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Cooperative and integrated supply chain management through smart contracts backed by blockchains

Mohammad Amin Yazdani

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Pour obtenir le grade de

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Spécialité Automatique, Traitement du signal et des
images, Génie informatique

Par Mohammad Amin YAZDANI

« Gestion coopérative et intégrée de chaînes logistiques par
smart contracts adossés à des blockchains »

Soutenue publiquement, le 2 octobre 2023 devant le jury composé de :

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Mohammad Amin YAZDANI

Résumé

Le management des chaîne logistique est l'une des activités et une des parties parmi les plus importantes et les plus difficiles pour les entreprises. L'existence de nombreux défis autour des chaînes logistiques font qu'il est essentiel d'intégrer des technologies nouvelles et efficaces pour améliorer diverses opérations. Parmi toutes les activités de la chaîne logistique, l'approche la plus efficace pour distribuer les produits à différents étages peut être un élément crucial doté d'un fort potentiel de développement. Cette question résulte directement de la gestion des flux de matières, d'informations, et financiers. Par conséquent, la mise en œuvre de technologies efficaces capables de contrôler tous les flux dans la partie distribution de la chaîne logistique et d'aider les décideurs à surmonter les différents obstacles est un point moteur de notre recherche.

Dans le cadre de cette thèse, nous avons étudié le problème de la distribution des produits dans un processus de chaîne logistique. Notre objectif est de concevoir un système intégré pour aider les décideurs avec différentes solutions pour une meilleure gestion des flux de matériels, d'informations et financiers. Pour ce faire, nous avons introduit une nouvelle approche pour les smart contrats en considérant une programmation en nombres entiers mixtes intégrée directement dans le contrat. Ensuite, nous basant sur les prépondérants de la technologie blockchain et de l'Internet des objets, nous avons discuté de la possibilité d'intégrer les données issues de ces outils au smart contrat et au système physique considère. Nous avons étudié trois développement en relation avec le processus de distribution : (i) choisi des temps de réaction possibles en fonction des événements survenus dans le système; (ii) des procédures dynamiques de sélection des fournisseurs dans l'algorithme du smart contrat et étude de son impact sur le processus de distribution ; et (iii) l'interaction possible entre les acteurs par le biais de collaborations. Nous avons réalisé plusieurs entretiens pour obtenir des données fiables et nous avons résolu les problèmes proposés en utilisant des méthodes exactes pour valider le modèle de programmation en nombres entiers mixtes proposé et analyser les résultats finaux.

Mot clés: Gestion de la chaîne logistique, Smart contrats, Technologie blockchain, Internet des objets.

Abstract

Supply chain management is one of the most crucial and difficult sections and components for businesses in both the present and future industries. The existence of numerous challenges and the significance of the supply chain make it essential to integrate new and efficient technologies to improve various operations. Among all the activities in the supply chain, the most effective approach for distributing products at various phases can be an important element with a high development potential. The matter is a direct result of the material, information, and financial flows management in the distribution sectors. Consequently, discovering effective technologies that can control all the flows in supply chain distributions and aiding decision makers in overcoming various obstacles may be a driving force behind our research.

Through this thesis, we have studied the problem of the distribution of products in a supply chain process. Our goal is to design an integrated system to help decision makers with different propositions for better management of material, information, and financial flows. To do so, we have introduced a novel approach for smart contracts by considering a mixed integer programming in its algorithm. Then, we have highlighted the important roles of blockchain technology and the internet of things, and we have discussed the possibility of integration between these tools with the smart contract and presented physical system. We have developed three important perspectives in relation to the distribution process consist of: (i) select the possible reaction moments based on the events in the system; (ii) the necessity of dynamic supplier selection procedures in the smart contract algorithm and its impacts on the distribution process; and (iii) possible interaction between actors through collaborations. We have done several interviews to have more reliable data, and we have solved the proposed problems using exact methods to validate the proposed mixed integer programming model and analyze the final results.

Keywords: Supply chain management, Smart contracts, Blockchain technology, Internet of things.

List of publications

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- **Yazdani, M. A.**, Roy, D., & Hennequin, S. (2022). Bi-objective Model for the Distribution of COVID-19 Vaccines. In *Modelling, Computation and Optimization in Information Systems and Management Sciences: Proceedings of the 4th International Conference on Modelling, Computation and Optimization in Information Systems and Management Sciences-MCO 2021 4* (pp. 208-220), Vietnam. Springer International Publishing.
- **Yazdani, M. A.**, Roy, D., & Hennequin, S. (2021). Smart Contracts Implementation in the Allocation of Covid-19 Vaccines. In *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems: IFIP WG 5.7 International Conference-APMS 2021, Nantes, France, September 5–9, 2021, Proceedings, Part III* (pp. 510-520). Springer International Publishing.
- Liu, S., **Yazdani, M. A.**, Hennequin, S., & Roy, D. (2022). Cloud Architecture-based Multi-agent Platform for Matching in Resource Sharing. *10th IFAC Conference on Manufacturing Modelling, Management and Control-MIM 2022, Nantes, France, 55(10)*, 3184-3189.
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- **Yazdani, M. A.**, Roy, D., & Hennequin, S. Smart contract proposition for facilitating collaborations between pharmaceutical supply chain actors (Under revision in Journal of Industrial Information Integration)
- **Yazdani, M. A.**, Roy, D., & Hennequin, S. Blockchain and smart contract for optimal distribution of products in pharmaceutical supply chains (Ready for submission in Computers and Industrial Engineering)

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Abbreviations

<i>Abbreviations</i>	
SCM	Supply chain management
SC	Supply chain
PSC	Pharmaceutical supply chain
BT	Blockchain Technology
IoT	Internet of things
MIP	Mixed integer programming
IS	Information sharing
IT	Information technology
EDI	Electronic data interchange
DC	Distribution center
ERP	Enterprise resource planning
RFID	Radio frequency identification
FCM	Fuzzy cognitive maps
FSCD	Fuzzy system for criteria definition
FAHP	Fuzzy hierarchical analysis process
NHL	Nonlinear Hebbian learning algorithm

General introduction

The global economy is supported by complex networks that support the flow of products and services from producers to consumers. This intricate system is known as supply chain, and it is vital to the success and competitiveness of businesses in today's interconnected global economy. Distribution is crucial to the supply chain because it entails the efficient movement and delivery of products to end customers. In addition, the incorporation of new technologies has emerged as a major propelling force, revolutionizing distribution processes and improving supply chain performance overall. In this thesis, we will examine the importance of the supply chain, with a particular emphasis on distribution, as well as the significance of integrating a technology to optimize operations and uncover unprecedented business opportunities.

The incorporation of new technologies has transformed distribution techniques in recent years, propelling the supply chain industry into a new era of efficiency and creativity. Internet of things, artificial intelligence, robotics, and blockchain technology have revolutionized old distribution paradigms, allowing organizations to solve difficulties and capitalize on opportunities like never before. Among all technologies, we are more interested in Internet of things and blockchain technology. Companies may manage and monitor shipments in real time, improve routes and vehicle utilization, and obtain important insights into their distribution operations by integrating Internet of things devices. Blockchain technology improves transparency and security in supply chain transactions, lowering the risk of fraud and counterfeiting while maintaining product traceability and authenticity. However, they can be other needs to help decision makers for better management of the supply chain process in all aspects of material, financial and information flows.

As technology advances, smart contracts have emerged as a game changer in the supply chain area. Smart contracts are self-executing agreements encoded platforms that enforce contractual terms and conditions automatically. By incorporating smart contracts into the distribution process, decision makers can gain a number of advantages, which we shall discuss in detail in this thesis. Besides, smart contracts enable automation and digitization of various tasks and processes, eliminating manual errors and enhancing operational efficiency.

The main motivations of doing this thesis are mentioned as follows:

- Proposing a supply chain from the perspective of the actors and integrating data exchange ways using blockchain technology and Internet of things as a safe and trustworthy data source.
- Introducing a novel make use of smart contracts by formalizing the scripts in a mixed integer programming format and differentiating its responsibilities as a decision maker assistance and third party removal.
- Giving the possibility of setting the time for treating the supply chain's flows (material, information, and financial) to the decision makers (Chapter 2).
- Considering dynamic supplier selection possibility and evaluation of the supplier performances (Chapter 3).
- Introducing collaboration strategies between the supply chain actors in the presence of blockchain technology (Chapter 4).

We discuss our motivations thoroughly in four different chapters, and we develop our novelties to respond to them. Chapters are organized as follows:

- The first chapter frames and contextualizes the proposed research work. An overview of the context behind this thesis is presented by addressing several terms related to supply chain and challenges for the industry of the future. In addition, a summary illustrates the different paradigms of business, supply chains, and technologies with a focus on modern paradigms. Then, we focus on the different concepts used in the trustworthy distribution process in supply chain. Among these concepts, we recall the importance of blockchain technology, Internet of things and smart contracts. At the end of this synthesis, we propose a general description of our research problem and we position it in relation to the possible challenges.
- The second chapter introduces a smart contract to assist decision-makers in dealing with distribution process difficulties by utilizing linked devices (sensors, traceability tools, and so on) to be more reactive and blockchain technology to bring transparency and confidence between supply chain participants. Furthermore, the given smart contract assists decision-makers in defining the moments of acting in response to potential events and problems in the system before to occurrences. The given smart contract employs a multi-objective method to reduce costs, increase purchases from certified suppliers, and reduce the projected delivery time for the products. Finally, the findings are summarized and compared in terms of economic advantages and service rate.

- Chapter three emphasizes gaps provided in the second chapter. It introduces two different smart contracts. For the first smart contract, fuzzy cognitive maps and expert ideas were used to select suppliers. The distribution process is the focus of the second smart contract. The diverse forms of inputs for each smart contract are the rationale for presenting two different smart contracts. The fuzzy cognitive map idea is modified to find the most essential criteria for a certain period of time and then dynamically pick suppliers. Finally, the findings, potential changes and improvement of the presented system have been discussed.
- Chapter four uses the framework presented in chapter two, along with more interactions and collaborative ways among different actors and stages. It presents numerous techniques to collaborations that make use of the possibility of information exchange among actors. A mathematical formulation based on mixed integer programming is used to model the collaborative activities. The proposed system combined with cooperation tactics may considerably contribute to the automation of the distribution process and facilitate actor interaction. Finally, these interactions may pave the way for more sustainable development ideas.

Finally, we end this thesis with a general conclusion with some remarks and avenues for future researches.

Chapter 1 Challenges in management of supply chains in Industry 4.0 context

This chapter contextualizes and frames our research work. First, we present an overview of the background behind this thesis by addressing several terms related to supply chain management and challenges for the industry of the future. Furthermore, several new technologies with the potential for integration with supply chain business have been introduced, and their advantages have been highlighted. Then, in the supply chain, we concentrate on the various types of flows, which are material, financial, and informational. We discovered that, among other technologies, blockchain and Internet of things could affect all flows and bring security and automation to the supply chain. Furthermore, our new approach toward smart contracts is presented in the information technologies systems. At the end of this summary, we propose a general description of our research problem and possible research gaps.

1.1 Industrial general context

Revolutions may ultimately follow one another in quick succession during the next ten years and beyond as technology advancements pick up speed. The previous three industrial revolutions lasted for decades, but the current revolutions only last until industry-wide adoption is complete. It is crucial to remember that Manufacturing 5.0 is an improvement over 4.0 and not a completely new system (Demir *et al.*, 2019). These revolutions are shown in a timeline in Figure 1-1. Observe how the interval between rotations is getting shorter. The first three revolutions happened one hundred years apart. To go from the third to the fourth one, it only took around 40 years. It is feasible that it will take fewer than 40 years to get to the fifth one.

