical resources are dedicated to continuously monitoring and analyzing network traffic and behavior. To accomplish this, a SOC will comprise threat intelligence technologies and procedures. In particular, Indicators of Compromise (IOCs) are artifacts observed in networks or hosts, which are evidence suggesting that cybersecurity has been compromised and are commonly distributed as cryptographic digests of malware and ransomware infection. A SOC will ingest IOC streams into its Security Information and Management System (SIEM). Through a SIEM and other technologies and activities, a SOC can collect insight on malware and ransomware attacks, threats that deploy several attack vectors (i.e., blended threats), denial of service and botnet activity, data on phishing attacks, reputational information about Internet domains, networks and hosts, among other valuable information for cyberthreat and cyberattack prevention. A SOC will triage alerts and take action or escalate incidents to CSIRTs to coordinate response and resolution (Krasznay and Hámornik 2019).

According to the report mentioned above (GCSCC 2020), in 2020, only 7 of the 32 countries in the LAC region had a critical infrastructure protection plan, and only

20 countries had established a cybersecurity incident response team in the form of a CSIRT or a CERT. In addition, 22 countries were considered to have a very low capacity to investigate cybercrime. Concerning the maritime industry, no country in the region has incorporated an operational body fully dedicated to maritime supply chain operations, such as a maritime CSIRT or a SOC. The lack of development both in the development of public policy and in the implementation of operating bodies is attributed by the OAS to financing deficits and regional human capital formation. ISC2 has estimated a deficit of human capital in cybersecurity to be around 515,000 workers in the Latin America region alone in 2022 (ISC2 2022). Consistently, the OAS estimated a human capital deficit in cybersecurity in the LAC region of close to 600,000 workers in 2020 (GCSCC 2020).

19.3.4 State of Cybersecurity Capabilities in Maritime Supply Chain Operations in the LAC Region

Based on data collected by IDB, OAS and Oxford's GCSCC, presented in the OCLAC 2020 report (GCSCC 2020), and public documentation from different countries in the LAC region, in this section, we discuss the current state of cybersecurity capabilities in the region and relate these findings to the operation of maritime supply chains. Our analysis is split into three dimensions of Oxford's CMM Model for Nations that hold a close relationship to the development of cybersecurity capabilities in the maritime industry, namely, Cybersecurity Policy and Strategy (i.e., Dimension 1 of CMM), Legal and Regulatory Frameworks (Dimension 2), and Standards, Organizations, and Technologies (Dimension 5). To compare the realities of different countries in the region, we sourced data from indicators of the report mentioned above, which have associated scores in a 1 (i.e., Start-Up maturity level) to 5 scales (i.e., Dynamic maturity level) and computed average scores per domain factor. In the following subsections, we discuss results per each of the dimensions.

19.4 Cybersecurity Policy and Strategy

In 2016 only five countries in the LAC region had approved a national cybersecurity strategy (BID 2016). The figure increased to twelve in 2020 (Global Cyber Security Capacity Centre 2020), including the following countries: Colombia (originally in 2011, then revised in 2016), Panama (2013), Trinity and Tobago (2013), Jamaica (2015), Paraguay (2017), Chile (2017), Costa Rica (2017), Mexico (2017), Guatemala (2018), Dominican Republic (2018), Argentina (2019), and Brazil (2020) (Global Cyber Security Capacity Centre 2020). Despite notable progress in five years, according to the OCLAC 2020 report, only 7 of 32 countries analyzed had a critical infrastructure protection plan. Furthermore, the OCLAC 2020 report informs that approximately one-third of the countries in the region lack the appropriate definition of a legal framework for dealing with cybercrime.

Figure 19.1 presents average scores (i.e., stages according to Oxford's CMM for Nations model (GCSCC 2021)) of factors in the 'Cybersecurity Policy and Strategy' Dimension of the OCLAC 2020 report (GCSCC 2020). As noted previously, Colombia, the first country to establish a national cybersecurity strategy in 2011, has taken the lead on this Dimension. Moreover, in 2016 Colombia improved its national strategy by strengthening risk management aspects and elements for fostering cooperation among stakeholders (Cámara de Comercio de Bogotá 2016). However, concerning the cybersecurity of critical maritime infrastructures, according to Gamboa et al. (2020), regulation of the ISPS Code has been adopted by Colombian authorities partially and even informally in consideration of specific commitments acquired by the SOLAS Conventions. Thus the Colombian Government has taken a discretionary approach to defining policy to protect critical maritime infrastructure.

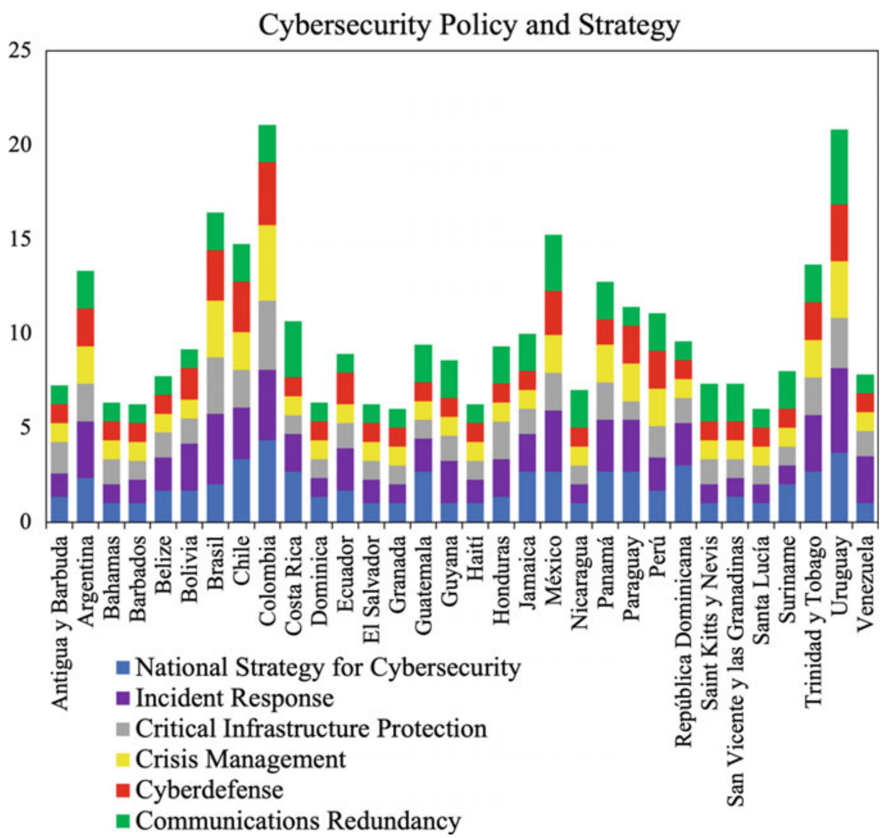

Fig. 19.1 Average maturity levels of states in the cybersecurity policy and strategy dimension of CMM for Nations, based on Global Cyber Security Capacity Centre (2020)

Despite the above, Colombia has the region's most mature crisis management capability. This is explained partly due to the operation of its CSIRT, which coordinates with security forces and government entities. Concerning the protection of critical infrastructure, Colombia also takes the lead over other Latin American countries due to CSIRT operations, the publication of guidelines for the management of digital security risks in public entities (Dirección de Gobierno Digital 2018), clear definition and protection measures applied to critical infrastructures, that is, especially focused on telecommunications network providers and services, as described in Resolution CRC 5050 of 2016 (Comisión de Regulación de Comunicaciones, República de Colombia 2016). In 2017, the Joint Cybernetic Command of the General Command of the Colombian Military Forces adopted a National Protection and Defense Plan for Colombia's Critical Cybernetic Infrastructure. The plan aims to improve resilience capabilities through five strategic lines, tending to strengthen cybersecurity of critical maritime infrastructure throughout the country: Identity, Protect, Detect, Respond and Recover. The plan includes implementing guidelines, certification and awareness programs, strengthening response capacities and recovery from threats (Comando Conjunto Cibernético 2017).

Chile also stands out due to a National Cybersecurity Policy launched in 2017, which emphasizes five aspects, including cyber defense of IT infrastructure, civilian rights in cyberspace, a culture of cybersecurity in society, establishing cooperation with foreign actors and entities, and promoting a cybersecurity industry aligned with strategic goals (Comité Interministerial sobre Ciberseguridad 2017).

Uruguay was observed with a high capability in cybersecurity policy and strategy despite not having a specific national strategy, but rather an organized framework that complies with international regulations applied in a national context, specifically in the cyberdefense of critical infrastructure and public organizations. Uruguay has reached top-level maturity in the categories of organization and coordination for incident response. Like most higher-performing countries in this area, Uruguay has a national CSIRT called CERTuy, and a SOC. The latter has operated uninterruptedly since 2016. Uruguay's CSIRT is under the tuition of the Government Agency of Electronic Government and Information and Knowledge Society (AGESIC) (Poder Ejecutivo UY 2009). This response team also receives technical support and advice and uses the CSIRT Americas Network,[3] which is part of OAS and CICTE. Similarly, other well-rated countries with a national CSIRT are Argentina, Brazil, Colombia and Mexico.

Concerning cyber defense capabilities, the highest-ranked countries, according to the GCSCC (2020), are Colombia and Uruguay, both of which have a defined functional organization. However, Colombia outperforms Uruguay in terms of strategy by adopting models and regulations that afford flexibility and adaptability, considering future cyber threats at a national level. On the other hand, Uruguay shows a better evaluation of Redundancy in Communications indicators, as it appears to

[3] https://csirtamericas.org/.

have developed better communication protocols and unique delegations of responsibilities, allowing better cohesion between the entities involved in cyber defense according to their qualification in the CMM for Nations Model (GCSCC 2021).

Santos Port Authority of Brazil has recently improved its cybersecurity policy and strategy. They have launched initiatives for data loss prevention, improved access control, and preventive penetration testing Santos Port Authority (2021a).

19.5 Legal and Regulatory Frameworks

Figure 19.2 presents the average scores of LAC countries in factors regarding the 'Legal and Regulatory Frameworks' Dimension of Oxford's CMM for Nations model. Table 19.1 presents detailed scores in this Dimension for the most advanced countries in the region. The Dominican Republic and Brazil are the countries with the greatest progress.