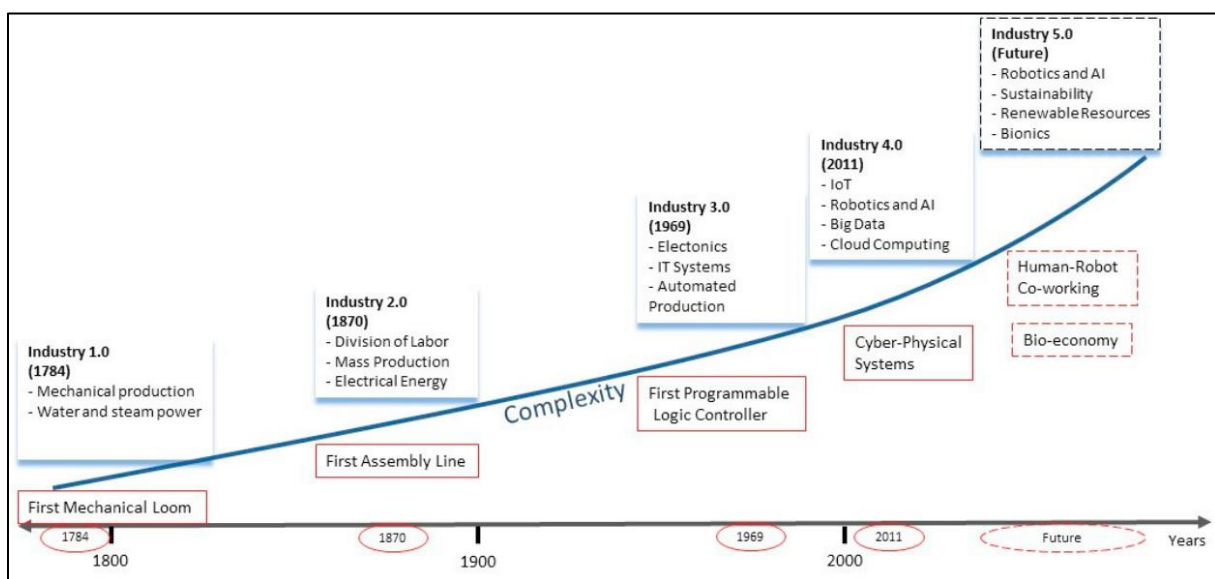


Figure 1-1- Evolutions from industry 1.0 to Industry 5.0 (Demir *et al.*, 2019)

In the last five years, the context of Industry 4.0, Industry 5.0, and supply chain management (SCM) has received notable attention. Up to the time of finalizing this thesis and based on google scholar, around 16300 papers were published related to Industry 4.0, 30,500 papers discussed Industry 5.0, and 172000 papers focused on SCM perspectives. While these numbers, respectively, are 30,767, 4,955, and 42,307 in the web of science. Between all the publishers, Taylor and Francis and Elsevier have gotten a good number of citations, which makes them more valuable for more reading and research.

Information technology (IT) systems have made tremendous revolutionary development over the past three decades, which has consequently affected every element of human life. The transition from personal computers to smart devices that use infrastructure services based on cloud computing is one of the most drastic developments. In addition, the Internet is connecting

to the wireless network at this new beginning of the Internet era, which is characterized by integrated computer-based automation systems. In addition to providing practically limitless opportunities for integrating people and machines in a cyber-physical system setting utilizing data gathered from various sources, these recent innovations have also made it possible for machines to directly communicate with one another. Industry 4.0 refers to the adoption of this type of network within the context of production and operations (Rad *et al.*, 2022).

Industry 4.0 has supply networks and business structures that significantly rely on cutting-edge digital technologies. According to (Büyüközkan & Göçer, 2018), Industry 4.0 technologies are the key to achieving the benefits of digitalization, which is defined as the transformation of processes, capabilities, and offerings within industrial firms and their associated ecosystems to gradually create, deliver, and capture increased service value resulting from a wide range of enabling digital technologies. The external interactions and conflicts between businesses are at the heart of some of the major difficulties posed by digitalization (Baratta *et al.*, 2023).

Less than ten years have elapsed since the first discussions of Industry 4.0 in the industrial sector, yet visionaries are already predicting the arrival of Industry 5.0. Industry 5.0 is expected to put more emphasis on the integration of human hands and brains back into the industrial framework than the present revolution, which focuses on transforming factories into Internet of things (IoTs)-enabled smart facilities that use cognitive computing and link via cloud servers (Baratta *et al.*, 2023).

According to (Birkel & Müller, 2021) and (Simonetto *et al.*, 2022), Industry 4.0's implementation in manufacturing has numerous effects on the entire supply chains (SCs). In order to maximize the transparency of all the phases from when the order is delivered to the end of the product's life, cooperation between suppliers, manufacturers, warehouses, and customers is essential. Furthermore, the entire SCM structure has changed as a result of the advent of digitalization and process automation. Analysis of Industry 4.0's effects on the SC as a whole is therefore important in order to comprehend the opportunities and potentials that may result from the implementation of these new technologies (Nouinou *et al.*, 2023).

We will talk about the SCs in greater detail in the following section before learning about their responsibilities and significance.

1.2 Supply chain definitions

One of the initial definitions of the SC put forth by (Govil & Proth, 2002) was as follows: a global network of companies working together to enhance the flow of materials and information

between suppliers and customers at the lowest possible cost and the fastest possible time. The satisfaction of the consumer is the SC's goal. When a company refers to a network, it signifies that they can conduct the same activity and engage in competition with one another. Depending on the issue and circumstance, each SC may contain a number of actors. (Chakuu *et al.*, 2019) divided the SC's financial participants into two distinct categories. The first one is Main actors, which includes the actors' buyer and provider. The second group of players are supportive actors, which also includes conventional banks, non-bank financial institutions (such as factoring companies and private equity investors), logistics service providers, and platform providers (such as fintech and IT companies). In addition, the SC refers to several concepts as financial instruments, including reverse factoring, warehouse financing, inventory financing, dynamic discounting, invoice discounting, and distribution financing. The green and sustainable aspects of the industry 5.0 can be considered in SCs concepts. A multi-stages SC with a supplier, manufacturer, remanufacturer, collector, retailer, and market was taken into consideration by (Wesana *et al.*, 2018) in a green SC. We can therefore hold to the notion that a SC typically consists of a supplier and a buyer, with the other components, stages, and actors able to perform in accordance with the problems (Aghsami *et al.*, 2023).

In the modern world, a business is more like a network of several partners than a lone autonomous organization. The managerial facets of a firm are much more vital due to internet usage and online relationships between parties. As a result, in today's cutthroat industries, a firm might be successful if the management is able to integrate the complex web of commercial relationships the organization has built. In addition, it is evident that the most prosperous businesses strive to grow their business relationships with both external suppliers and clients (De Lima & Seuring, 2023). Therefore, maintaining the supplier and customer relationship is crucial for expanding the business, especially in the cutthroat environment of today's market (Frazzon *et al.*, 2015). It is clear from the aforementioned words that SCM, is important in today's industry.

The three main definitions of SCM can be broken down into three categories: adhering to a managerial philosophy, applying a managerial philosophy, and a set of management processes (Croom *et al.*, 2000). SCM is an integrated philosophy to manage the complete flow of a distribution channel from the supplier to the end user, according to (Hicks *et al.*, 2000). The other definition of SCM is given in (Silva Filho & Neagu, 2000) as follows: The SCM strategy involves multiple firms between parties that needed trustworthy connections to share demand and sale data over the long term. According to (Azevedo & de Sousa, 2000), there are several

key distinctions between SCM and traditional industrial controls. 1) The SC is separated from such functionality pieces as manufacturing, warehousing, and distribution, and it functions as a single process. 2) SCM is a decision-making process that has a big impact on overall expenses and sales. 3) SCM makes an effort to balance the inventories using the last-resort strategy rather than the first. 4) Rather than interfaces, integrated pieces are necessary to notice. According to (Arji *et al.*, 2023), SCM is the management of a network of relationships within an organization and between interdependent organizations and business units. It consists of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances, and information from the original producer to the final customer with the benefits of adding value, and maximizing profitability.

Before any installation of SCM, two factors should be taken into account. The first one is the elements related to necessities, and the second one is impediments. To address such an issue, we have to refer to certain characteristics, structures, or approaches in SCM. This concept will be related to the SC typology. It gives organizations insights into the particular opportunities and challenges associated with each type, enabling them to develop effective strategies and improve their operations. Some common typologies include functional, agile, lean, and hybrid SCs. According to the particular focus and analysis criteria, various typologies can be used to categorize SCs. These concepts can target the conventional linear flow of materials and information with emphasizes on efficiency, cost reduction, and integration within each functional area of the SC. It can also discuss about flexibility and responsiveness to market demands and customer requirements, focuses on quickly adapting to changes in demand, product variety, and lead times. One of the most important criteria focuses on minimizing the environmental impact of SC operations. It involves integrating sustainable practices, such as reducing carbon emissions, optimizing energy consumption, promoting recycling, and using eco-friendly materials (Ming *et al.*, 2014).

In this thesis, we mostly give examples of pharmaceutical products for evaluating our system. In this concept typology, complex regulatory requirements, quality control, stringent documentation processes, product innovation, optimizing inventory management, reducing lead times, and diverse products are considered (Haraguchi *et al.*, 2023).

The pharmaceutical sector is the second-most lucrative sector in the world. Despite this, a minor hiccup in medicine manufacture or distribution can have a big impact on people's lives and the economics of entire societies. The pharmaceutical supply chains (PSCs) top priority is to supply the pharmaceuticals as a strategic good. Additionally, it is essential to find methods to reduce

PSC issues and boost end customer satisfaction (Tucker & Daskin, 2022). The quality of the pharmaceuticals, the timing of delivery, and the location are all carefully considered in this industry’s global network of associations, procedures, and activities (K. M. Iacocca & Mahar, 2019). The PSC has grown in scope and variety over the past few decades in response to the escalating demand for various pharmaceutical products and to meet related issues. By simplifying the exchange of information between participants and guaranteeing good traceability, Industry 5.0 tools can be very beneficial. In any case, it is crucial to ensure the preservation and security of important data as well as the appropriate level of response in the event of issues. (Hosseini Bamakan *et al.*, 2021) discussed Industry 5.0 in the PSC, ranging from waste management to digital identification and data integrity. Modeling the applications (to design/redesign and evaluate) and the PSC optimization framework are the two separated groups for evaluations and results ((Fatemi *et al.*, 2021) and (K. Iacocca *et al.*, 2022)). Based on the literature, the prerequisites, obstacles, and SCM implementation in the business are listed in Table 1-1 based on PSC point of view.

Table 1-1- Necessities factors and barriers to implement SCM in the business and industries

Necessities	Authors	Barriers	Authors
Workers health and safety issues	(Agarwal <i>et al.</i> , 2020)	Lack of knowledge	(S. A. R. Khan <i>et al.</i> , 2020)
Green products	(Sun <i>et al.</i> , 2022)	Lack of raw materials	
Policies and governmental sustainability laws	(J. Li <i>et al.</i> , 2020)	Funding and implementation costs	
Customer satisfaction	(Z. Tian <i>et al.</i> , 2021)	Technological barriers	
IS	(S. A. R. Khan <i>et al.</i> , 2020)	Poor infrastructures	
Effective inventory management	(Panda <i>et al.</i> , 2020)	Poor communications	
Effective role of supplier in the sustainability implementation		Lack of interest	
Sustainability project tracking and monitoring	(Yadav <i>et al.</i> , 2020)	Lack of standard IT systems	(Gahlot <i>et al.</i> , 2023)
Education and training	(Samper <i>et al.</i> , 2022)	Lack of technical skills	(Samper <i>et al.</i> , 2022)
Products design		Different between the customer demands and the business targets	

Regarding the necessities and barriers, it is possible to dig into the subject of SC with more detail and discover its importance and key elements in the next section.

1.3 Importance of supply chains for industries

Given the enormous increase in market competitiveness in recent years, SC has become an integral aspect of any organization as the primary link between suppliers and end customers (Kovač *et al.*, 2022). Each SC can play a decisive role and it can have several important key elements.

1.3.1 Supply chain critical roles in industries

The effective production, transportation, and delivery of goods and services to clients is made possible by the SCs, which are essential to many businesses. From (Yevu *et al.*, 2021), (Kurniawati & Cakravastia, 2023),(Yazdani *et al.*, 2022) ,and (Ponte *et al.*, 2022) SCs are in charge of various facets of businesses processes, including:

- Procurement: This position is in charge of locating and acquiring the raw materials, parts, and other products required for production.
- Operations: This position is in charge of managing the manufacturing process, which includes manufacturing activity planning, scheduling, and execution.
- Logistics: This position is in charge of overseeing product distribution and transportation, including shipping, warehousing, and inventory control.
- Customer service: This position is in charge of managing any difficulties or complaints that may emerge, as well as making sure that customers receive their products on time and in excellent shape.
- Quality assurance : Assuring that products adhere to quality standards and specifications as well as locating and resolving any flaws or problems falls.
- Sales and marketing: This position is in charge of making product promotions and sales to customers as well as obtaining customer feedback and SC process improvements.

Ultimately, each of these positions is crucial to making sure the SC runs smoothly and successfully, which eventually results in client happiness and corporate success. In the next section, we will discuss more about SC key elements.

1.3.2 Key elements

Based on (Deepu & Ravi, 2023), (Malacina & Teplov, 2022), (Mamoghli *et al.*, 2018), (Petronijevic *et al.*, 2022) and (A. A. Khan & Abonyi, 2022) the essential components of a SC usually consist of:

Firstly, the actors can be mentioned as follows:

- Suppliers: These organizations or people offer the parts or components required for the creation of goods or services.
- Manufacturers: These are the companies that use the components and raw materials that suppliers provide to create the completed products or services.
- Distributors: These companies assist in the transfer of completed goods from the producer to the final consumer or retailer.
- Retailers: These companies offer completed products for sale to consumers directly.
- Customers: The people or companies who pay for the final products or services.
- Transportation and logistics: This involves the movement of products through the SC's many phases as well as the control of inventory, storage, and delivery.

The related activities can be mentioned as follows:

- Information and communication technology (ICT): This category covers the application of technology to monitor and control the movement of information and commodities along the SC.
- Purchasing and sourcing: These processes entail finding and choosing suppliers, settling contracts, and maintaining connections with them.
- Inventory management: This entails controlling inventory levels to maximize output and cut expenses.
- Risk management is locating and controlling hazards that could have an effect on the SC, such as alterations in demand, supply, or transportation.

In the next section, we will discuss about the possibility of increasing the SC's performances.

1.3.3 Increase supply chain performances

According to (Patil *et al.*, 2023), when Industry 4.0 components are added to a traditional SC, it becomes a SC 4.0. Transparency, real-time data, proper demand management, enhanced collaboration with retailers and suppliers, and customization of the SC to meet market demands are the major methods for adopting the SC 4.0. (Qader *et al.*, 2022) noted that SC 4.0 aims to provide a more adaptable, quick, personalized, and effective SC in this respect. In order to clarify and explore the effect and application of Industry 4.0 in the context of SC, as well as identify the key indicators that would serve as the basis of Industry 4.0 in the context of SC. (Frederico *et al.*, 2019) defined SC 4.0 elements based on a global survey report. In this survey, the majority of experts concur that new technologies like cloud computing (82.7%), robotics (73.3%), BTs (60.1%), additive manufacturing (59.3%), the IoTs (78.7%), and big data (86%), have a favorable impact on the SC's performances. The performance improvement can be mentioned as on-time delivery, quality, responsiveness, cost-effectiveness. Improving the performance of the SC requires clear communication, collaboration, and a mutual understanding of the goals and expectations. Aligning these performances towards common objectives, such as cost reduction, responsiveness, and customer satisfaction, can lead to significant improvements in overall SC performance (Kankam *et al.*, 2023).

Many researchers have used mathematical techniques to include Industry 4.0 components in the SC. For the reverse SC problem in the waste electric and electronic equipment business, for instance, (S. Liu *et al.*, 2018) offered an IoT-based solution in which the inventory can be tracked using sensors. To demonstrate the effect of BT on a logistics system, (Dolgui *et al.*, 2020) used an event-driven dynamic method. They made an effort to strike a balance between contract prices and SC lead times. Big data was included by (Gholizadeh *et al.*, 2020) while building a SC with hybrid uncertainty while taking into account the pillars of sustainable development. Besides, all of the mentioned transformation, will impacts the decision making in the SCM perspectives (Nurhayati *et al.*, 2023).

To improve the SC performances regarding the newly implemented transformation, it is necessary to consider decision-making approaches regarding all elements of SC. Regarding (Kumar & Sharma, 2021), before all the decision-making approaches in a SC, it is important to implement the best evolutionary industrial features to the system regarding the financial threshold of the global system. Therefore, in the next section, we will discuss more about the SC decision-making tools.

1.4 Decision making perspectives in supply chains

Decision-making approaches are mainly responsible for the different types of flows. The flows consist of material, informational, and financial ones. Regarding the material flows, it is necessary to formulate the network and solve the formulation based on different solving approaches. Regarding the information flow, dealing with data and using different tools for managing data can play a critical role. Regarding financial flows, it has to have a pre-defined deal between entities to take the decision. At the end, it is important to note that there are possibilities to integrate all the mentioned aspects and discuss tools to automate the process while increasing the security of the system.

1.4.1 Material flows management

The planning, implementation, and control of the actual physical transportation of goods and materials from suppliers to customers is a crucial component of SCM. By reducing costs and optimizing efficiency, material flow management makes sure that the appropriate items are delivered to the right place at the right time and in the right condition (Jamalnia *et al.*, 2023). Collaboration and coordination between different SC participants, such as suppliers, manufacturers, distributors, retailers, and customers, are necessary for effective material flows management. In order to establish a smooth and effective flow of goods, it entails the integration of several operations including transportation, inventory management, and warehouse management. As it entails moving commodities and resources from one place to another, transportation is a crucial component of managing material flows (Seuring *et al.*, 2022). The method of transportation chosen is determined by a number of elements, including the distance between the places, the type of items being transported, and the associated costs. Routes must be carefully planned, vehicles must be used to their fullest potential, and cargo must be tracked in real time to assure prompt delivery. Another essential part of material flow management is inventory management, which entails controlling the stock of products and commodities to guarantee their availability. The costs of stock outs and inventory keeping must be balanced for effective inventory management. To maximize inventory levels, it is necessary to employ techniques like forecasting, demand planning, and safety stock levels (Moshood *et al.*, 2021).

Managing material flows is a crucial component of SCM that entails organizing, carrying out, and overseeing the actual movement of products and materials. It encompasses tasks like transportation, inventory management, and warehouse management and calls for cooperation and coordination amongst different SC actors. For the SC to operate efficiently, expenses must be kept to a minimum, and timely delivery of items must be guaranteed (Farooque *et al.*, 2019).

Therefore, several approaches can exist toward material flows management and solving its issues.

1.4.1.1 Resolution approaches

The control of the physical system for material flows can be done in several ways with different tools. Our approach is mainly dedicated to the distribution of the products in a more optimistic way through the upstream and downstream of the SC for the controlling perspectives. Different strategies, such as pull or push systems, base stock policies (Hennequin *et al.*, 2022), and so on, exist to control the flows. In our case, a mathematical formulation is supporting our strategy that can be suitable to achieve different objectives such as service level, sustainability and so on.

The mathematical formulations and simulations are one of the most popular methods for managing material flows, according to academics (Oliveira *et al.*, 2019) and (Van Engeland *et al.*, 2020). Linear programming, integer programming, mixed-integer programming (MIP), nonlinear programming, stochastic programming, network flow models, queueing theory, and other mathematical formulations are utilized in SC optimization. There are several methods for solving the models. The formulations may be solved using heuristic methods, exact methods, simulations, and game theories, either in a single-objective or multi-objective approach (Eskandarpour *et al.*, 2015). Examples of such methods are provided in the section.

1.4.1.2 Problem formulations and solving approaches

In the context of SC many problem formulations and solving approaches exist. Mathematical programming is frequently used because it enables the integration of numerous behavioral traits under varied circumstances (environmentally, technologically, policies, and so on). (Ahmad *et al.*, 2021) suggested a mixed-integer multi-objective modeling for the mathematical programming paradigm. They employed three alternative methods to solve the issue: the fuzzy approach, the α -aggregation operator, and the minimum sum bounded operator. They claimed that by choosing the best production strategy, distribution tactics, and disposal facilities in a SC, it is possible to create a network that is both environmentally beneficial and socially acceptable. The main goals of the mathematical formulation by (Franco & Alfonso-Lizarazo, 2020) were to reduce total expenses and expired medications. They choose the appropriate deadline for acquiring the Pareto solutions. (Kargar *et al.*, 2020) proposed a multi-objective mathematical formulation to reduce costs, increase treatment centers' overall technology scores, and reduce the number of storage facilities overall. Finding potential managerial solutions for decision-makers is made possible by solving mathematical formulations;

nevertheless, the reactivity is not easily integrated into the mathematical formulations. This reactivity may be in response to the modifications that the parties have agreed upon or in response to other potential circumstances (Kim *et al.*, 2019). As a result, a tool that can adjust to the many suggestions made by system participants as well as be flexible enough to change and determine the time of decision-making is required. One instrument that has this power is the smart contract, which can effectively enable system reactivity (Su *et al.*, 2020). In this regard, it is important to focus more on simulation and optimization perspectives.

There are numerous ways to focus simulation and SC network optimization. The mathematical formulations are one of the most popular ones according to scholars (Settanni *et al.*, 2017) and (Ivanov, 2010). (Kalantari *et al.*, 2023) develops an optimization method using a multi-objective model that takes advantage of the ability of drivers to disseminate information in the procurement of transportation services. The goals are to balance time, cost, and driver suitability when assigning shipping orders to drivers. The interplay between drivers is highlighted to demonstrate cooperation based on a mathematical concept. (Vaziri *et al.*, 2019) offers a vehicle routing problem with fair carrier collaboration that considers segmented multi-pickup and delivery services in order to better serve clients. A MIP model is created to optimize the overall profit and the fair distribution of profit among the carriers by accounting for the decrease in trip time. A genetic algorithm is used to solve the given problem. The sensitivity analysis's findings indicate that increasing the fairness collaboration coefficient between the carriers may lower overall profit. (J. Zhang & Li, 2023) proposes an optimization framework for a network of cooperative vehicle drones that distributes goods and includes a method for cooperative vehicle drones, location selection, perishable goods, and epidemic impact. Additionally, it is intended to serve as a bi-objective mathematical framework for reducing both total costs and value losses connected with product distribution. An efficient two-phase hybrid heuristic solution based on extended Non-dominated sorting Genetic Algorithm-II and enhanced K-means Clustering is provided to address the investigated optimization problem. For a collaborative SC in the medical equipment manufacturing industry, (Bhalaji *et al.*, 2022) provides a notion of integrated decision-making methodology based on the Delphi method and the grey-based decision making trial and evaluation laboratory technique. By maximizing, planning, monitoring, and managing SCs in real-time, they seek to illustrate the risks connected with applying cooperation tactics in developing nations.

In the next section, we will discuss about the importance of financial flows inside the SC systems.

1.4.2 Financial flows

The movement of money or other financial resources among the various SC participants is referred to as financial flow. Customers, manufacturers, distributors, retailers, and suppliers all fall under this category. Financial flow in a typical SC starts when a customer pays a retailer for a good or service. The distributor is subsequently compensated with this money by the store, who then pays the producer. After that, the producer reimburses its suppliers for the raw materials required to make the product. The financial flow is crucial to SCM because it makes sure that everyone engaged is compensated for their contributions to the chain. A more effective SC might result in quicker delivery times and greater coordination thanks to more efficient money flow. It can also aid in lowering the danger of monetary problems, such as late or non-payment, which can ruin business ties and disrupt the SC (Pfohl & Gomm, 2009).

In the next section, we will discuss about the importance of information flows.

1.4.3 Information flows

Of course, in each system, many kind of data exist that can be shared or not. However, we also have to consider the physical system that we use to share data. Therefore, deciding and investing on such tool can be a challenge and it can bring the importance of the collaborative approaches in the system.

Each actor can use SC to exchange their information. A key component of the SC and one of the most important resources in the chain is information sharing (IS). For the SC integration to be effective and efficient, all parties should manage their IT, and it is essential that they all share accurate, comprehensive, and relevant information (Viegas *et al.*, 2019). To achieve the IS goal: the implementation of an effective, efficient, and reliable IS in the SC is crucial. According to (Bodendorf & Franke, 2022), these aspects are: 1) Why is information shared? 2) What information should we share? 3) How the information should share? 4) What are Prerequisites, barriers and driver?