Dominican Republic obtains high compliance rates in Legislative Frameworks for ICT Security, Substantive Legislation Against Cybercrime, and Procedural Legislation Against Cybercrime. Its national strategy is part of the Digital Republic Program created through Decree 258-16 (Medina 2019), where the legal framework and institutional strengthening is one of the fundamental pillars. Also, Dominican Republic has specific legislation covering cybercrime (i.e., Law No. 53-07 (Poder Ejecutivo RD 2007) on Crimes and High-Tech Crimes). Similarly, Law 172-13 (Poder Ejecutivo RD 2013) aims at "comprehensive protection of personal data stored in files, public records, data banks or other technical means of data processing intended to provide reports, whether public or private." In addition, the 2010 Constitution grants

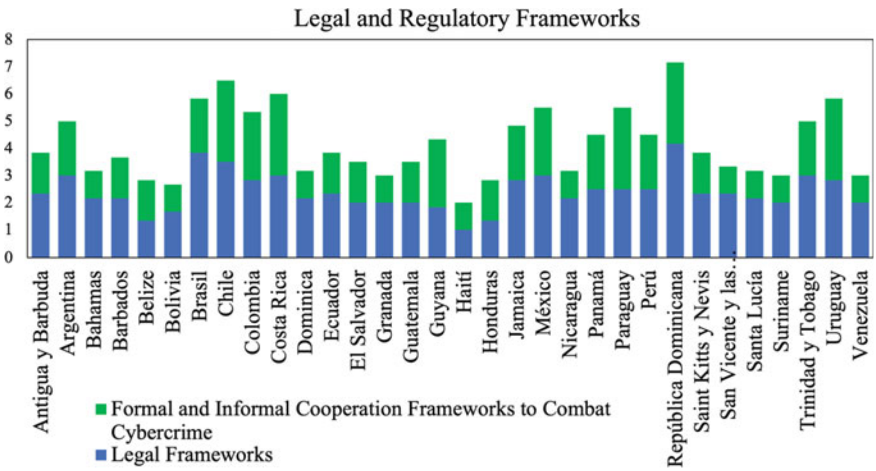

Fig. 19.2 Average maturity levels of states in the legal and regulatory frameworks dimension of CMM for Nations, based on Global Cyber Security Capacity Centre (2020)

Table 19.1 Maturity of leading LAC states in legal and regulatory frameworks for cybersecurity, based on Global Cyber Security Capacity Centre (2020), expressed as stages 1–5 of CMM

Country	Legal frameworks						Formal and informal cooperation frameworks to combat cybercrime	
	Legislative frameworks for ICT security	Data protection	Consumer protection	Intellectual property	Substantive cybercrime law	Penal legislation against cybercrime	Formal cooperation	Informal Cooperation
Brazil	4	4	4	3	4	4	2	2
Chile	3	3	4	5	3	3	3	3
Dominican Republic	5	3	3	4	5	5	3	3
Uruguay	4	5	2	2	2	2	2	4

every citizen the right to access any personal data held by government entities and the right to request authorities to update, amend or eliminate any data that could illegitimately affect the rights of a person (Poder Ejecutivo RD 2013). Recently, Dominican Republic has signed an agreement with the United States Trade and Development Agency (USTDA) and the North American company HudsonAnalytix, to implement a technical assistance project evaluating cyberrisk and cybersecurity levels in its ports (Santos Port Authority 2021b).

Brazil obtains scores similar to the Dominican Republic but also stands out in Data Protection Legislation and Consumer Protection Legislation. Brazil relies on various provisions established in the Federal Constitution (Poder Legislativo BR 2019), the Brazilian Penal Code (Poder Legislativo BR 1940), the Consumer Protection Code (Garcia 2020) and the Brazilian Civil Rights Framework to protect privacy on the Internet. Recently, the main port of Brazil and Latin America (i.e., Santos Port Authority) reported plans to update its cybersecurity processes to comply with European General Personal Data Protection Regulation (GDPR) (Santos Port Authority 2021a).

Uruguay and Chile's legal frameworks should also be highlighted. On the one hand, Uruguay has legislation protecting personal data and privacy, as described in Law No. 18331, which applies to databases in the public and private sectors (Registro Nacional de Leyes y Decretos 2008). On the other hand, Chile has recently updated its legislation against cybercrime. Law No. 21459, passed on June 2022, supersedes former Law No. 19223 (Poder Legislativo CL 1993, 2022) from 1993. This updated legislation was developed to be aligned closer to the Budapest Convention. It introduces new penal figures and sanctions for various cybercrimes, including the attack on IT system integrity, illegal access, illegal interception, data integrity, data forgery, cybernetic fraud and device abuse. The Law modifies the Penal Code (i.e., article 218 bis), demanding that digital service providers maintain data for criminal investigations for up to 180 days. This requirement applies to port operators; thus, law compliance requires that data backups of transactional systems are kept secure and operational. In addition to the updated legislation on cybercrime, Chile counts with legislation for personal data protection, namely, Law No. 19628 (Poder Legislativo CL 2022). Also, a constitutional reform was passed in 2018, recognizing citizens' right to their honor, private life, and personal data protection (Poder Legislativo CL 2018).

Colombia has developed maturity in legal and regulatory frameworks similar to that of Uruguay, which is slightly lower than Brazil (see Fig. 19.2). Challenges in Colombia regarding legislation aimed at protecting critical maritime infrastructure have been noted by Gamboa et al. (2020). Their study highlights that domestic Law in Colombia lacks regulation allowing the effective state control of maritime operations in the country's jurisdictional waters to prevent cybernetic risks in port facilities. Additional legislation and regulations are needed to prevent, manage and control cybersecurity incidents from foreign ships using the right of innocent passage in Colombia's territorial sea.

19.6 Standards, Organizations and Technologies

Figure 19.3 presents the average scores of LAC countries in factors regarding the 'Standards, Organizations and Technologies' Dimension of Oxford's CMM for Nations model (GCSCC 2021), as per the OCLAC 2020 report (GCSCC 2020). Table 19.2 presents detailed scores (i.e., maturity stages on a 1–5 scale) in this Dimension for the most advanced countries in the region. As can be seen, Uruguay has the most advanced capability maturity in factors including Standards Compliance, Software Quality, Technical Security Controls, Responsible Disclosure and, especially, Cryptographic Controls. For example, Uruguay has a cybersecurity framework organized regarding international standards applicable to national regulations to improve the cybersecurity of critical infrastructure and public organizations (AGESIC 2018). Likewise, it is possible to highlight Brazil, which obtains high levels of compliance with ICT Security Standards. The financial and ICT sectors are more advanced in cybersecurity since they are frequent targets, so they invest highly in cybersecurity.

Santos Port Authority in Brazil has strengthened security against cyberattacks in its corporate network by adopting technologies and standards widely at the organizational level (Santos Port Authority 2021a). For example, user access rights and policies have been revised with measures such as generalized blocking of USB ports of staff's PCs, periodic forced updating of user passwords, forensic procedures for dealing with computers and devices suspected of infection, and updates to centralized security.

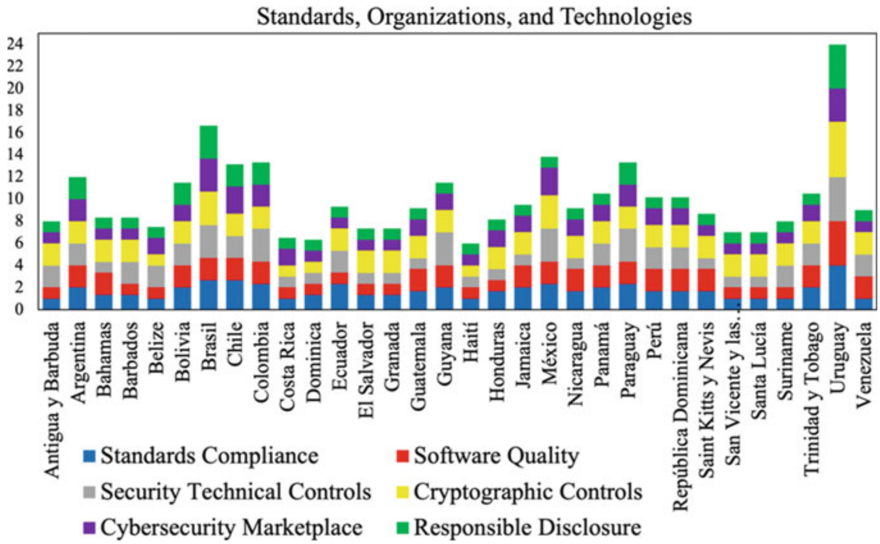

Fig. 19.3 Average capability maturity levels of states in the standards, organizations and technologies dimension of CMM for Nations, based on Global Cyber Security Capacity Centre (2020)

Table 19.2 The maturity of leading LAC states in standards, organizations and technologies for cybersecurity, based on the Global Cyber Security Capacity Centre (2020), is expressed as stages 1–5 of CMM

Country	Standards compliance[a]			Software quality	Technical security controls	Cryptographic controls	Cybersecurity market[b]		Responsible disclosure
Brazil	4	2	2	2	3	3	3	3	3
Uruguay	4	4	4	4	4	5	3	3	4

[a] Includes ICT Security, Procurement, and Software Development Standards
[b] Includes Cybersecurity Technologies and Cybercrime Insurance

The Dominican Republic also presents advances in cybersecurity standards and risk prevention. For example, the private ports of Caucedo and AES-Andrés have been certified by the Specialized Port Security Corps and the Dominican Port Authority (PortalPortuario 2021). These certifications validate measures adopted by ports for strengthening the protection and surveillance of technology-assisted operations in their facilities.

19.7 Discussion

19.7.1 Prospects for Cyberstrategy and Policy in the LAC Region

Cybersecurity of maritime supply chains in the LAC region is an issue of growing concern that, until less than a decade ago, was not prioritized by many states in the region (Díaz 2021). In recent years, there has been increasing awareness in LAC countries about the need to formulate national cybersecurity policies and strategies, especially regarding the cyber defense of critical infrastructures, particularly those related to maritime supply chains. Through resolutions and specialized programs, supranational bodies such as the OAS and the IMO have facilitated the advancement of states of the LAC region towards developing basic maritime cybersecurity and cyberdefense capabilities (GCSCC 2020; Inter-American Committee against Terrorism 2021). Prospects in this regard are optimistic, particularly due to OAS-led programs and efforts to develop cybersecurity capabilities in its member states. Most importantly, by adopting the CMM for Nations model (GCSCC 2021), the OAS has led the implementation of a consistent methodology to diagnose the maturity of cybersecurity capabilities at the state level and has launched the Maritime Port and Security Program through CICTE (Organization of American States (OAS) 2022).