The answer to the first question is that the SC performs better as a result of the IS. Better benefits forecasting and inventory level reduction are possible in the intermediate future. IS benefits include making collaboration for long-term relationships easier (Tiwari *et al.*, 2023). Cost savings and risk mitigation for the SC are potential benefits of the IS (Partanen *et al.*, 2020). The second question's response is that each partner must alter the information for sharing to other portions because IS is dependent on the SC's context. For instance, information regarding operations, performances, and finances can be advantageous, cost-effective, and increase

responsiveness (Guan *et al.*, 2020). The internet and various other instruments from today's society may be used to distribute IS, which is the answer to questions three and four. Technology infrastructure and financial issues may be the constraints and precondition.

The main paradigms of the IS are represented by dealing with data, useful tools and result executions.

1.4.3.1 Dealing with data

The management of data in SC is a challenging undertaking, but it is crucial to preparing the network for critical decision-making. Collaboration with partners is required in order to reach a consensus on the level of data sharing before the data is collected, cleaned, organized, and analyzed. In this way, the use of technology that can share and analyze data effectively can be increased (Ketzenberg *et al.*, 2023). Another crucial factor can be improved through continuous monitoring and improvement. It is crucial to routinely check the SC data and make any necessary adjustments because it is continually changing. Actors and decision-makers in SC can use this to stay on top of prospective issues and spot on-time chances for progress. Making wise decisions and optimizing SC processes ultimately depend on good data management. Utilizing the power of data to increase efficiency, lower costs, and increase customer satisfaction is achievable with the help of practical tools and techniques (Jonkman *et al.*, 2022). Therefore, in the next section we will discuss more about the useful tools in SC data sharing.

1.4.3.2 Useful tools

Some common tools such as Electronic data interchange (EDI), Enterprise resource planning (ERP), Radio frequency identification (RFID), and Collaborative Planning exist in the SCM concepts (Addo-Tenkorang & Helo, 2016). Between all the tools and technologies, blockchain technology (BT) has gained considerable attention from industries, scholars, and governors. BT can be considered a public or private shared ledger technology for peer-to-peer (P2P) network digital transactions among all vested parties and participants. It is a group of distributed data blocks that are linked together using cryptographic addresses, with the first block being referred to as the genesis block. Data exchange and traceability in IS systems are two of the many benefits that BT offers (Hu *et al.*, 2023). Although it has limitations, merging the BT and IoT systems could lessen the issue of data sharing and improve the efficiency of the IT system (Ashraf & Heavey, 2023). The IoT can include all information-sharing devices like mobile phones, QR tags, and other items that can be used manually or automatically. By enhancing collaborative approaches, on the other hand, ensuring regulatory compliance, and providing a decentralized framework for exchanging health records and data, BT can have a huge impact

on the SCM. In this manner, important data might be stored in BT utilizing a hashing method in a decentralized manner. The overall performance of the SCs could be significantly impacted by using such data for collaborative methods regarding actors' preferences (Prajapati *et al.*, 2022). For SCM activities, however, it is necessary to include a decision-maker who will consider the facts gathered. This part of the system can be controlled by the execution methods. Though all the information technologies can help the decision makers, they do not have the ability to take the decisions and execute final results (Kordestani *et al.*, 2023). Therefore, in the next section, we will discuss more about the results execution methods.

1.4.3.3 Results executions

Based on using BT, the scripts are executable on top of the platform using all the gathered information for implementing a decision. This term is called a smart contract that allows parties to encode business roles as various legal agreements. Each party according to their own expectations offers these agreements to the system.

One of the first definitions of the smart contract by (Lavery, 1999) which came long before Bitcoin and BT is “*a computerized transaction protocol that executes the terms of a contract.*” Besides, he mentions that it can reduce the necessity of trust between the parts of the transaction. Moreover, a smart contract can have the capability of creating mechanisms for online paying rather than using cash. The other definition of smart contracts by (Delmolino *et al.*, 2016) is “*Smart contracts are computer protocols designed to oversee, enforce, or verify performances or negotiations of contracts.*” Regarding that, there will be no third party during all transactions in the smart contract, in addition to the irreversibility and documentation of all records, these protocols can prove their reliability and credibility. Moreover, it can create a conducive environment for users during the phase of the smart contract (Almasoud *et al.*, 2020).

With the capability of the secure transfer of value peer-to-peer with the internet connection between on-chain and off-chain parties, BT can create the requisites for the smart contract implementation in the wide ranges in several scenarios. When the smart contract has met a condition, BT will execute the code at the moment, and no external entity can affect the contract and output. Besides, each party can have access to BT, so there is no need for trust. Besides, other time-consuming matters will be saved because all the parties can see what is going on through the contract. The smart contract can reduce the need for terms and conditions as well. Moreover, digital signatures in the smart contracts in the BT can bring transparency cause the transaction senders is the one who triggered the smart contract (Ante, 2021).

Smart contracts are useful in several aspects of production and SCM through BT. (Dolgui *et al.*, 2020) implemented a smart contract on the flow shop scheduling. The decision making of the scheduling problem according to the smart has three roles: 1) a machine signals the completion of an operation under processing, 2) a product signals the completion of the processing of an operation on a machine, and there is at least one machine either in the state waiting or finished and 3) there are at least one machine and one operation in the state waiting. Rely on these three inputs the proposed smart contract can make decisions. In SC, it is possible to properly implement the BT in the whole SC for recording off-chain and on-chain transactions. Rely on Smart contracts, the transaction and enforcement costs can be decreased by realizing trackable and irreversible transactions. Besides, adding a self-enforcing feature to the industry 4.0 characteristic can be completely compatible and helpful for the SC performance. Therefore, the SC starts the transactions between SC parties and optimize the whole SC (Prause, 2019). (F. Tian, 2017) identifies the challenges of implementing the BT in the food SC. They were able to increase safety, improve the efficiency and transparency of food by introducing a decentralized traceability based system based on IoT and BT. Any party can add the condition to create a smart contract, and when all the parties accept their condition and contract, it will be fixed and unchangeable. Most of the time, the decision to implement BT and investment for that kind of technology can be challenging for the business owners because it can be costly and time-consuming for participants. According to (De Giovanni, 2020), the BT's asset is not a problem because in their SC, and it is possible to recover such investment by increasing the number of participants in the long-term. Besides, smart wholesale price and smart revenue sharing contract for enhancing coordinate firms' relationships can be useful in the field of SC. BT main concern in the agri-food SC are: 1) identify essential elements that affect the BT in an agri-food SC. 2) The level of adoption of several BT factors in the SC. 3) Finding the highest level of utility based on the users' rating. In addition, the smart contract can be added to help parties to add their preferences through the whole chain (Saurabh & Dey, 2021).

Regarding all the mentioned literature, it is probable to discover more about the possible transformations in the SC concepts.

1.4.4 Possible transformations

Regarding the different types of flow that exist in the SC, a level of transformation and entering the new era are necessary to automate the whole process and increase the security of the whole system.

1.4.4.1 Automation

SC automation is the process of streamlining and optimizing the movement of information, money, and commodities across channels using a variety of technologies and software tools. This can encompass all automated order processing, inventory management, shipping, and delivery procedures (S. Liu *et al.*, 2022). The main components to increase the level of automation can be IoT like sensors and devices that can track the location and status of goods and materials across the SC, AI like machine learning algorithms that can analyze data and forecast demand, stock levels, and shipping times, and BT to secure digital ledger that can track and confirm transactions across the SC. Businesses may decrease costs, enhance productivity, and boost customer satisfaction by automating a variety of SC activities. However, putting SC automation into place can also mean making large upfront expenditures in infrastructure and technology, as well as continuous maintenance and updates (Narayanaswami *et al.*, 2019).

SC processes can be automated using BT. Through smart contracts, which are self-executing contracts in which the terms of the agreement between the buyer and seller are directly encoded into lines of code. Smart contracts, for instance, may be used to automatically initiate payments when products are delivered to the final customer. Because middlemen are no longer required, the SC process is sped up and expenses are decreased. As a result, it can be said that BT can be a means of achieving automation and increasing security (H. Zhang *et al.*, 2019).

1.4.4.2 Traceability

Traceability is a critical aspect of SC, allowing businesses and consumers to track the journey of products from their origin to the end consumer. With the advancement of technology, BT has emerged as a powerful tool for enhancing traceability in SCs. BT, often associated with cryptocurrencies like Bitcoin, is a distributed ledger technology that enables the secure and transparent recording of transactions across multiple parties. Implementing BT-based traceability in SCs brings numerous benefits. They can be mentioned as end-to-end visibility, enhanced product authentication, quality control, and compliance (Rao *et al.*, 2023). By discussing traceability, the room is open to discussing transparency.

1.4.4.3 Transparency

The lack of transparency is one of the major problems with SCM. The transportation of commodities from the source to the final customer is difficult to trace because of the participation of several intermediaries. By offering a safe and open platform where all parties can follow the flow of products in real-time, BT provides a solution to this issue. Every transaction on the BT is permanently and impenetrably recorded, making it impossible for

anybody to change the information. By doing this, you can increase transparency, lower the possibility of fraud, and guarantee that everyone working on the SC is on the same page. Traditional SCs are vulnerable to fraud, hacking, and forgery, which can cause firms to lose a lot of money. Every transaction with BT is encrypted and network-validated, making it impossible for anybody to change or tamper with the data. By doing this, the SC's integrity is guaranteed, and companies are shielded from possible fraud-related damages (Hosseini Bamakan *et al.*, 2021).

Combining all aspects of digitalization and creating an integrated system that is interconnected is one of the crucial requirements for attaining security. To achieve this, we will talk more about SC digitization and use cases in the next section.

1.5 Supply chain digitalization and smart technologies

In our case, smartness refers to the ability of an object or system to perform specific tasks or functions in an efficient and effective manner. It often implies the application of technology or automation to enhance performance and provide convenience or ease of use (Yi *et al.*, 2023).

Companies have embraced SC digitization and smart technology more often in recent years to increase efficiency, transparency, and responsiveness throughout the whole SC. In this section, we go into further detail regarding these kind of technologies and how they contribute to the system's sustainability. Finally, we suggest the SCs types that are most likely to develop these technologies.

1.5.1 Digital technologies

The use of digital tools like IoT, big data analytics, artificial intelligence, and BT to digitize and automate the SC process is referred to as technologies. SC digitization offers enhanced visibility and transparency, which is one of its key advantages. Companies can follow the movement of items and keep an eye on their condition in real-time with the use of IoT sensors. Big data analytics may be used to examine this data in order to spot trends, anticipate probable hiccups, and enhance the SC procedure. Artificial intelligence may be used to automate repetitive operations, make data-driven choices, and increase forecasting accuracy. A decentralized and secure method for managing the SC is also being built using BT (Pan *et al.*, 2021). Overall, businesses must accept the digitization of the SC if they want to stay competitive in today's market. Companies may increase productivity, save expenses, enhance customer service, and achieve better long-term outcomes by utilizing smart technology

(Broccardo *et al.*, 2023). We will discuss more about sustainability and its enablers in the next section.

1.5.2 Toward sustainability

According to recent world changes and issues, including socio-environmental concerns, global warming, and climate change, the idea of sustainability has drawn increased attention. Sustainability is a driving force in 21st-century industries to protect the world from abrupt and harsh changes that may affect human life on the globe in the future. A sustainable production system is described as *"the idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not harm the environment"* by the Cambridge Dictionary. Sustainability *"is not an absolute, independent of human conceptual frameworks,"* according to (Allen & Hoekstra, n.d.). Instead, it is constantly positioned within the framework of choices regarding the spatiotemporal scale and the type of system to be sustained. Many managers and industries attempt to integrate sustainability issues into their SCs due to the relevance of sustainability (Seuring & Müller, 2008). Green products are one of the most important requirements for a future company; yet, the market for these items is not yet prosperous, but it has remarkable potential. Business owners attempt to change their SC from dirty ones toward sustainability as a result. Reduced fossil fuel use, the use of environmentally friendly products, adding remanufacturing process, and increased power and energy consumption are all necessary for sustainable development (Goepf *et al.*, 2014).

Focus on sustainability and digitalization has increased recently as two interconnected challenges that are critical for the future of our planet. While digitalization refers to the use of digital technologies to enhance and improve numerous parts of our life, sustainability refers to the capacity to meet our current demands without compromising the capacity of future generations to meet their own requirements (G. Singh *et al.*, 2023).