The CMM for Nations model covers the complexities of a State's cybersecurity challenges, from political and strategic concerns to tactical and operational aspects. However, other complementary cybersecurity assessments can be leveraged by government authorities, leadership in the maritime sector, and other relevant stakeholders for awareness, discussion and decision-making. For example, the International Telecommunication Union (ITU), United Nations' specialized agency for ICTs, developed the Global Cybersecurity Index (GCI) to measure the development of cybersecurity in nations worldwide, including five dimensions: Legal, Technical, Organizational, Capacity Development, and Cooperation (International Telecommunication Union (ITU) 2020). The indicator was launched in 2015, and the latest version of the GCI report was published in 2021 based on data from 194 countries collected in the previous year. The GCI is based on an aggregate score by which countries are ranked and compared. GCI and CMM cybersecurity assessment models measure similar aspects regarding developing cybersecurity in nations (Global Forum on Cyber Expertise 2021). However, CMM does not aim at ranking countries but is centered on the evidence required to determine that a certain stage of maturity has been reached for a factor/aspect in a state. To reach a level of maturity in any CMM dimension, all indicators for a factor/aspect of that Dimension must have been met. The CMM, therefore, directly indicates what areas require further development in a state to reach the next stage of maturity and the data required to evidence such a level of capability maturity.

To encourage the development of cybersecurity capabilities in countries of the LAC region, states' commitment to supranational institutions, such as the OAS, through human and financial resources contributions is essential. This is because the region's public and private actors involved in maritime logistics face shared cybersecurity risks, threats and challenges. In addition, ensuring the continuity of regional initiatives such as those promoted by OAS, including their escalation to all states in the LAC region, will require that states determine institutional formulas to monitor and develop their cybersecurity capabilities locally and autonomously while cooperating with regional institutions. Venues for systematization and dissemination of knowledge at the regional level are needed to inform different roles according to multiple specialty areas in cybersecurity (Petersen et al. 2020). In addition, as in other areas that concern the operation of states, political decisions on cybersecurity must be informed by technical knowledge and expertise. Therefore, states must adopt knowledge management systems and organizational structures aimed at creating, sharing and systematizing cybersecurity knowledge at the local level while continuing to cooperate with supranational institutions, involving technical actors from both the academic and professional worlds.

OAS recommends that its member states underpin cybersecurity strategies and implementation plans with existing frameworks and standards for critical infrastructure cybersecurity and develop key governance and policy documents to guide their organizations and staff in securely using systems and data. However, once countries define their cybersecurity and critical infrastructure protection strategies and policies, it is necessary to strengthen cooperation between public and private actors for prevention, resilience and recovery from cybersecurity incidents in the maritime industry. This is because security vulnerabilities in maritime logistic operations can originate from public and private entities cooperating in this environment (Cheung et al. 2021). Digital transformation and the Fourth Industrial Revolution bring widespread use of IoT technologies, artificial intelligence, machine learning, and large-scale machine-to-machine communication to maritime supply chain operations. This context presses that public–private cooperation can take place effectively because there is a growing integration of services and systems in maritime logistics. Therefore, the development of cooperation models is required at policy, governance and procurement levels among public and private entities and at a technical level.

19.7.2 Recommendation of Good Practices for Cyber Secure Operations in LAC Maritime Supply Chains

Several good practices for strengthening the cybersecurity of maritime operations have been recommended by the Maritime and Port Security Program of CICTE to OAS member states (Inter-American Committee against Terrorism 2021). For successful implementation of measures, parties involved in maritime supply chains must allocate in budget plans CapEx and OpEx that are needed for comprehensive cybersecurity. Then, good operational practices come from a wide range of aspects. A key practice for countries developing cybersecurity capabilities in the LAC region is implementing training programs that effectively consider the needs of maritime industry personnel, ensuring that training is continuous and recurring.

In designing and implementing IT/OT infrastructure for maritime operations, access control to cyber-physical systems is of utmost importance, including segmentation (independence) of communication networks for IT and OT operations and personnel and machinery access management to physical and digital assets. In addition, Port Facility Security Plans (PFSPs) must be thoroughly updated to include cybersecurity aspects. Other good practices essential for strengthening preventive and defensive cybersecurity capabilities are email security, including email usage policies, anti-spam measures, and staff training on the safe use of email. Awareness and protection against social engineering, commonly spread by email as the primary attack vector, although potentially based on multi-vector attacks, is also essential.

CICTE recommends good practices for network security, vulnerability management and situational awareness. These include periodic offensive exercises against infrastructure, services and applications to promptly detect (and remedy) threats and vulnerabilities (Inter-American Committee against Terrorism 2021). Application security is also emphasized as part of vulnerability management. Namely, mobile applications and IoT platforms require security audits and controls, as these are being widely adopted in vessel and port operations. Patch management for software must be functional in every IT operation. This permits keeping software updated in an automated manner, including operating systems and applications, throughout the logistics chain. Patching must effectively minimize system downtime while being performed as often as necessary to minimize the opportunity for attackers to exploit known vulnerabilities in IT/OT systems and applications. In addition, commonplace ransomware attacks must be countered by measures to prevent data loss and facilitate data recovery. In this regard, data backups must be performed in highly secure remote locations. Redundancies in data backups are needed for critical systems. Also, data recovery drills must be conducted with staff responsible for enacting data recovery plans.

Maritime organizations must collect and analyze information about cyberthreats and share information about threats and successful attacks. To prevent incidents occurring at the intersection of public and private actors, to implement early-alert systems that operate within existing national CSIRTs and SOCs in several states of the LAC region. An important reference in this matter is the Spanish Internet

Early Warning System (SAT-INET) (Centro Criptológico Nacional N/D), which depends on the National Cryptologic Center (CCN-CERT) that is affiliated with Spain's National Intelligence Center (CNI). Through an operation similar to that of a SOC in Managed Security Service Provider (MSSP) mode, SAT-INET deploys probes in affiliated entities—public and private—to detect the presence of indicators of compromise and anomalous activity. The benefits of such an approach are particularly (1) that affiliated organizations have access to a large set of incident detection rules integrated by CERT or CSIRT experts. This allows the detection and control of a greater number of threats than an individual entity may cope with by its means. (2) Early detection of incidents already replicated in other assigned domains, also known as inter-domain detection of threats. (3) Detection based on the correlation of events and the provision of information by all entities monitored by the early-alert system and the respective CSIRT's cyber-intelligence operation. (4) Delivery of valuable statistical reporting to administrative staff in charge of IT/OT, and (5) the CSIRT can offer affiliated parties stronger resilience capabilities to contain and eliminate cyberattacks.

As maritime organizations are key players in the complex global logistics environment and rely on digital and increasingly integrated systems that exchange data with a large number of external parties, maritime organizations are required to take measures to ensure that customers, vendors and other third parties take appropriate measures to minimize their vulnerability to cyberattacks. Thus, maritime organizations should take notice of sensitive data they exchange with third parties, such as confidential contracts and cargo details and personnel information that is exchanged between parties. Maritime organizations need to implement third-party management programs to deal with this effectively. Namely, there must be roles and responsibilities for personnel working with third parties and a tiered ranking of security controls for managing each third party according to the required security level. Procurement contracts must be updated to include clauses enforcing cybersecurity standards and measures, including governance, physical security, personnel security, information security, risk management and cyberincident response requirements. Maritime organizations should also consider clauses, such as indemnification and a requirement for cyberliability coverage, that reduce the maritime organization's financial risk if a vendor's practices result in a cyberincident. Lastly, there must also exist training requirements for third parties. All third parties, including vendors and contractors, should complete cybertraining before exercising roles that require dealing with any digital asset or IT/OT system connected to a network.

19.8 Conclusions

In this chapter, we have described the state of development of cybersecurity capabilities in the countries of the LAC region and the challenges maritime supply chains currently face in operating securely. Recently, several cybersecurity attacks have compromised the operation of multiple ports, resulting in operational and economic damage. Although there are a few countries in the LAC region that are more advanced in their cybersecurity capabilities, several states in the region are at an early stage of capability development without yet defining their national cybersecurity policies and strategies, including security policies for the defense of critical infrastructures concerning port and maritime operations. Faced with this, the Organization of American States has led several relevant efforts and advancements for the region's progress. Efforts made by the states of the LAC region and OAS need to crystallize and persist over time, as cyberspace is a domain that is not limited by physical borders, whereby states face shared risks and challenges. The nature of the cybersecurity vulnerabilities presented in this chapter shows that the protection of maritime supply chains requires specialized strategic, political and tactical-operational definitions and joint action of stakeholders in these areas through juridical-legal and organizational structures that facilitate coordinated and efficient action for effective cyber defense and resilience.

On the other hand, maritime supply chains are a highly dynamic environment due to the diversity of stakeholders that interact in them and the multiple interfaces, devices and technologies involved in digital data exchange. In the maritime industry, human operators interact with cyber-physical systems that integrate information and operational technologies. This has been identified as a source of cybersecurity risks by multiple authors and studies (Alcaide and Llave 2020; Ben Farah et al. 2022; Cheung et al. 2021; Park et al. 2019). In addition, the growing adoption of Industry 4.0 technologies in maritime supply chains results in machine-to-machine interactions that increase the possibility of new cyber vulnerabilities and increase the risks of cyberattacks. In this chapter, we have identified a series of practical recommendations on cybersecurity for stakeholders who make decisions in maritime supply chains and operate the technologies involved. Finally, it cannot be overemphasized that there is a significant shortage of human capital trained in cybersecurity in the LAC region. This calls for the involvement of higher education institutions and public and private entities in maritime supply chains to cooperate in providing comprehensive education and training to governing bodies and technical personnel.