Reducing the environmental impact of diverse sectors and activities is one of the key ways that digitalization may promote sustainability. Digital technology, for instance, can facilitate remote work, which can lessen the need for commuting and, as a result, minimize carbon emissions. Digital technologies can also be employed in a variety of sectors, including manufacturing and agriculture, to improve energy use and lower waste (Kumar Jena & Singhal, 2023). Smart grids, for instance, can be used to regulate and lower energy consumption, while precision farming can assist farmers in making the most use of resources like water and fertilizer. Therefore, sustainability is a kind of new terms with high demand of new technologies for automation and security.

Among all types of SC, those with the following characteristics may be more in demand for new technologies. It could be referred from (Ramirez Lopez *et al.*, 2022) and (Abdallah & Nizamuddin, 2023) as follows:

- SC with responsibility for tracking the movement of products from the manufacturer to the end user in order to prevent counterfeiting and diversion of products and ensure that they are used for their intended purposes. This may be more important for the vital and costly products.
- SC with need to automate many of the processes that are done by hand now, like keeping track of inventory and managing transactions. This can reduce the cost and time required to move products through the SC and, ultimately, improve outcomes. If the final customer is a patient, it can be more important.
- SC that needs efficient security for the products by providing a tamper-proof record of all transactions. This can help prevent theft and ensure that products are stored and transported under the appropriate conditions to maintain their effectiveness.

PSCs are one of the most needed types of SC for BT and new technologies, according to this future. It is a complex process that involves the manufacture, transportation, storage, and distribution of drugs and is fraught with difficulties such as counterfeiting, diversion, theft, and product recalls.

1.6 Research gaps

In this section, the main research gaps will be discussed. Table 1-2 presents a summary of related works on data providers and approaches in SC.

Regarding the literature background, it is possible to introduce several research gaps which we will try to answer in the next chapters. Firstly, it is a gap to make use of the interests of transparent and traceable tools in a SC system and discuss their impacts on the actors' decision-making approaches. Then, it is possible to introduce an algorithmic tool that can be at the top of system for proposing possible solutions for the SC actors. In this regard, the presented algorithmic tool can play the role of a third-party remover. Having the possibility of defining the action toward events prior all the occurrences will be interesting as well. For this approach,

it is necessary to well define the problems. After all, evaluating the performance of the SC actors based on different criteria in a dynamic perspective could be a gap that is never discussed in the literature.

It is important to mention that the initiators of the smart contracts can be the suppliers, manufacturers, and warehouses in a SC. They are the decision-makers of the systems who make decisions based on the smart contract propositions.

To cope with the mentioned scientific gaps we proposed several solutions. Firstly, we propose a SC network regarding the actors' perspectives and integrating data sharing approaches using BT and IoT as a secure and trustable sourcing of data. Then we introduce a new approach for smart contracts by formalizing the scripts in a MIP form and distinguishing its roles as a decision maker assistance and third party remover. In our smart contract algorithmic approaches we define different possible reactions based on different timing. We evaluate their impacts on the final objectives of the system and to improve the algorithm, we propose a dynamic tool in the smart contract to update and evaluate the performance of the suppliers in the SC regarding the real world cases and data. Finally, we introduce collaboration strategies between the SC actors in the presence of BT, highlighting the different types of collaborations based on material and information flows and automating the collaborative procedures through the presented smart contract.

Table 1-2- Literature background on data providers and approaches in SC

References	Data collection			Objectives					Industry 5.0 technologies			SC characteristics		Resolution approach
	Offline	Online										Multiple products type	Multiple periods	
		Fixed frequency	Event-based	Total Cost	Delivery time	Supplier qualifications	Service level	defective removal	BT	IoT	Smart contract			
(S. K. Singh & Goh, 2019)	✓			✓								✓	✓	Multi-objective / gamma-connective technique and the minimum bounded sum operator technique
(Fatemi <i>et al.</i> , 2021)	✓			✓			✓	✓				✓		Multi-objective Genetic algorithm/ LP-metric
(Ahmad <i>et al.</i> , 2021)	✓			✓				✓				✓	✓	Multi-objective / Kintro
(Franco & Alfonso-Lizarazo, 2020)	✓			✓			✓					✓		Single-objective / Xpress-MP
(Yazdani <i>et al.</i> , 2021)	✓	✓		✓				✓			✓	✓	✓	Multi-objective/ CPLEX
(Hasan <i>et al.</i> , 2019)			✓		✓			✓	✓	✓	✓		✓	Remix IDE
(De Giovanni, 2020)			✓	✓					✓		✓		✓	Multi-objective / Game theory
(Dolgui <i>et al.</i> , 2020)			✓	✓			✓		✓	✓	✓	✓	✓	Single-objective / Business process model and notation
(Stević <i>et al.</i> , 2020)	✓			✓		✓						✓	✓	Compromise Solution (MARCOS) method
(X. Liu <i>et al.</i> , 2021)			✓						✓	✓	✓			Hyperledger fabric
(D. Agrawal <i>et al.</i> , 2022)			✓	✓					✓	✓		✓		Multi-objective / SOLO
This thesis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Multi-objective / CPLEX

1.7 Conclusion

In this chapter, we have presented a synthesis of the different paradigms of supply chains (SCs) in business and the new digital technologies to contextualize our work. Particular attention was paid to digitalization in the concept of supply chain management (SCM) and more specifically on pharmaceutical supply chain (PSC). Among all the solutions that can help SCM, we focused on the applications of blockchain technology (BT), Internet of things (IoT), and smart contracts. These concepts are important factors for the future development of SC in material, information, and financial flows and integrating automation and security in the whole network. We presented research gaps based on findings in these contexts, and we introduced several possible contributions that can integrate the benefits of new technologies into the SCM. Our main positions to find solutions will be dedicated to the distribution approaches, and then we will try to consider various problematic situations that are never discussed and bring up solutions that can be helpful for the decision-making process. The following chapter will discuss the presented SC, formulate the mixed integer programming (MIP) problem, and present different timings based on the smart contract's reaction to an event in the SC.

Chapter 2 is dedicated to present a physical system and an integrated system for an adaptable distribution process. Chapter 3 discussed the roles of dynamic supplier selection in the distribution process of the presented system, and Chapter 4 highlighted the importance of collaborations and interactions between actors for better distribution process of the presented system.

Chapter 2 Supply chain distribution adaptability

Transparent, trustable, and fair distribution of products is a critical task for most communities. With the emergence of Industry 5.0 tools and their applications, it is more expected to reach an adaptive and reactive management system for supply chains. This system may meet society's expectations from a distribution process. In this chapter, a smart contract is proposed to help decision-makers to cope with distribution process challenges. The smart contract can recover required data by using connected objects (sensors, traceability tools, etc.) to be more reactive and make use of blockchain technology to bring transparency and trust between actors. Besides, the presented smart contract help the decision-makers to define the moments of acting toward the possible events and problems in the system prior to occurrences. The presented smart contract use multi-objective approach to minimize cost, maximize purchases from the qualified supplier, and minimize the products' expected delivery time. Finally, the results are presented and compared in terms of economic gains and service rate.

2.1 Introduction

Industry 5.0 technologies can have various positive impacts on supply chain management (SCM) as the development of the system's functioning to reach better performance, end-to-end connectivity, lower cost, and higher service quality. As presented in the previous chapter, among the different involved technologies, blockchain technology (BT) and Internet of things (IoT) systems are applicable in various Industry 5.0 applications and can effectively overcome their challenges (Shah *et al.*, 2022). IoT systems may be devices that monitor the temperature of vehicles, Radio-Frequency Identification RFID tags, sensors, barcodes, GPS, and so on to bring traceability to the system. It also could be the quality controller of the production lines and be used in the smart drug containers (Ben-Daya *et al.*, 2019). Although using an IoT system can be beneficial, some drawbacks related to IoT devices should be taken into consideration. They can be vulnerable to hacking and manipulation, and some devices' information-sharing capability is not developed. These issues bring the idea of combining the IoT systems with an autonomous and trusted network (Pournader *et al.*, 2020). BT, as a distributed peer-to-peer network, is immutable and up-to-date only through peer consensus. This feature makes it secure, invulnerable to hackers, and hard to change. Hash performs as a digital fingerprint in each block, and its uniqueness brings security and encrypted data. Because each block has the last block's hash, all the blocks are joined through their hashes. Such a connected system can bring trust between parties without needing a third party, decentralization, transparency, and immutability (J. Liu *et al.*, 2021). BT associated with IoTs can provide secure, reliable, and traceable data; however, they cannot take the decision between different stages of a SC in a larger scale by using the provided data (Pranto *et al.*, 2022). Therefore, it is necessary to use a decision-making tool that can manage different types of flows (information, material, and financial) in SC by using the data coming from BT and IoTs.

Smart contracts are protocols and computerized codes permitting the management of transactions digitally. BT-backed smart contracts have a contract hash and a contract address to store data and maintain security in BT. The smart contract's main legacy in systems is granting trust between various firms and removing a third party as a decision-maker. With the help of smart contracts in the SC, all the actors could have a clearer vision of the market's demand and make better decisions (T. K. Agrawal *et al.*, 2022). The integrated system of BT, IoT, and smart contract can benefit different types of supply chains (SCs), such as pharmaceutical, food, and so on.

Based on the literature in Chapter 1, it is important to note that we will focus on the optimal distribution of products. Our strategy can mainly focus on the smart contract's several uses with the help of data providers in the top of the information and material system.

Using industry 5.0 technologies paves the way for capturing data at the predefined moments. First, the data can be received at the moment that an event occurs in a physical system by using the IT technologies. However, the time at which a reaction in the physical system takes place in relation to the data provided may be different from the time of their arrival. Then, it could be interesting to select the decision-making frequency approach setting to the decision-makers. Furthermore, it seems promising to consider smart contracts (as computerized contracts with several actors' deals) as a multi-objective optimization scheme, where different objectives and SC characteristics are pursued. It is tried to obtain the cost, delivery time, supplier qualification, service level, and defective removal. It is important to mention that the smart contract gives the possible actions suggestions for better management of different flows (material, information, and financial) to the decision-makers, who can be the suppliers, manufacturers, warehousemen, and so on (defined in Chapter 1).

The main innovations of this chapter can be mentioned as follows:

- Give the possibility of pre-defining the moment of actions toward events to the decision-makers by proposing a smart contract.
- Using an integrated system in the form of mixed integer programming (MIP) to optimize customer satisfactions

In the next section, the SC main system, consisting of physical system and an integrated system is presented. Section 3 introduces different information retrievals and section 4 proposes the mathematical formulation. Section 5 highlights the numerical results. Section 6 presents managerial insights. Section 8 concludes the chapter and presents future perspectives.

2.2 System description

Figure 2-1 represents the graphical abstract of the proposed SC with the integrated system.

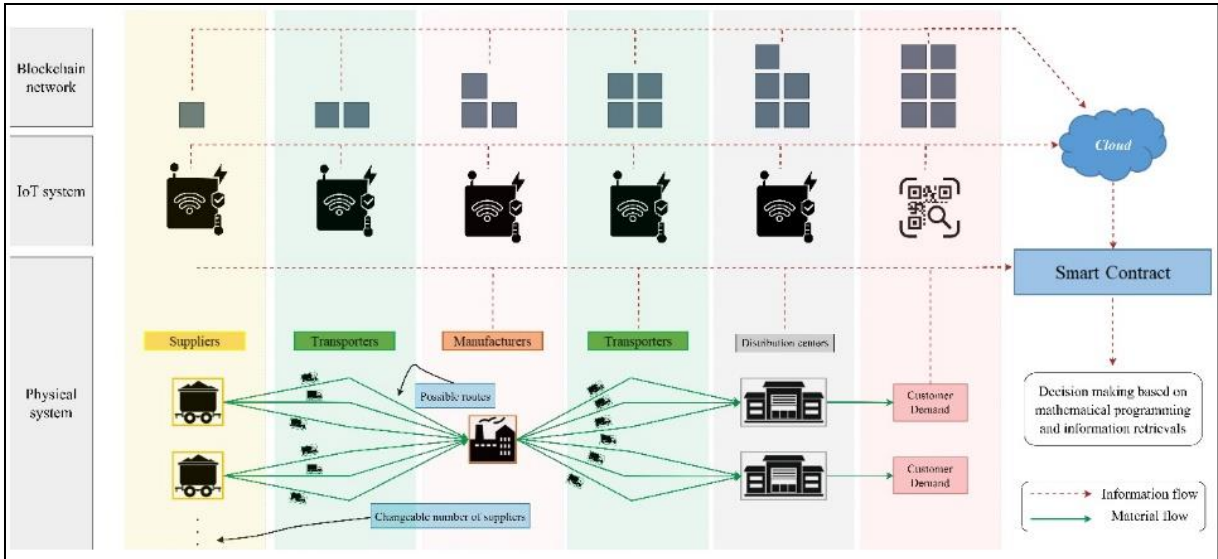


Figure 2-1- Graphical abstract of the proposed SC with the integrated system

In two different sub-section, the physical system and the integrated system will be discussed.