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Chapter 20
Strategy in Supply Chain and Logistic Ecosystems in Megaregion Sonora-Arizona

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Abstract This chapter shows the effort made by higher education institutions, governments, and companies to jointly build the strategy to define the supply chain in two logistics ecosystems as a cooperation response in Megaregion Sonora-Arizona. The areas considered were: social, gastronomic, tourism, and business and logistics development, whose objective was to build—based on projects—ecosystems in each workshop, as well as the search for funds. The method shows the procedure in five stages: (1) sensitization, (2) business and logistics conceptualization workshop, (3) development project proposal, (4) present ecosystems, and (5) search for funding sources for implementation. The main results are the constitution of two ecosystems: (1) agro-food and tourism logistic ecosystems and; (2) Health and Tourism. The main conclusions established that the two logistics ecosystems, the agro-food and tourism sector and the second in the health and tourism sectors, have the flexibility and development potential in the short and medium-term to respond to post-pandemic related to their logistics and commercialization between two states.

Keywords Ecosystems · Supply chain and logistics · Cooperation

20.1 Introduction

The Coronavirus-19 disease outbreak appeared for the first time in Wuhan, China, in December 2019, announced by the World Health Organization (OMS 2019). Since its propagation, it has transformed the world regarding decisions to face up to the

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diverse events emerging during and after the same pandemic. In this sense, different forms of dealing with the disease have been reported deriving from the main one: to avoid diseases and to propagate the virus exponentially among the world populations. Sensitizing programs, such as “stay at home,” may raise awareness to minimize deaths caused by Covid-19 and prevent hospitals from collapsing, above all in the most vulnerable countries from the medical perspective and available hospital infrastructure. On the other hand, the pandemics have also affected the world’s diverse supply chains, notably reducing the number of tourists that travel worldwide and controlling exported food from other countries toward Mexico and the United States of America.

Since one of the main bets is in terms of logistics and economy on the part of the Sonora-Arizona Megaregion, the main characteristics of both states should be strengthened according to their geographical, economic, and logistics infrastructure dimensions they have. Sonora and Arizona form part of the Megaregion concept because of their geographical position and based on knowledge and exchange of goods. The Sonora-Arizona Megaregion provides enterprises with a competitive platform for their growth and shared resources. The focus on logistics infrastructure is associated with connecting the two states through modern transportation and knowledge exchange among higher education institutions to strengthen the supply chain between states and countries.

The State of Sonora is located in northwestern Mexico with a territorial extension of 179,355 km^2 and a population of 2.85 million inhabitants, bordering the southwestern State of Arizona in the United States of America. Their commercial relationships are meaningful; for example, only bidirectional traffic recorded approximately 1500 train runs, 800,000 cargo trucks, 25.6 million cars, and 50.2 million persons crossing the Sonora-Arizona border through the ports of entry in 2018 (El Economista 2019).

The State of Arizona, with a territorial extension of 295,254 km^2, has a population of 7.279 million. The most important economic activities in Arizona are industry, mining, agriculture, and those related to tourism activities. The sectors that hire more people are in the following order, services (given the importance of its tourism sector), commerce, industry, and construction. One of the most important economic activities performed along the commercial Arizona-Sonora-Sinaloa Corridor is the production and distribution of Sinaloa products towards the north. Exporters in the State of Sinaloa send more than 60,000 trucks loaded with products toward Arizona during the season, representing an environmental and logistical challenge for the Nogales-Mariposa port-of-entry (Lee et al. 2014). Commerce between Arizona and Mexico increased by 7.7% from 2017 to 2018 for a total of 16,600 million USD, with an estimated 27,600 million USD in goods-in-transit in both routes through the ports of entry. Thus, this relationship is necessary to strengthen the United States-Mexico-Canada Agreement and Mexico-United States-Canada Treaty (USMCA/TMEC) (El Economista 2019).

The Fourth Report of the Sonora State Government stated that the supply chains that reach the Sonora-Arizona borereder are mostly fruit and vegetables, followed by paper, plastic, wood, and wood products. More than 80,000 t were dealt with by the

Arizona-Sonora ports-of-entry to be used in the fruit and vegetable industry; 85% of the cargo vehicles crossed through Nogales III-Mariposa.

According to Pro Sonora (2020), the State of Sonora has supported infrastructure that hosts a wide network of highways and roads (36,210 km) that connect with the United States through highways I-10, I-15, and I-19; airports with cargo and commercial flight capacity besides daily international flights; industrial trains with 2,011.68 km of railways -Ferromex -as provider- moves 52% of industrial cargo; a deepwater port located in Guaymas and connected with the cargo train for import and export (grains, minerals, fertilizers, among others), and an important network of registered carriers (386) and customs agents (138). The main industries in the Megaregion are automobile, aerospace, mining, medical and electrical-electronic devices, information technologies, and renewable energies.

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In the context of the Sonora-Arizona Megaregion, a meeting between the Sur Sonora Connect and Performance Improvement Institute consortium took place in the headquarters sites in Chicago, Barcelona, and Buenos Aires in the last quarter of 2019 to start with the development of the annual meeting between the participants of the states of Arizona and Sonora (Soluk et al. 2021).

The Sonora-Arizona Megaregion event was determined to take place remotely with the name of Performance Facing Pandemics: Techniques to reorganize and create continuous improvement systems in Megaregions through the value chain. Deriving from this proposal, the mission was established to promote the internationalization of the Sonora-Arizona Megaregion with the question—What is required to strengthen the logistics and trade, tourism, food, and local community sectors? Thus, the four workshops were established: (1) Tourism, (2) Food; (3) Logistics and Trade; and (4) Social Performance.

This study shows the proposed methodology and results of the Logistics and Trade Workshop with the support of the National Laboratory in Transportation Systems and Logistics-ITSON Headquarters. ITSON is responsible for coordinating five workshops with different participants, mainly from Sonora and Arizona but with academic and entrepreneur keynote guest speakers of Baja California, Sinaloa, and Chihuahua, as part of the northwestern region where the Laboratory has a presence and the responsibility to generate solutions for the food and agriculture supply chain. For Arizona, the University of Arizona and Arizona State University, as well as the Technology Creative Corp enterprise in El Paso, Texas, are considering the contribution

Fig. 20.1 The connection between Sonora (Mexico) and Arizona (U.S.A.) is through the different main cities of both states. *Source* Pro-Sonora, Secretaría de Economía (2020)

from Mexico and Sonora State Governments to finance the laboratories through the National Council for Science and Technology (CONACYT,) and the Foundation of Food and Agriculture Research.

The proposal offers information with the results from the initial awareness-raising stage until the proposal of the two ecosystems is achieved -as a result of its anchoring- in response to the event vision. The logistics and Trade Workshop's objective was to promote participation in logistics and commerce topics facing Covid-19 pandemics and post-pandemic to generate integrator projects in high-value logistics ecosystems and seek financing through integrated projects.

20.2 Literature Review

The strategy makes decisions about what not to do as important as decisions about what to do. Deciding which target customer group, varieties, and needs the company should serve is critical to developing a strategy. So is deciding not to serve other customers or other needs and not to offer certain features or services. Consequently, the strategy requires constant discipline and clear communication. One of the most important functions of an explicit and well-communicated strategy is to guide employees in making decisions that stem from trade-offs in their activities and day-to-day decisions. Improving operational effectiveness is a necessary part of management, but it is not a strategy (Porter 2011).

There are two characteristic activities in the supply chain: primary and secondary; primary activities are characterized by the transformation of raw materials and outputs into products or services, as well as delivery and after-sales support, including logistics to deliver materials and their storage, as well as operations to achieve the finished product and order and distribution logistics, marketing and sales, and installation and after-sales service. On the other hand, secondary activities support primary activities. They include purchasing and supplies, developing technical knowledge, procedures and people skills, the hiring, promotion, evaluation, rewarding and development of personnel and the company's infrastructure (Porter 2011).

The Logistics and Trade Workshop that groups them- is associated with Kaufman (2000) ideal vision in the search for society to achieve self-sufficiency, well-being, and health as the three directing indicators to create logistics ecosystems, and also Porter (2011) about the different between strategy and operational improvement.

The Mega planning approach was introduced by Kaufman (2000). This proposal was centered on and emphasized the concept of needs -not as a verb but as a subject. As a verb, it takes the organizations to assume a solution before identifying the real problem that should be resolved. On the other hand, as an adjective, it allows first to identify the gaps between "what it is and what it should be." This distinct space is what is called need; then, only at this moment can the means to solve the problem be set out toward the expected results, from the Mega perspective, which should influence improving society.

In this sense, Kaufman (2007) proposed the Organizational Elements Model (O.E.M.) divided into five planning levels: (1) Mega approach was associated with markers that were related to the results and their consequences for external clients and society; (2) Macro approach referred to the results that the organizations produced internally for the benefit of society; (3) Micro approach was associated to the products or services made within the organization; (4) Processes referred to the ways, means, activities, procedures, and methods used internally in the organizations; and (5) Inputs were associated to human, physical, and financial resources used by the organization. This Mega planning approach was supported by Bernárdez (2006) and Kaufman (2000) in their works on organizational development and performance technologies, and similarly, by Bernárdez (2009) in their work-related with training linked to development based on instructions.

As Chihiro and Kayano (2005) argue, the concept of goals and means to understand the concept of needs better, arguing that goals were directed to results, impacts, and consequences of what was used, while the means were defined as the ways we use them (methods, processes, equipment, among others) to deliver the results.

The most recent contribution of the definition of ecosystems arose from a literature review at the time when the concept had appeared for the first time, approximately in 2005. In a conceptual review of the term ecosystems and concepts related to proposing a synthesized definition of ecosystems, Brethower and Smalley (1999) argued that "An ecosystem is the evolving set of actors, activities, and artifacts in the organizations] and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors" (Kaufman and Guerra-Lopez 2013).

On the other hand, Granstrand and Holgersson (2020) developed work related to science, technology, and innovation transformation, stating that their objective was to create a society centered on human beings. In this society, the products and services were provided to satisfy different potential needs and reduce the economic and social gaps, so all people lived comfortable and vigorous life. His vision was based on acknowledging current global trends where the rhythm of technological, economic, and social changes have accelerated the enterprises' and communities struggle to keep up to date.

The research developed by Fukuda (2020) proposed a model to demonstrate the possibility of achieving social transformation by applying the triple helix model under the leadership of a higher education institution and its research centers, the government in its three levels (Municipal, State, and Federal), and the private sector represented by companies Villanueva and Lagarda-Leyva (2009) that shared the Mega vision (Etzkowitz 1998; Guerra-López and Rodríguez 2005; Kaufman 2007). The three allies participated during the whole process. Their main commitment was to increase development opportunities for the inhabitants of the southern Sonora region through the creation of four innovation ecosystems and nine associated strategic initiatives, which the Organisation later documented for Economic Cooperation and Development (Kaufman 2007).

Starting from the previous empirical contributions, Puukka et al. (2013) developed research on logistics innovation in maritime ports and inductively showed specific cases of those that had performed logistic innovations centered on the role of inter-organizational relations for innovation in maritime ports. These ports provide a rich field -although unexplored- to understand the interactive nature, given the regional economic system's multiple and strong interdependencies among port operators and enterprises.

On the other hand, De Martino et al. (2013) were based on the empirical review of the technological policies in Japan and the United States of America. During the last three decades, this document intended to demonstrate -with an approach from an ecosystem perspective- the hypothetical vision described previously and provide a new vision directed to services. Among the main conclusions, they established that the new reality in the transition of an information society to a ubiquitous society required a change from function-oriented to solution-oriented disciplines making the U.S.A. and Japan aware of the importance of the co-evolutionary dynamics involved in an ecosystem.

Research developed by Chihiro and Kayano (2005) describes important implications for business innovation and digital business model innovation research, offering valuable insights into the role of dynamic capabilities and environmental dynamism in the digital economy. In general terms, a logistics innovation ecosystem seeks to generate synergies among the organizations that conform to them. Through their supply chains, the organizations develop technological solutions for a region or country's endogenous and exogenous development in complex interactions. These interactions have evolved in time to deliver impact results on social, economic, and environmental commitment, supported by technologies and human resources with the capacity to succeed.

Complex systems are based on system thinking, which different authors from Senge et al. (2006) have studied to use mathematical models to explain ecosystem dynamics through the relationship cause-effect (Forrester 1990; Sterman 2000; Lagarda-Leyva 2019a, b). Likewise, these cause-effect relationships take place using simulators to observe possible future scenarios that allow assessing decision-making beforehand and based on quantitative models (Schwartz 1996; Lagarda-Leyva and Ruiz 2019; Aracil and Gordillo 1997).

On the other hand, changes in consumer, digital technology, and environmental awareness behavior have altered the conventional food supply chains, which implies challenges for logistics and the last mile of food product delivery. In this sense, Melkonyan et al. (2020) showed a study to develop tools and explore the sustainability potential of logistics and last-mile distribution strategies. For this purpose, three elements of the distribution network are used (1) centralized with only one click to pick up; (2) decentralized with a home delivery option; and (3) based on a collective logistics concept.

In this same context, Govindan (2018) stated in his research that globalization increase and the growing world population greatly impact the sustainability of the supply chains, especially within the food industry. Food is produced, processed, transported, and consumed due to the complexity that persists in coordinating members of the food supply chain, where food waste has increased in recent years. To achieve sustainable production and consumption, the parties interested in the food industry should coordinate themselves and have viewpoints toward optimizing resources responsibly.

According to Craven et al. (2020), sectors will be affected differently. Some sectors, like aviation, tourism, and hospitality, will see lost demand (once customers choose not to eat at a restaurant, those meals stay uneaten). This demand is largely irrecoverable. Finally, Kuckertz et al. (2020), cited by Soluk et al. (2021), informed Covid-19 that such a severe discontinuity in an economic activity constitutes an exogenous shock and has a potentially devastating effect on companies.

20.3 Method

20.3.1 Object Under Study

The object under study focuses mainly on dry and cold products with variability in their rotation in the supply chain of a food marketing company in southern Sonora.

20.3.2 Materials

For the development of the proposal, remote materials were used through surveys with the participants, previous exhibits, and interviews with project leaders to request their participation:

- Mentimeter (Stockholm, Sweden) for Surveys for interactive presentations;
- Interviews were carried out with crucial project leaders located in enterprises, universities, and government;
- Zoom Platform (San Jose, CA, U.S.A.) was used for the remote workshops with participants and coordinators of the discussion tables;
- Excel software (Microsoft, Redmond, WA, U.S.A.) was used to process data.

20.3.3 Procedure

The method considered the following procedures to achieve the objectives of the discussion tables, which were set up in the following stages:

1. **Raising awareness among the participants on the event approach**. During this stage, the event participants received information through conferences related to the pandemics and the opportunities for developing the four topics (1) Food, (2) Tourism, (3) Logistics and Commerce and (4) Social Performance. Each conference was taught by the coordinator of each discussion table related to one of the topics. In this sense, the Logistics and Commerce table focused on four Level 1 projects.
2. **Exhibiting level 1 projects of the logistics and commerce table**. Projects set up by each one of the responsible persons allowed the participants to understand the importance of their collaboration for Level 2 projects.
3. **Presenting the proposals facing Covid-19 pandemics and post-pandemics**. The Logistics and Commerce workgroup called the participants to show project proposals, and as a result, four projects were generated. The discussion tables considered that Level 3 projects should be selected from other discussion tables (food, tourism, and social performance) as supplementary projects where the logistics and commerce topics could participate.
4. **Selecting the project to integrate the final proposal**. This part developed a weighting exercise. Once the projects were presented (19 out of 20), all the event participants graded the projects, selecting 10 considered with greater priority, of which 100% of them were logistics projects.
5. **Anchoring the projects through generating interest from the agencies or institutions**. The last stage of this exercise was generating the project statutes to subject them to different financing sources in the function of the national and international Calls.

20.4 Results

This awareness-raising stage on the event approach -named Round 1- had more than 100 participants connected remotely through the Zoom (San Jose, CA, U.S.A.) platform. This platform allowed sensitizing the participants on the Covid-19 pandemic and the importance of generating solutions to improve the performance of Sonora and Arizona value chains under the Mega approach (Social impact) proposed by Kaufman (2007) in the context of the pandemic. In this stage, the list of participants was also determined per the discussion table.

As a result, two needs were identified: (1) health and well-being, related to social performance and food, and (2) survival-related to tourism and logistics. To gather information from the participants' opinions on boosting Sonora-Arizona Megaregion's internalization, the following questions were set out for each workshop discussion table, which was the same as shown in Table 20.1.

Table 20.1 Questions to identify internationalization opportunities in Megaregion Sonora-Arizona

Table	Topics discussed	Question
Tourism	Tourism platform to generate value proposals Hospitality for Hope in Arizona Hotel restructuring in Spain	What infrastructure and services are required to attract global tourism in the health and gastronomic sectors?
Food	Opportunities for the food and agriculture sector in Sonora The critical success factor of the food and agriculture sector in Denmark Redesigning global value chains in the food sector	What are the challenges to creating Sonoran eco-friendly and nutritional products trademarks for global marketing?
Logistics and commerce	Exploiting the potential of digital tools in the logistics process Opportunities for developing business by using the Internet of things (I.T.) and Business Intelligence (B.I.) Fresh food supply chain and connections with COVID-19 A technological solution to improve the Food and Agriculture Supply	What are the challenges of the logistics sector to connect the Sonora-Arizona Megaregion sector with the world in the food and tourism sectors?
Social performance	Identify projects that have a social impact and how to construct support networks	What challenges should be confronted to prepare the populations of the different Sonora-Arizona Megaregion for new jobs?

Table 20.2 Level 1 projects

Level 1 projects	Presented projects	Organization
Innovation node	Make good use of the digital tool potential in logistics and commerce processes	Instituto Tecnológico de Ciudad Juárez
EMCOR	Opportunities for business development in the information technology field using I.T. and B.I.	Software Enterprise
International logistics and productivity improvement laboratory	Technology-enabled, Rapid-response Fresh Food Supply Chains and connection to COVID-19	Arizona State University
National lab for transportation systems and logistics	Technological solutions to improve fluidity in the food and agriculture supply chain	Instituto Tecnológico de Sonora

20.4.1 Level 1 Project Presentations for the Logistics and Commerce Discussion Table

In a cooperation context among three higher education institutions from Arizona and Sonora and with the participation of a software developing enterprise, the following four projects presented in the workshop were selected; questions were set out to deal with the Megaregion in terms of information and communication technologies, as well as the logistics costs (see Table 20.2).

To conceptualize the proposal complexity of the Logistics and Commerce table discussion -in terms of including project levels 1, 2, and 3- the causal model shown in Fig. 20.2 was based on the methodologies (Schwartz 1996; Lagarda-Leyva and Ruiz 2019; Aracil and Gordillo 1997) discussed.

Cases in populations affected by COVID-19 pandemics and post-pandemic, collaboration from the states of Arizona (U.S.A.) and Sonora (Mexico) should be promoted by both governments to increase the demand in project development in the four grand topics of interest: Food, Tourism, Logistics and Trade, and Social Development.

The Logistics and Commerce discussion table generated positive synergies with five higher education institutions ITSON, ASU, ITCJ, UABC, UACJ, U of A,[1] and four enterprises: EMCOR for software development; Creative Technology Corp., for health (Professional Ventilators and Telemedicine), Hospital San José (attention to the local population and tourism), as well as Lecheros Unidos (Tourism); ITSON and A.S.U. laboratories and the Nodo de Creatividad received funds from CONACYT and Foundation for Food and Agriculture Research (FFAR).

[1] ITSON: Instituto Tecnológico de Sonora; ASU: Arizona State University; ITCJ: Instituto Tecnológico de Sonora; UABC: Universidad Autónoma de Baja California, U of A: University of Arizona.