2.2.1 Supply chain physical system

A SC with five main actors is considered. Suppliers, manufacturers, warehouses, transporters, and customers are the actors in the proposed system. The manufacturers select their suppliers at the beginning of each period, and the selected suppliers are responsible for transferring the raw materials. Each manufacturer has its own assigned suppliers, and several manufacturers can have the same assigned suppliers. The location and number of manufacturers are fixed. The final products are sent from the manufacturers to the warehouses by transporters. There are multiple routes to achieve a warehouse from a manufacturer and achieve the manufacturers from the suppliers for each transporter. The most important factors for the transporters are timing and conditions during the transportation. The SC needs reliable transportation for different types of products because the final products can perish if they are not in a specific condition. The final products are stored in the warehouses to answer the demand. The perished and not qualified products should remove from each part of the SC as wastes. Besides, they are numerous important notes related to the presented SC that are mentioned below.

- During the production of the products, they should be under control in the manufacturing process, and they have to be produced according to the specific condition. Before sending products from manufacturers and after receiving products in the warehouses, the products should be examined. They should respect the state that the buyer and seller (warehouses and manufacturers) previously dealt with. Besides, during transportation, several necessary conditions for the products should be monitored all the

time. Based on literature, the leading indicators are the temperature of the shipping vehicles, sanitation, humidity, lighting, ventilation, segregation, and atmosphere.

- Final customers should have access to accurate and reliable data related to the products. It means that the customer should be aware of the suppliers' raw material used in the products, the production quality level, transportation aspect, and other steps up to the time he purchased the product. This kind of information will elevate the customer's trust in the product's originality and lead to a better evaluation of the final products from his side.
- The perished and damaged products during production, transportation, and warehousing should be eliminated from the SC's material flow as soon as possible and should not be transferred toward the demand zones.

To overcome such challenges, an integrated system of BT, IoT, and smart contracts will be discussed in detail in the next subsection. The approaches toward the integrated system stay same in all other chapters.

2.2.2 Integrated system of data sharing

As a peer-to-peer network, BT records and shares all transactions through blocks. Among the advantages of BT, those that interest us are the data transparency and traceability (Singh Yadav *et al.*, 2021). For example, new suppliers and transporters will be the new miners of the proposed BT in each period, and their transaction(s) will be recorded through the blocks. In the proposed SC, the role of the BT is to provide trusted and more accurate data for the system. To make the role of BT clearer and more adapted according to the introduced physical system, the links between BT and the physical system and the terms of BT are defined below.

- As shown in Figure 2-1, each actor can be considered as a miner in the network and the actor's actions will be considered as the transactions inside the BT.
- The transactions consist of different types of information from material, financial, and information flows coming from the physical system. All the actions consist of moving materials, transforming materials and conveying the final products toward customers, and all the occurrences that would happen on the products during transportations are considered as the transactions arising from the material flow. The information about the state of the products, demand prediction, and events (which will be completely defined in the next sub-section) is defined as the transactions that come to the BT from the information flows.

By using BT associated with IoT, the final customer can have access to data and traceability of products by using identification tools (QR code, barcodes, NFC, and RFID (Paul *et al.*, 2022)). This access can pave the way for receiving better feedback and comments about the products from the customers.

Besides, as mentioned in the previous chapter, BT with IoT can only take the decision in few actions related to miners. Therefore, an off-chain decision-maker tool called the smart contract is used to overcome the financial and material flow decision-making challenges more quickly and responsively (Aparecido Petroni *et al.*, 2020). The main approaches of this thesis toward the smart contract is presented in Figure 2-2 and it can be mentioned below

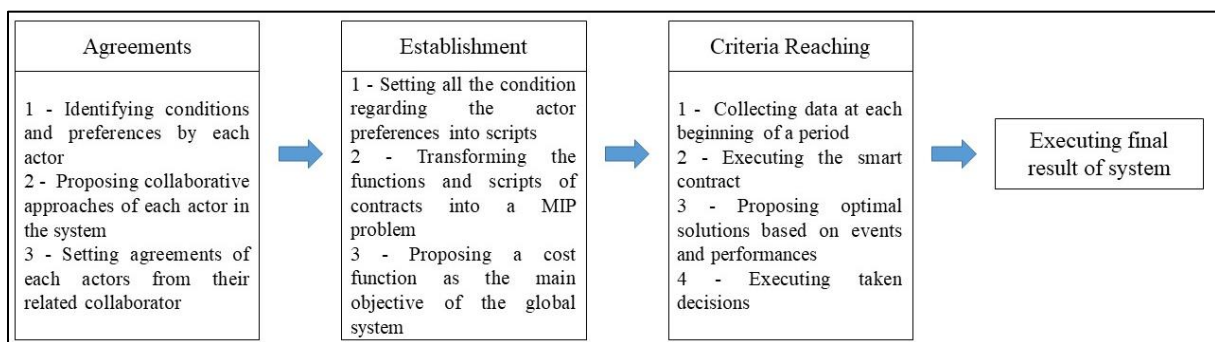


Figure 2-2- The main approaches toward smart contract in this thesis

- The smart contract algorithm’s scripts is represented by the mathematical formulation in an optimization scheme for different types of objectives for the global system of SC.
- As it is represented in Figure 2-1, the necessary data for the smart contract will be provided by the physical system directly and other related data from the cloud (the data from BT and IoT).
- In the presented scheme, the smart contract can have the capability of proposing the optimum and exact solutions for the usage of resources in the system through better allocation and distribution of the products in the whole network.

2.2.3 Considering events

Possible problems can be considered as events. These events will be defined in the mathematical formulation. They can be mentioned as follows:

- Sensor alarms for the quality of a product
- Perishability detection of product
- Demand information (arrival, answers and so on)
- Products information (production, transferring and so on)

- Transferring necessity of the products and raw materials

To cope with mentioned problems regarding these events several possible reactions are mentioned in the next section.

2.3 Possible information retrievals

In this section, three different approaches corresponding to three levels of information retrieval are considered. Besides, reactivity of the system comes from the number and the moments that the smart contract proposes possible decisions in the system. The approaches are as follows:

2.3.1 Basic model

In this approach, all the decisions will be made at the beginning and the end of each period by the smart contract. During the period, the integrated system will store the data and send the necessary information to the smart contract, and the best solution will be proposed to satisfy the demands at the end of the periods for the presented PSC. It is important to note that this approach is expected to be more practical and effective when the system is more stable and few problems may happen during a period.

2.3.2 Checking points model

The smart contract will divide each period into a specific number of checking points. The data will be collected from the integrated system at each checking point. If any problem is found in the system, the decisions will then be made at the checking point time. The number of checking points is defined according to the decision maker's preferences, the data in the integrated system, and other elements of the information system. Besides, they can vary from period to period. This approach allows more monitoring and helps to have a hint about the condition of the system regularly. The choice of moments for checking points could be defined based on experiences and data analysis (not presented in this thesis).

2.3.3 Event-based model

In this scenario, whenever a change happens in the system, the smart contract could do a reaction. The events can be sensor alarms in the different stages of the PSC or the rising demand for a specific product in a period at a given time. At the beginning of each period, the demand can be considered as an event in this point of view. It is important to note that at the moment of an event, all the collected data of the integrated system will be checked for possible problems in the other stages of the PSC. This approach allows the system to react to important problems at the right time. Besides, we have a better hint of the market's real demand compared to the other approaches; however, if there are too many problems (events), the smart contract could

have difficulties in giving efficient responses. Figure 2-3 illustrates three periods, ten checkpoints, and twenty events. It is important to mention that the name “event-based” is a misuse of language and does not represent an event-based simulation or programming approach.

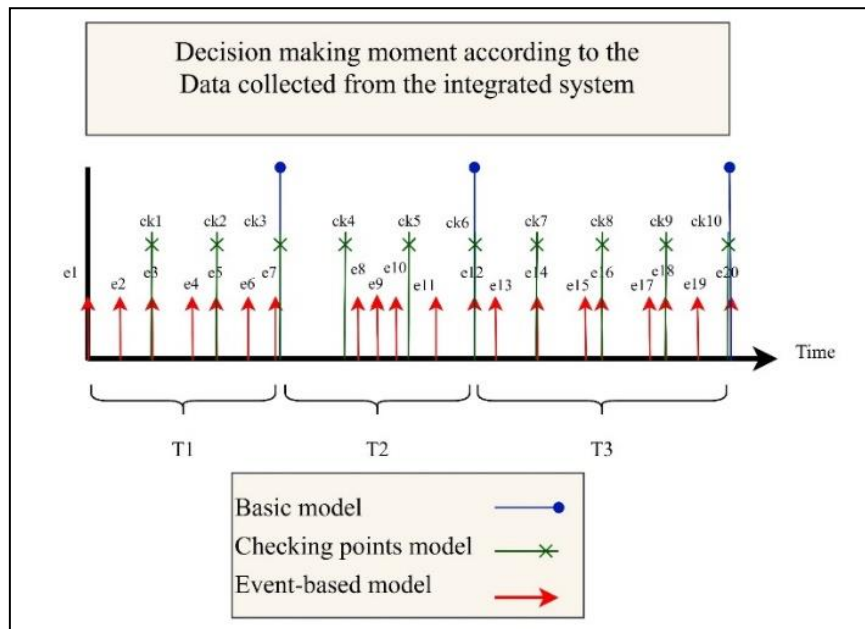


Figure 2-3- All possible approaches based on information retrievals

In the next section, we will formulate the SC network considering information retrievals of smart contract.

2.4 Formulate the supply chain

In this section, the presented problem will be formulated and then in the next section we try to solve it. It is important to note that the mathematical formulation can be dedicated to the SC with the perishable products such as pharmaceutical supply chains (PSCs).

2.4.1 Assumptions

The problem assumptions are as follows:

- Products defection are identified by IoTs (when the conditions are not met during all stages of SC.)
- The unmet demands are considered as lost sales.
- In the basic model and checking point model, there is no lead-time considered for the direct purchasing; so, when it is necessary to do the direct purchasing, final products can arrive when needed to answer the demand. In the event-based approach, no lead

time is considered for direct purchasing; however, it happens precisely when direct purchasing is required, which differentiates this approach from others.