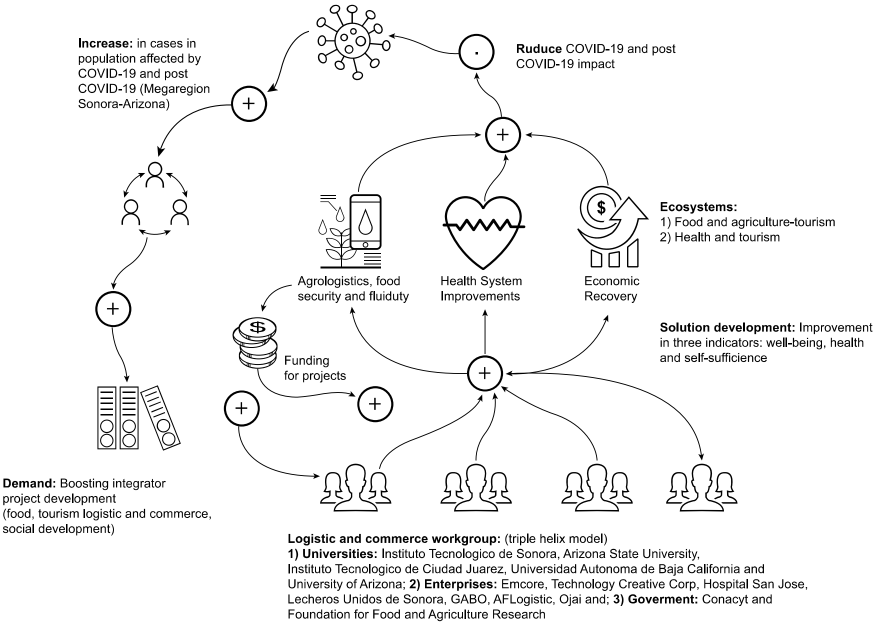

Fig. 20.2 Causal diagram balance type

The development of (1) Food and Agriculture-Tourism and (2) Health-Food ecosystems were supported by the triple helix model by Etzkowitz (1998) to respond to the three Mega indicators of Kaufman (2007) related to well-being, health, and self-sufficiency. The ecosystems seek to reduce current and post-COVID-19 effects by improving the logistics in the food, agriculture, health and tourism sectors. In this sense, the Food Security project collaborates with the University of Arizona, the Laboratorio Nacional en Sistemas de Transporte y Logística-ITSON and UABC.

20.4.2 Digital Tools and Software

The innovation and creativity node set out two questions, (1) What opportunity areas do you consider a priority to make the most of digital tools? And; (2) What activities of the process, project, or area should be digitalized in your organization? The results for the first question indicated that the six options set out were in order of importance as follows: (a) sales and customer service (37.5%); (b) logistics (31.25%); (c) recruitment, selection, and training (12.5%); product/service and productivity with 1%, respectively, while planning was 0%.

The second question was related to the activities of the process, project, or area considered digitalizing in their organization which concentrates the information about warehouse inventories connected with production through collaborative work schemes designing technological solutions, planning and coordination of the platforms, distribution of customer process is related to Customer service, demand distribution and monitoring, assessing consumers' experience, marketing and communication; and finally inverse logistics used for estimation and food waste.

The link with the greatest development opportunities was distribution-customer followed by production-services.

The software enterprise EMCOR set out two questions, one related to technological tools based on software and the possibility of adapting it to their organization. The first question set out was related to technological tools based on software, where three possibilities were placed. The most relevant was to improve the logistics operations with clients and providers with 46.67%, whereas cost control and speed in provision processes, transformation, and deliveries to customers, as well as adapting them to the new logistics operators and breaking with old paradigms, had 26.67% each one.

In the case of question number 2, the new challenges for developing software pointed out -in greater measure- to improve the logistics operations with clients and providers with 43.75%, while cost control and speed in the provision, transformation, and customer delivery process showed 25%. Finally, adapting them to the new logistics operators, breaking old paradigms was 25%. The possibility of adapting technological tools (software) in the logistics departments of their supply chain was in total four and five, which could be transversal; that is, they would apply to all the links: provision (1) production (2) and distribution-client (3) links.

The transversal projects were the greatest contribution concentration by the participants. These projects were five (1) Logistics potential starting from technologies and sharing information through logistics directors; (2) Enterprise resource planning (ERP) for support systems for decision/administration/business intelligence; (3) Process redesign; (4) Automation in sale forecasting/data capture; (5) Adoption of opportunities and transfer with financial systems.

Thus, according to the previous information, consistency existed in the results that derived from question 1 with question 2, given that in both cases, the response dealt with the client and how the product would be delivered from the logistics point of view at the moment of having this area digitalized in their organization. However, it was also relevant that it was not associated with raw matter provision and production proposals with the work schemes and planning and coordination platforms. A value aspect associated with the organization of the United Nations (U.N.) is estimating the food waste that this type of food and agriculture organizations generates.

20.4.3 Logistics Costs and Technological Solutions

The International Logistics and Productivity Improvement Laboratory raised two questions about export–import logistics costs and the main determinants. The main elements associated with these costs -in small shipments to other countries and regions within the country- had the greatest percentage associated with flexibility with 46 and 18% of the following three: customs, information, and infrastructure. The main cost determinant was external factors at 46%, internal factors at 27%, and government at 18%, while 9% was the least effect associated with customers.

The National Lab for Transportation Systems and Logistics proposed two questions associated with the response of the supply chains facing COVID-19 and the challenges to be confronted. The points of agreement, in which the participants placed their response according to the four elements associated with 4.0 technologies, experienced high-leadership staff developed technological and collaboration solutions.

Concerning the main requirements that would be considered during and post-pandemic, those that stood out in the first and second place were developing technological solutions to anticipate and minimize risks in supply chains with 35.29% and collaborating Universities -Enterprises-Governments with 29.41%; in third place, having top expert leaders in logistics and supply chain topics with 23.52%; and finally, having processes of 4.0 technologies with 11.76%.

In another topic related to three of the main challenges between Mexico and the United States for (1) food and agriculture supply chains, 50% are associated in favor of that mentioned among the participants in cooperation and management to occur; (2) the aspect of fluidity came in second place with 25% and; (3) supply chain risks had 25%.

Finally, concerning the projects that should have a greater priority in the next two years in the food and agriculture supply chain, four projects were set out in the following priority order:

1. Development of business models in response to the most demanding markets (demands) with product (food) security and hygiene.
2. Development of flexible technological solutions for each supply chain link.
3. Massive data analyses for decision-making.
4. Creation of agreements between the governments of Arizona and Mexico to increase cooperation possibilities.

In this last part of the dynamics, the participants were asked to express any project idea they would propose, from which they categorized by families that had to deal with any of the supply chains in Table 20.3.

Table 20.3 Project ideas generated that would impact mega indicators

Mega indicator	Project idea	Scope
Well-being	(1) Promote logistics excellence in the region; (2) Assess supply chain risk; (3) Observe vulnerability indicators in the supply chain (exogenous and endogenous); (4) Measure fluidity in the supply chain with big data to detect bottleneck and potential implementation of physical Internet	Regional
Health	(1) Design and develop a professional ventilator; (2) Assess supply chain risk	Regional
Self-sufficiency	(1) Use information technologies for quick response to the customer; (2) web platforms for collaboration between small and medium producers to identify their main requirements	Regional
Another indicator	Technical service, marketing, and logistics in the supply chain, logistics model	Regional

20.4.4 Proposal Presentations Facing COVID-19 Pandemics and Post-pandemic

Four Level-2 projects were presented, and their objectives were as follows: Fluidity index analysis in the southern Sonora-Arizona corridor: Analyze the fluidity index in cargo transport in the southern highway corridor of the Sonora-Arizona corridor to improve the service offering that derives in increasing efficiency and security of the supply chain.

Food security in the wake of the global pandemic: Food loss and waste reduction and the need for resilient and robust food supply chain: Assess food waste and loss during the global pandemics that allow developing resilience and robust strategies in the long term to guarantee food security and sustainability of the food and agriculture value chain of the Mega-region Arizona-Sonora.

Development and commercialization of chitosan for skin lesion treatments: Design and commercialize chitosan biomaterials for their application in patients that require any skin treatment, especially those that suffer from diabetes and foot problems, varicose ulcers, and surgery wounds, among others.

The participants presented and assessed the four project proposals, of which the best (10 out of 19) were graded by themselves in the event based on a 5-point Likert scale where the maximum value was 5 and the minimum was 1.

To sum up: In total, the proposed projects were 20, as follows: three Food, eight Tourism, four Logistics products, and five social performance; only 19 (95%) projects presented of the total (20%).

Two were not graded by the event participants (table performance). A five-point Likert scale was used where 1 had the lowest and 5 the highest weight.

1. The product or service generated contributed to the well-being indicator;
2. The product or service generated contributed to the health indicator;
3. The product or service generated contributed to the self-sufficiency indicator;

4. The project should be considered and supported with external funds; and
5. The proposal was feasible from the technical and financial perspective at the time proposed.

Table 20.4 shows the information related to the Logistics and Trade table—an example where the components related to the Mega approach (social impact) and cost–benefit were assessed.

The project with the highest interest for its anchoring was Chitosan Biomaterial Development and Commercialization of Chitosan for Skin Lesion Treatment, with 4.4 points out of 5. The list of the 10 best projects also got first place in the total average of the products' different discussion tables, which can be observed in Table 20.5.

Level 2 projects of the two ecosystems were analyzed starting from the diagnosis based on five statements set out and related to the trends of the consumers according to the document developed by the Mexican Ministry of Economy; the new consumer has more personalized taste each time; the new purchase-decision process of the consumer; creation of new commercialization channels; the revolution of means of payment; current business is more competitive and comple20.

The main results are derived from each one of the consumer trends. It was established that the cost approach and response level to clients were of greater importance at the level of competencies to satisfy the customer and consumer demands.

Similarly, the result of the greatest importance considered by the participants in market segmentation plans for each food and agriculture chain was the shortest cycle time in adopting consumer innovation, implying the highest demands and increasing clients' expectations. Finally, infrastructure and flexibility should be generated to align and manage payment channels to speed up the transaction in the supply chain.

20.4.5 Project Selection to Integrate Logistics Ecosystems

In this section and with the coordination of Level 3 projects, the proposal of the two logistics ecosystems could be determined, one associated with the agro-logistics-tourism-food and the second with tourism-health.

The projects and their scope were as follows:

- Telemedicine System for Hospitality: Design and develop Integral Telemedicine systems for hotels, which could be applied at regional or international levels.
- Professional Medical Ventilator: Design, develop, make, and commercialize the first model of a series of three professional low-cost ventilators. The first one is divided into two sub-projects: one for the coronavirus pandemic and the other one for the Node-Tec-Juarez program for the development of high-technology medical equipment as part of the Complejo de Investigación, Innovación, Desarrollo y Diseño (CIIDD) of the same institution (Instituto Tecnológico de Ciudad Juárez, Chihuahua, México).