2.4.2 Mathematical formulation

2.4.2.1 Notations

The notations of the model are as follows:

Notations	Definitions
Sets	
t	The time from 1 to t (which represents the end of a period t), or Index for the event time e_t for a given period, with $e_t \in \{1 \dots E_t\}$ or Index for the checking point time ck_t for a given period, with $ck_t \in \{1 \dots CK_t\}$
S_t	Set of all possible suppliers s_t in period t with $s_t \in \{1 \dots S_t\}$
M	Set of manufacturers m with $m \in \{1 \dots M\}$
D	Set of distribution centers d with $d \in \{1 \dots D\}$
P, P'	Set of raw materials P' and final products P with $p' \in \{1 \dots P'\}$ and $p \in \{1 \dots P\}$
I	Set of routes i between manufacturers m and distribution centers d with $i \in \{1 \dots I\}$
J	Set of routes j between suppliers s_t and manufacturers m with $j \in \{1 \dots J\}$
V	Set of transporters v between manufacturers m and distribution centers d with $v \in \{1 \dots V\}$
Parameters	
pmc_{mt}^p	Cost of producing product type p in the manufacturer m at period t (per unit)
$qrc_{s_tmvjt}^{p'}$	Cost of transferring raw material p' from supplier s_t to the manufacturer m with transporter v in rout j at period t (per unit)
$pdcc_{mdvit}^p$	Cost of transferring product type p from manufacturer m to the distribution center d with transporter v in rout i at period t (per unit)
$hinv_{dt}^p$	Holding inventory cost of product type p in the distribution center d at period t (per unit)
$cund_{dt}^p$	Lost demand cost of product type p in the distribution center d at period t (per unit)
cdp_{mdvit}^p	Cost of direct purchasing of product type p that should send from manufacturer m to the distribution center d with transporter v in rout i at period t (per unit)
$es_{s_t t}^{p'}$	Expert system weight for purchasing raw material p' from supplier s_t at period t
$dmaxmd_{mdt}^p$	The maximum accepted delivery time for product type p from manufacturer m to the distribution center d at period t
$dmaxsm_{s_t mt}^{p'}$	The maximum accepted delivery time for raw material p' from supplier s_t to manufacturer m at period t
$\theta_{s_t t}^{pp'}$	The needed percentage of raw material p' to produce product type p by purchasing from the supplier s_t at period t (per unit)
$esdem_t^p$	Estimated demand of the product p at period t
$cap_{s_t t}^{p'}$	The capacity of the supplier s_t to supply the raw material p' at period t
dem_{dt}^p	The demand of the product type p from the distribution center d at time t
qc_{mt}^p	The possible percentage of detected product type p in manufacturer m at time t by sensors during the quality control of the production

Chapter 2: Supply chain distribution adaptability

fsf_{mt}^p	The possible percentage of detected product type p in manufacturer m at time t by sensors before sending toward the distribution centers
tf_{vit}^p	The possible percentage of detected product type p with transporter v in route i at time t by sensors during transportation
$tr_{vjt}^{p'}$	The possible percentage of detected raw material type p' with transporter v in route j at time t by sensors during transportation
df_{dit}^p	The possible percentage of detected product type p in distribution center d that come from route i at time t by sensors at the time they arrived to the distribution centers
BM	A very big number
$dism_{mdi}$	The distance between manufacturer m and distribution center d in the route i
$diss_{s_t m j}$	The distance between supplier s_t and manufacturer m in the route j
$aspm_{mdvi}$	The average speed of transporter v to transfer products from manufacturer m to distribution center d in the route i
$asps_{s_t m v j}$	The average speed of transporter v to transfer raw materials from supplier s_t to manufacturer m in the route j
$ouic_{dt}^p$	Cost of transferring final products of product type P from distribution center d at period t to answer the demand
Variables	
pm_{mt}^p	Number of produced product type P in the manufacturer m at time t
$qr_{s_t m v j t}^{p'}$	Number of transferred raw material p' from supplier s_t by the manufacturer m with transporter v in the route j at time t
pdc_{mdvit}^p	Number of transferred product type P from manufacturer m to the distribution center d with transporter v in the route i at time t
inv_{dt}^p	Inventory level of product type P in distribution center d at time t
und_{dt}^p	Number of unmet demand of product type P in distribution center d at time t
dp_{mdvit}^p	Number of direct purchased product type P from manufacturer m to send to the distribution center d from route i at time t
x_{mdvit}^p	1: If the product type P transfer from manufacturer m to the distribution center d with transporter v in route i at time t 0: Otherwise
$y_{s_t m v j t}^{p'}$	1: If raw material type p' transfer from supplier s_t to the manufacturer m with transporter v in route j at time t 0: Otherwise
oui_{dt}^p	Number of transferred final products of product type P from distribution center d at time t to answer the demand
Z_1	Cost objective function
Z_2	Purchase from the qualified supplier objective function
Z_3	Accepted delivery time objective function

The main objectives of the proposed PSC are given by:

- Minimize total cost
- Maximize purchase from the qualified supplier
- Maximize accepted delivery time

These objective functions are defined in what follows:

2.4.2.2 Objective functions

Three different objective functions are introduced to minimize cost, maximize purchase from qualified suppliers and minimize the average delivery time.

The objective function and constraints are as follows.

$$\begin{aligned}
 Min Z_1 = & \sum_t \left(\sum_p \sum_m pmc_{mt}^p pm_{mt}^p + \sum_{p'} \sum_{s_t} \sum_m \sum_v \sum_j qrc_{s_tmvjt}^{p'} qr_{s_tmvjt}^{p'} \right. \\
 & + \sum_p \sum_m \sum_d \sum_i \sum_v pdcc_{mdvit}^p pdc_{mdvit}^p + \sum_p \sum_d hinv_{dt}^p inv_{dt}^p \\
 & + \sum_p \sum_d cund_{dt}^p und_{dt}^p + \sum_p \sum_{p'} \sum_m \sum_d \sum_i cdp_{mdvit}^{p'} dp_{mdvit}^p \\
 & \left. + \sum_p \sum_d ouic_{dt}^p oui_{dt}^p \right) \tag{1}
 \end{aligned}$$

Equation (1) is the cost objective function. It consists of seven different parts:

- i) Costs of producing final products,
- ii) Transferring raw materials from the suppliers to the manufacturers,
- iii) Transferring the final products from the manufacturers toward the distribution centers,
- iv) Inventory holding cost,
- v) The cost of unmet demands,
- vi) Repurchasing cost from manufacturing cost,
- vii) Cost transferring products to the demands.

$$Max Z_2 = \sum_{p'} \sum_{s_t} \sum_m \sum_v \sum_j \sum_t es_{s_t t}^{p'} qr_{s_tmvjt}^{p'} \tag{2}$$

Equation (2) depicts purchase from the qualified supplier objective function.

$$\begin{aligned}
 Min Z_3 = & \sum_t \left(\left[1 - \left[\sum_p \sum_m \sum_d \sum_v \sum_i \left(\frac{dismd_{mdi}}{aspm_{mdi}} \right) x_{mdvit}^p / dmaxmd_{mdt}^p \right] \right]^2 \right. \\
 & \left. + \left[1 - \left[\sum_{p'} \sum_{s_t} \sum_m \sum_v \sum_j \left(\frac{dissm_{s_tmj}}{aspsm_{s_tmj}} \right) y_{s_tmvjt}^{p'} / dmaxsm_{s_tmt}^{p'} \right] \right]^2 \right) \tag{3}
 \end{aligned}$$

Equation (3) is the products' expected delivery time objective function. For any perishable or decayable final products and raw materials, the receiving expectation time level starts diminishing and decreases quickly after the production. The transportation phase duration can play a pivotal role in this manner, as crucial as the condition during the transportation in the proposed PSC. A monotone continuous decreasing function $\alpha^p(TT)$ is presented to explain the expected delivery time of the final products and raw materials (van Donselaar *et al.*, 2010). When the product is completed, the time is 0; the expected time of the products will be calculated when the distribution center d receives it at time k , which can demonstrate by $\alpha^p(TT_k)$. As it can be seen in Figure 2-4, $\alpha^p(TT_k) = 1 - \left(\frac{TT_k}{TT_k^{max}}\right)^2$; $0 \leq TT_k \leq TT_k^{max}$. When the transportation time exceeds the TT_k^{max} , the DC will refuse to store the product. This procedure exists in the same point of view for the raw materials. Where TT_k^{max} is shown with $dmaxmd^p_{mtd}$ and $dmaxsm^p_{stmt}$ for the freshness of the final products and raw materials.

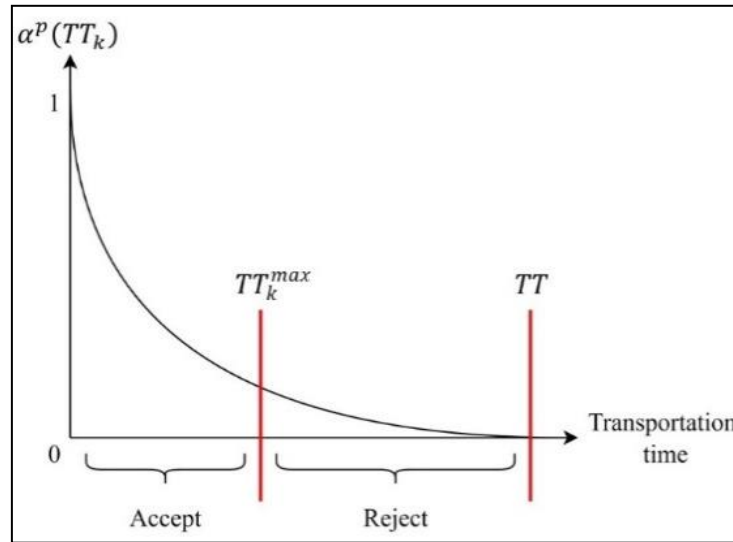


Figure 2-4- Final products expected delivery time and acceptances level

2.4.2.3 Constraints

The constraints are as follows:

$$\sum_{s_t} \sum_v \sum_j \theta_{s_t}^{pp'} q r_{s_t m v j t}^{p'} (1 - tr_{v j t}^{p'}) = pm_{m t}^p \quad \begin{matrix} \forall p \in \{1 \dots P\} \text{ and} \\ .p' \in \{1 \dots P'\}, \\ \forall m \in \{1 \dots M\}, \\ \forall t \in \{1 \dots T\} \end{matrix} \quad (4)$$

$$\sum_m pm_{m t}^p = esdem_t^p \quad \begin{matrix} \forall p \in \{1 \dots P\}, \\ \forall t \in \{1 \dots T\} \end{matrix} \quad (5)$$

$$\sum_m \sum_v \sum_j qr_{s_tmvjt}^p \leq cap_{s_t}^p \quad \begin{array}{l} \forall p' \in \{1 \dots P'\} \\ \text{and } p \in \{1 \dots P\}, \\ \forall s_t \in \{1 \dots S_t\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (6)$$

$$pm_{mt}^p (1 - (qc_{mt}^p + fsf_{mt}^p)) = \sum_d \sum_v \sum_i pdc_{mdvit}^p \quad \begin{array}{l} \forall p \in \{1 \dots P\}, \\ \forall m \in \{1 \dots M\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (7)$$

Constraint (4) shows the relationship between raw materials and products. Constraint (5) depicts the production amount according to the BT data. Constraint (6) describes the capacity of the suppliers. The products that are ready to send to the distribution centers should pass from the sensors, and their quality during production should also be checked. This aspect is represented in constraint (7).

$$inv_{dt}^p = inv_{dt-1}^p + \sum_m \sum_v \sum_i pdc_{mdvit}^p (1 - (tf_{vit}^p + df_{dit}^p)) - oui_{dt}^p \quad \begin{array}{l} \forall p \in \{1 \dots P\}, \\ \forall d \in \{1 \dots D\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (8)$$

$$dem_{dt}^p = oui_{dt}^p + und_{dt}^p + \sum_m \sum_v \sum_i dp_{mdvit}^p (1 - (tf_{vit}^p + df_{dit}^p)) \quad \begin{array}{l} \forall p \in \{1 \dots P\}, \\ \forall m \in \{1 \dots M\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (9)$$

Constraint (8) is the inventory level controller. Constraint (9) illustrates that the inventory or direct purchasing will answer the demands; otherwise, they will be unmet.

$$pdc_{mdvit}^p + dp_{mdvit}^p \leq BM x_{mdvit}^p \quad \begin{array}{l} \forall p \in \{1 \dots P\}, \\ \forall m \in \{1 \dots M\}, \\ \forall d \in \{1 \dots D\}, \\ \forall v \in \{1 \dots V\}, \\ \forall i \in \{1 \dots I\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (10)$$

$$\left(\frac{dismd_{mdi}}{aspm_{mdi}} \right) x_{mdvit}^p \leq dmaxmd_{mdit}^p \quad \begin{array}{l} \forall p \in \{1 \dots P\}, \\ \forall m \in \{1 \dots M\}, \\ \forall d \in \{1 \dots D\}, \\ \forall v \in \{1 \dots V\}, \\ \forall i \in \{1 \dots I\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (11)$$

$$qr_{s_tmvjt}^{p'} \leq BM y_{s_tmvjt}^p \quad \begin{array}{l} \forall p \in \{1 \dots P\}, \\ \forall s_t \in \{1 \dots S_t\}, \\ \forall m \in \{1 \dots M\}, \\ \forall v \in \{1 \dots V\}, \\ \forall j \in \{1 \dots J\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (12)$$

$$\left(\frac{dis_{sm_{s_t m}}}{asps_{sm_{s_t m}}} \right) y_{s_tmvjt}^p \leq dmaxsm_{s_t mt}^p \quad \begin{array}{l} \forall p \in \{1 \dots P\} \text{ and } \\ p' \in \{1 \dots P'\}, \\ \forall s_t \in \{1 \dots S_t\}, \\ \forall m \in \{1 \dots M\}, \\ \forall v \in \{1 \dots V\}, \\ \forall j \in \{1 \dots J\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (13)$$

Constraints (10) and (11) depict sending the products less than the maximum accepted time to the distribution centers. Constraints (12) and (13) do the same task for the maximum accepted time for the manufacturers. To highlight our results, we propose in the next section a numerical application.