Table 20.4 Sonora-Arizona Megaregion per discussion table

	Projects	MEGA Indicator (Strategic)	Cost–benefit	Average value			
		WB	SS	H	V	A	
Food							
1	Healthy Mexican Sonoran food for the world to enjoy	3.9	4	3.5	3.8	3.7	3.78
2	Post-COVID-19 Fairs and Exhibits	3.7	3.7	2.8	3.4	3.5	3.42
3	Dolphin Bio-fertilizer and food supplement through marine microalgae	4.3	4.3	4.2	4.3	4.2	4.26
Tourism							
4	Community development strategy in the new world scenario. The Milk Run	4.4	4.4	3.8	4.1	4.1	4.16
5	Health and Innocuousness System in Tourism "Sonora Quality"	4.2	4	4.1	3.9	3.9	4.02
6	Safe integral medical attention in southern Sonora Lab and Hospital San José	4.2	3.8	4.5	4.1	3.6	4.04
7	Sierra (Álamos)—Mar (Huatabampo) Navojoa Tourism Cluster Circuit	4.4	4.2	3.6	3.6	3.8	3.92
8	Reactivating Tourism and Employment activities through Sanitizing Spaces and COVID-19 Prevention Project	4.1	4	4.3	3.7	3.8	3.98
9	Telemedicine for Hospitality Service	4.4	4.3	4.6	4	4.3	4.32

(continued)

Table 20.4 (continued)

	Projects	MEGA Indicator (Strategic)	Cost–benefit	Average value			
		WB	SS	H	V	A	
10	Professional Medical Ventilator	4.3	4.3	4.6	4	4.4	4.32
11	Sonora-Arizona Film Industry Promotion Fund	3.7	3.6	2.9	3.6	3.7	3.5
Logistics							
12	Fluidity Index Analysis in the South Sonora—Arizona	4.5	4.5	3.3	4.0	3.9	4.04
13	Chitosan Biomaterial Development and Commercialization for Skin Lesion Treatment	4.6	4.4	4.8	4.5	4.4	4.54
14	Developing Plant Extracts with functional properties	4.3	4.4	4.2	4	4.2	4.22
15	Food security in the wake of the global pandemics– Food loss and waste reduction and the need for resilient and robust food supply chains	4	4.5	4.4	4.4	4.4	4.34
Social performance							
16	Strategic Alliance for Economic Empowerment of Women	3.9	4	3.4	3.6	3.9	3.76
17	English Language Training	4.7	4.4	3.9	4.5	4.5	4.4

Note WB = Well-being; SS = Self Sufficiency; H = Health; V = Viability; A = Anchoring
Source Own elaboration

- Dolphin bio-fertilizer and food supplement through marine microalgae: Implement the use of marine microalgae as food supplement and 100% natural bio-fertilizer because it does not degrade the crop or compete with land or freshwater dedicated to food production or human settlements. Crops are cultivated in a land unsuitable for agriculture and with sea or brackish water and reach great densities.
- Health tourism influx was detected contributing to important income channeled to other sectors of community service activities, such as transport, local commerce, hospitality, communication, food, and other goods, which provide benefits in the

Table 20.5 Presentation of the 10 projects with the best grade

Project	Table	Average
Development and commercialization of chitosan biomaterial for skin lesion treatments	Logistics	4.54
Training for English language proficiency	Performance	4.40
Food security in the wake of the global pandemic—Food loss and waste reduction and the need for resilient and robust food supply chains	Logistics	4.34
Telemedicine System for Hospitality Industry	Tourism	4.32
Professional medical ventilator	Tourism	4.32
Dolphin bio-fertilizer and food supplement through marine microalgae	Food	4.26
Development and commercialization of plant extracts with functional	Logistics	4.22
Community development strategy in the new global scenario. The Milk Route	Tourism	4.16
Fluidity index analysis in the Southern Sonora—Arizona Corridor	Logistics	4.04
Safe and integral medical attention in southern Sonora Lab and Hospital San José	Tourism	4.04

Notes for each month, the number of projects for each table is shown, of which the first 10 are listed, providing the % of acceptance considering values between 4.04 and 4.54 in average: (1) Food: 3 projects presented, 1/3 = 33.33% of acceptance; (2) Tourism: 8 projects presented, 4/8 = 50% of acceptance; (3) Logistics: 4 projects presented 4/4 = 100% of acceptance; (4) Social Performance: 4 projects presented, 2 assessed, 1/4 = 25% of acceptance. The number of participants in Round 3 was from 65 to 52 persons during the event

different axes and support employment creation and maintenance of southern Sonora. At the same time, the foreign community may find a peaceful and secure ambiance in the region, strengthening links with the Mexico-United States border.

- The Milk Run is a feasible community development strategy in the new global scenario. Its objective is to implement an innovator business model based on the integral strengthening of the productive units and their integration in value networks capable of solving real community problems and creating innovation ecosystems in the rural sector.

With the information of all the projects that could be involved, the following interrelation proposal was set out to derive on a tourism-food supply chain integrator response project and those related to health tourism. Thus, the two ecosystems were generated: (1) Food and Agriculture Logistics Ecosystem; (2) Health-Tourism Logistics Ecosystem shown in Fig. 20.3.

In a disaggregation level of the two final projects seen from the logistics and commerce perspective in its supply chain, the proposed projects were food security and better use of food in the Sonora-Arizona Megaregion, as well as the project analysis of transport fluidity in the southern Sonora-Arizona corridor also observed the possibility of converging with those related to fruit and vegetables. For example, the enterprise Agropecuaria GABO may go together with the export product Roma tomato or the marine microalga project through distribution, such as AFL-Logistics,

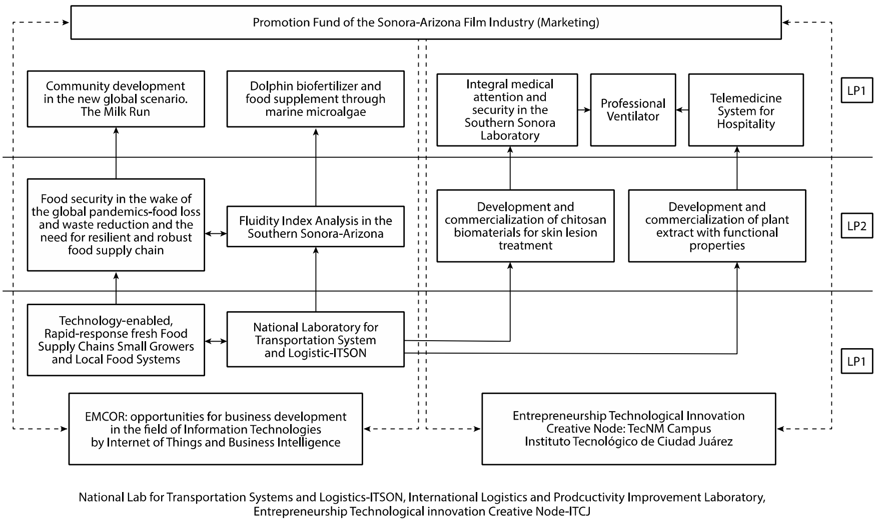

Fig. 20.3 Logistics ecosystems: Food and Agriculture-Health-Tourism. *Source* Own production. *Notes* LP1, LP2, LP3 = Project levels; TecNM = Tecnológico Nacional de México

for shipping the products to the warehouses of Rio Rico in Nogales (Arizona) by land transport.

On the other hand, for meat or its derived products, the project Milk Run would be considered or that of meat -in this case, pork- with the company Ojai Alimentos, which would shortly export toward the United States where they can exploit the Arizona State market (see Fig. 20.4).

The Food and Agriculture-Tourism Logistics Ecosystem, where Level 1 projects would have the capacity to offer support from their infrastructure and services to Level 2 and Level 3 projects. They would then connect with the food and agriculture chain (fruit, vegetable, meat) in the fresh and dry chain toward the United States and world markets.

Similarly, Fig. 20.5 shows the Tourism-Health Logistics Systems. Level 1 projects would have the capacity to offer support from their infrastructure and services to Level 2 projects (natural products from the region: chitosan and copalquin tree (Rhamnus purshiana) and Level 3 (Hospital San José, Professional Ventilator and Telemedicine) to connect them as tourism-health chain for the United States markets.

The support to the tourism projects may be performed in the following manner:

- Provision link: Provider analyses, decision models for purchases and inventories:
- Production-service: studies in the supply chain to improve efficiency in the productive and service processes with reliable solutions;
- Distribution: studies to improve fluidity in transport means, connecting supply and demand, decision-making models based on product export and import from Mexico with Arizona;

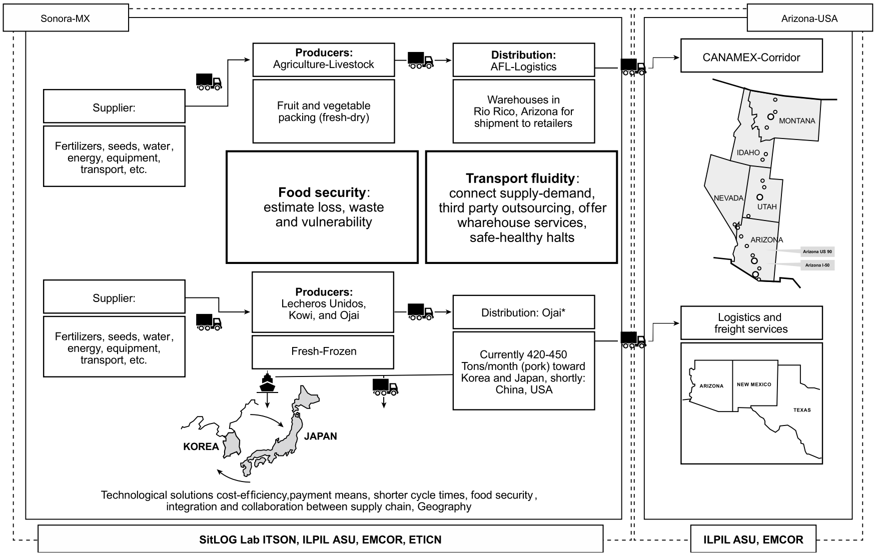

Fig. 20.4 Food and agriculture-tourism Logistics Ecosystem, project initiative for the Sonora-Arizona Megaregion, Mexico-U.S.A. *Notes* National Lab for Transportation Systems and Logistics ITSON (Sit-LOG Lab-ITSON, International Logistics and Productivity Improvement Laboratory (ILPIL), Entrepreneurship Technological Innovation Creative Node-ITCJ (ETICN-ITCJ)

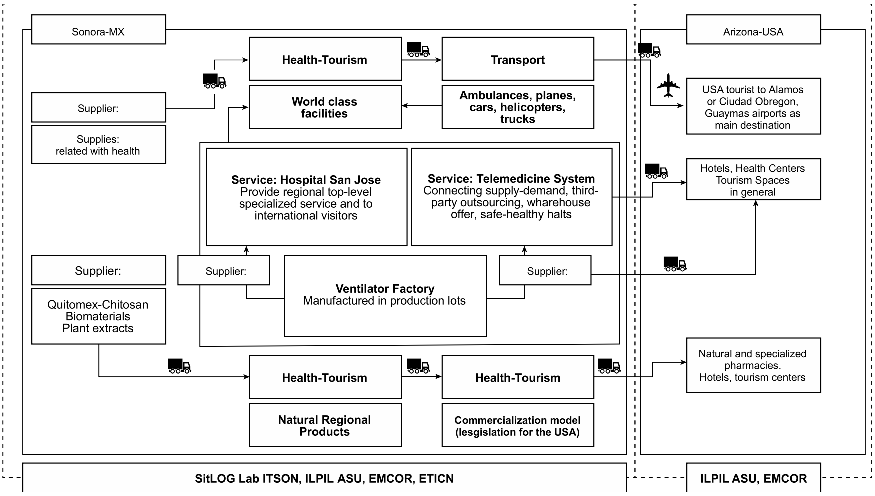

Fig. 20.5 Tourism-Health, logistics ecosystem. *Source* Own production. *Notes* National Lab for Transportation Systems and Logistics-ITSON (Sit-LOG Lab-ITSON, International Logistics and Productivity Improvement Laboratory (ILPIL), Entrepreneurship Technological Innovation Creative Node (ETICN-ITCJ); ITSON = Instituto Tecnológico de Sonora; ASU = Arizona State University; and ITCJ = Instituto Tecnológico de Ciudad Juárez

- Inverse Logistics: development to minimize loss and food waste of business models for using non-consumable products for humans, which can be used for other purposes.

The support provided to the tourism projects may be as follows:

- Supply link: Provider Analyses, decision models for purchases and inventories
- Production service: Studies in the supply chain to improve the efficiency of the productive and service processes with reliable solutions.
- Distribution: Studies to improve the fluidity of transport means, connecting supply with demand, decision-making models based on export–import products from Mexico to Arizona.
- Inverse Logistics: Solution development to minimize loss and food waste, business models for using non-consumable products for humans, which can be used for other purposes.

20.4.6 Anchoring Projects by Generating Interest on the Part of Agencies or Institutions

For project development, three types of scope were established starting from a formal project statute:

- Logical scope: stage in which goals and actions are determined to define the products obtained and their financing based on the capacities of each one of the ecosystems.
- Organizational scope: each ecosystem project must have a leader in Sonora and Arizona besides the collaborators who jointly develop the products or services of each supply chain. Academics, entrepreneurs, and clients should be involved.
- Financial scope: the main financial resources shall derive from compromised products, considering infrastructure and the human resources in each ecosystem.

The projects, according to Soluk et al. (2021), follow three important stages related to planning, incubation, and acceleration stage.

The proposed ecosystem projects were valued and determined according to (Soluk et al. 2021; Bernárdez 2006, 2009; Chiesa and Manzini 1998) proposal that each project should be found in the following maturity levels according to Table 20.6.

The four main actions to achieve anchoring the projects should start in this sequence according to that expressed by the participants in the Logistics and Trade discussion table:

- Development of practical and reliable solutions, above all in the most vulnerable supply chains;
- Reflection of the results of the real coordination and cooperation between Sonora and Arizona;

Table 20.6 Sonora-Arizona Projects in maturity level for each ecosystem

Project name	Maturity level	Organization	Ecosystem
National Lab for Transportation Systems and Logistics	Acceleration	Instituto Tecnológico de Sonora (ITSON)	1 & 2
Technology-enabled, Rapid-response Fresh Food Supply Chains, Small Growers and Local Food Systems	Acceleration	Arizona State University (ASU)	1
Opportunities for business development in the field of information technologies by the Internet of Things (IoT) and Business Intelligence (B.I.)	Acceleration	EMCOR	1
Creativity Node and Technological Innovation and Entrepreneurship	Acceleration	Instituto Tecnológico de Ciudad Juárez (TecNM-ITCJ)	2
Fluidity Index Analysis in the Southern Sonora—Arizona corridor	Planning	ITSON	1
Food security in the wake of global pandemics—Food loss and waste reduction and the need for a resilient and robust food supply chain	Planning	Universidad Autónoma de Baja California (UABC)	1
Community development strategy in the new global scenario. The Milk Run	Incubation	Lecheros Unidos	1
Dolphin Biofertilizer and food supplement through marine microalgae	Planning	Instituto Tecnológico de Ciudad Juárez (ITCJ)	1
Development and commercialization of chitosan biomaterials for skin lesion treatment	Acceleration	ITSON	2
Development and commercialization of plant extracts with functional properties	Planning	ITSON	2
Safe and integral medical attention in southern Sonora	Acceleration	Laboratorio y Hospital San José	2
Professional ventilator	Incubation	Technology Creative Core El Paso, TX	2
Telemedicine system for Hospitality	Incubation	Technology Creative Core El Paso, TX	2

Note 1 = Agriculture and food-Tourism Ecosystem; 2 = Health-Tourism Ecosystem
Source Own production with information from each organization's projects

- Determination of implementing each project according to their maturity to generate results and promote them as success cases;
- Collaboration of academics, entrepreneurs, and government with quarterly advance reports.

Finally, among the main considerations of the logistics discussion table to achieve the success of the logistics ecosystems were 12, detailed as follows:

1. Work as a system;
2. Have a systemic view linked to working as a solid team;
3. Recover investment starting from project implementation;
4. Apply mechanisms for transparency of achievements and results;
5. Show mutual trust among participants for collective work;
6. Establish a governing model starting from the current treaties;
7. Have a potential market vision between Sonora and Arizona;
8. Get financing and support to carry out the projects under the Arizona and Sonora regulations;
9. Find potential clients for the products and services of the supply chains;
10. Follow the new sanitary regulations that emerge for the supply chains starting from COVID-19;
11. Observe the reactions facing the new sanitary regulations demanded from the product providers in the United States of America;
12. Find a way of reducing logistics costs to place regional products in Arizona.

Currently, the group is in search of anchoring the food security project jointly with the University of Arizona and the National Lab for Transportation Systems and Logistics-ITSON to implement such a project in the function of the operating regulations established to assign human, financial, and infrastructure resources.

20.5 Conclusions

The development of the proposal for the construction of the logistics ecosystems has been a theoretical and practical experience during the COVID-19 period by achieving integration of the initial participation of more than 100 participants in four discussion tables. Later on, an average of 25 experts were included in the logistics and commerce topics represented by academics, entrepreneurs, and governments to determine the projects that should conform to each one of the logistics ecosystems and face up COVID-19 pandemics and post-pandemics.

The Agriculture and Food-Tourism Logistics Ecosystem gain special importance the sponsors that would be willing to invest in implementing it in the short term through the partnership of the two higher education institutions in Mexico (ITSON, UABC) and one in the United States (U of A) in the initiative Sonora-Arizona Megaregion through the coordination of the state governments and their representatives.

Similarly, the Health-Tourism Ecosystem is backed up by two higher education institutions through ITCJ Entrepreneurship and Technological Innovation and Creativity Node. These institutions are linked in cooperation with National Lab for Transportation Systems and Logistics-ITSON to coordinate the efforts of the two related projects with ITSON plant products and chitosan to place orders in hospitals (San José de Navojoa) and hotels through the Telemedicine and Professional Ventilator projects developed jointly by ITCJ and the Technology Creative Core with headquarters in El Paso, TX.

The following recommendations in the proposal should be highlighted starting from the seven main results obtained to implement the two logistics ecosystems.

Achieve anchoring each of the projects that conform to each of the ecosystems in order of priority and maturity; anchoring should be the response to the rigorous assessment and the professionalism of the entities that provide the resources.

Define maturity based on evidence of each one of the projects, referring to their planning, incubation, or acceleration stage.

Determine on the part of Sonora-Arizona Megaregion the projects that should be supported in the function of their priorities and benefits of both states based on the ideal vision (health, well-being, and self-sufficiency).

Establish the operation regulations facing the current Covid-19 pandemic and post-pandemic to generate trust between both countries through regulation, legislation, and better practices in logistics and commerce defined for the products and services that each one of the innovation ecosystems offers.

Consider generating training programs to establish their process's investment and tangible and intangible benefits clearly in case the projects require maturity and be approved by any professional agency for this purpose. In other words, projects should pass the planning stage to incubation and acceleration, according to the Institute for Performance Improvement model.

Empower the link of graduate academic programs among the Sonora and Arizona institutions with professional and scientific vocational guidance to develop the innovation ecosystems through student and academic staff exchange, either remote or on-site.

Establish the rules of operation in a clear manner for the participants through a call by both governments for financial support as proof of the high commitment generated with the projects.

Finally, the commitment generated in the five rounds -during the 5-week event and where an average of 80 persons participated for each round- denotes an effort of both states, which is praiseworthy. Nonetheless, it is important to maintain all the participants motivated through the recommendations set up. This initiative should deliver the results that impact the ideal vision and generation of the value chains during the Covid-19 and post-pandemic in terms of closing the gaps that impact Sonora and Arizona's well-being, health, and self-sufficiency.

Future work: The Food Security Project should be developed in the short term jointly with the University of Arizona, where the intention is to have the first diagnosis of only one regional product of Sonora demanded by Arizona and with which the National

Lab for Transportation Systems and Logistics-ITSON has been working for more than eight years. The product selected is the export product Tomate Roma harvested in the southern region of Sonora and shipped to Rio Rico in Nogales, Arizona, through the different agriculture and livestock farming of the southern Sonora and northern Sinaloa regions.

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