In the next section, the proposed model is solved by generating the uniform values.

2.5 Numerical results

In this section, an example in several scenarios is presented to show the validity and performance of the proposed approach. Figure 2-5, shows the graphical abstract of the presented example. In the presented example, five suppliers, three different routes between different stages, four manufacturers, and five DCs are considered.

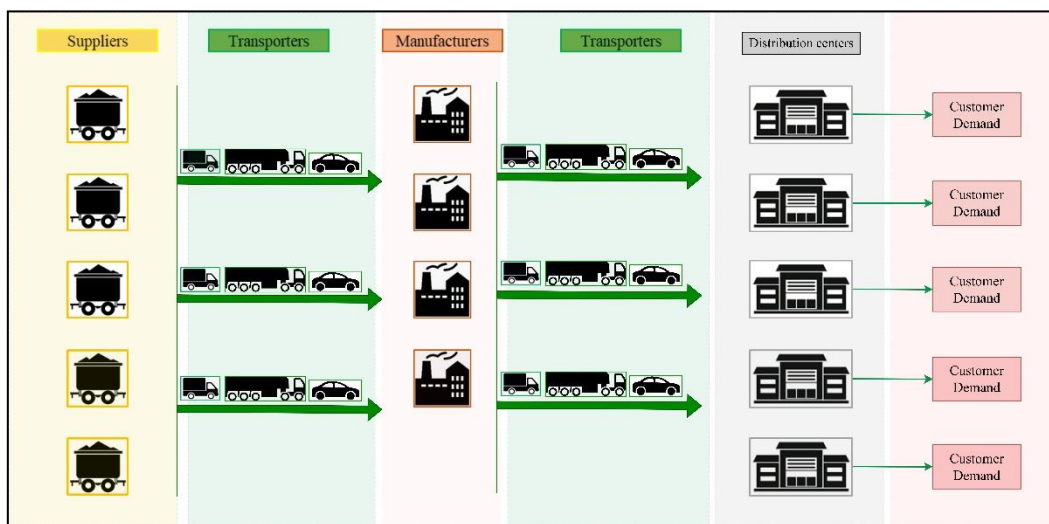


Figure 2-5- Graphical abstract of the presented problem

The final product is a high-growth protein product that is environmentally sensitive. An example is Warfarin, a drug that prevents blood from clotting. The users are usually people with specific types of irregular heartbeat and people who have suffered a heart attack also it can be say that the customers in the PSC are hospitals, pharmacies, doctors, and ordinary people. Several concerns during the production and transportation exist for this drug, such as the risk of counterfeit products, product diversion, variances in equipment and facilities, and storage in 59–86°F (15-30 °C). Besides, the manufacturers and suppliers are responsible for producing such products as Lupin from India, Farmak from the Czech Republic, and Otto Brandes GmbH from Germany. The transporters are the vehicles with special conditions for transferring and monitoring the condition of the products during the transfer.

GAMS 31.2.0 and CPLEX solver are used to solve the proposed mathematical model on laptops with the following configuration: Core i7 and 2.20 GHz processor (ii) 16 GB RAM. It is important to note that different possibilities of the integrated system flaws detections timing have been discussed.

2.5.1 Generating example

In this section, uniform distribution has been used to generate data to solve the problem. We use uniform distribution because of the following reasons:

- it is easier for more discussion and analyses
- it is well understood between all scholars,
- it is easier to control the range for further analysis
- it is efficient

The values of the parameters are depicted in Table 2-1.

Table 2-1- Data generation of parameters

<i>Parameter</i>	<i>Value</i>	<i>Parameter</i>	<i>Value</i>
pmc_{mt}^p	uniform(5,10)	dem_{dt}^p	uniform(25,40)
$qrc_{s_tmvjt}^{p'}$	uniform(2,4)	qc_{mt}^p	uniform(0.01,0.02)
$pdcc_{mdvit}^p$	uniform(0.2,0.8)	fsf_{mt}^p	uniform(0.005,0.01)
$hinv_{dt}^p$	uniform(2,5)	tf_{vit}^p	uniform(0.005,0.01)
$cund_{dt}^p$	uniform(5,10)	$tr_{vjt}^{p'}$	uniform(0.005,0.007)
cdp_{mdvit}^p	uniform(6,9)	df_{dit}^p	uniform(0.005,0.006)
$esdem_t^p$	uniform(100,200)	$dismd_{mdi}$	uniform(50,300)
$dmaxmd_{mdt}^p$	uniform(300,560)	$disss_{s_tmj}$	uniform(80,300)
$dmaxsm_{s_tmt}^{p'}$	uniform(100,700)	$aspm_{mdvi}$	uniform(50,90)
$\theta_{s_t t}^{pp'}$	uniform(1.2,1.3)	$aspsm_{s_tmvj}$	uniform(60,90)
$cap_{s_t t}^{p'}$	uniform(70,200)	$ouic_{dt}^p$	uniform(0.5,1.2)

Three periods are considered, ten different suppliers are available for the considered time horizon. Four manufacturers, five DCs, three different products and raw materials, three different routes between all actors, three distinct vehicles, ten checking points, and twenty events are considered.

2.5.2 Scenario 1

In this scenario, events are fairly distributed in a period. It means it is expected that the failures and changes in different stages will happen uniformly during the period. Besides, demand postponements are considered as events. It means that an event appears each time that the market demand appears. The results are presented in Table 2-2.

Table 2-2- The results of scenario 1

	Basic model	Checking points model	Event-based model
<i>Variables</i>	<i>Value</i>	<i>Value</i>	<i>Value</i>
Total cost (Z_1)	11905.964	11891.276	11434.030
Purchasing (Z_2)	716.983	724.114	806.119
Average of delivery (Z_3)	1079.63	1079.94	1079.94
Total inventory (<i>inv</i>)	87.716	89.733	0
Total answered demand by inventory (<i>oui</i>)	1203.587	1204.512	1438.899
Total direct purchasing (<i>dp</i>)	99.606	100.510	3.089
Total unmet demand (<i>und</i>)	146.884	144.126	6.771

According to the result of Table 2-2, The lower cost happens for the event-based model. It is the result of several consequences. First of all, the smart contract will propose the decision with a more exact prediction of the market demand. Furthermore, in each event, a new transaction of the initially signed contract will be set between the manufacturer and the DC to supply the material, and they cannot disobey to provide the products. At the beginning of the system, the main acceptance of being the miner of the BT and participating in the system is to answer the demand at the moment of the making decision. Therefore, holding no inventory and releasing them all toward the market at each period will be the consequence. Finally, several faults will be reported to the IoT system’s smart contract, and a new contractual framework for direct purchasing will happen.

Nevertheless, the amount of direct purchasing and unmet demand will be at the lowest possible value because most of the demand is already responded with the inventory. Besides, when the smart contract decides in the checking point, the performance can be a little better than the basic model in terms of the cost. The reason is that the smart contract will be notified sooner about the changes in the system and react at the proper timing.

2.5.3 Scenario 2

In this scenario, it is assumed that changes and faults are not uniformly generated, and they are randomly divided over a period. To do so, we consider the three different periods as before. Periods one and three are uniform like before, but period 2 is not uniform. The reported demand in each checking point is introduced to show the changes during a period and depict not uniformly demand changes. For example, if the reported demand is (0.05, 0.05, 0.9), it means that there are three checkpoints in period two, and the percentage of the demand is reported in the order of 0.05, 0.05, 0.9. Besides, events can happen during the period, but the total amount is the same as the checking points for the demand. For example, up to checking point 1, the total demands that can happen are 0.05 percent of the total demand of the period as the events. The results are depicted in Table 2-3.

Table 2-3- The differences of the objective function 1 by different reported demand

Reported demand	Basic model				Checking points model				Event-based model			
	Total unmet demand (<i>und</i>)	Total direct purchasing (<i>dp</i>)	Total answered demand by inventory (<i>out</i>)	Total cost (Z_1)	Total unmet demand (<i>und</i>)	Total direct purchasing (<i>dp</i>)	Total answered demand by inventory (<i>out</i>)	Total cost (Z_1)	Total unmet demand (<i>und</i>)	Total direct purchasing (<i>dp</i>)	Total answered demand by inventory (<i>out</i>)	Total cost (Z_1)
Uniformly	147	100	1204	11905.964	144.126	100.510	1204.512	11891.276	6.771	3.089	1438.899	11434.030
(0.05,0.05,0.9)					143.924	100.510	1204.714	11899.432	5.71	3.089	1439.894	11435.010
(0.1,0.1, 0.8)					143.964	100.510	1204.674	11897.207	6.11	3.089	1439.889	11434.930
(0.15,0.15,0.7)					144.004	100.510	1204.633	11894.983	6.22	3.089	1439.830	11434.70
(0.2,0.2,0.6)					144.045	100.510	1204.593	11892.758	6.525	3.089	1439.50	11434.510
(0.25,0.25,5)					144.085	100.510	1204.552	11891.329	6.64	3.089	1438.950	11434.220

This analysis shows that in the presented smart contract, the event occurrence does not significantly influence the final results and decision; however, the approaches toward decision-making can considerably impact the presented system. Besides, the results can have slight changes with different reported demands. The reason is that when the event is happening with a greater impact, that means when the event is more vigorous in a period, the smart contract will supply it with the most accessible resources to prevent the huge cost of the unmet demand. It means more products to be purchased in the first step to avoid the unmet demand cost. Direct purchasing remains the same because the input value in our problem for period two at some levels is higher than the unmet demand. Therefore, the presented smart contract makes the contract of the direct purchasing just in the time, which is beneficial and the same for all. Besides, it is vital to note that the event-based model has the best performance in all distribution patterns.

Furthermore, in this section, we do not consider the fact that two or more events can happen simultaneously, which could generate conflict from a decision point of view. In this case, preferences should be defined to help the decision-making. The preferences could be linked with demands, faults, and so on.

2.5.4 Comparisons of the level of intervals

Two main perspectives are considered to compare the three models of information retrievals. The PSC's service level and profit are the main issues to consider the differences between the models in each scenario.

The service level is developed by (Ivanov, 2018) to compare the performance of the simulated model. This calculation is a value between zero and one related to the portion of the answered demand in the total demand for each product. It is obtainable by using equation (14):

$$Service\ level = \frac{\sum_t \sum_m \sum_d \sum_i dp_{mdvit}^p + \sum_t \sum_d oui_{dt}^p}{\sum_t \sum_d dem_{dt}^p} \quad \forall p \in \{1 \dots p\} \quad (14)$$

Furthermore, the profit formula, which is given by total selling products times the selling price minus total cost, is depicted in equation (15):

$$profit = \sum_t \left((\sum_p \sum_m \sum_d \sum_i SP_p dp_{mdvit}^p + \sum_p \sum_d SP_p oui_{dt}^p) \right) -$$

objective function z1 – transaction cost (variable cost of using the integrated system) – investment cost (fixed cost of using the integrated system)

(15)

Where SP_p is the selling price of the product p generated value as uniform (10,15). The number of transactions in our system can be achievable by the total number of times that the direct purchasing happens, which can be obtainable by using equation (16):

$$\sum_t \sum_p \sum_m \sum_d \sum_i dp_{mdvit}^p \leq BM * nt_t \quad \forall t \in \{1... T\} \quad (16)$$

Where nt_t is the number of transactions in the period t . The investment cost is the same for all the approaches. The service level and profit of scenario 1 are given in Table 2-4 by considering no transaction cost for the integrated system.

Table 2-4- the service level and profit of scenario 1

Scenario 1	Basic model	Checking points model	Event-based model
Service level ($p=1,2,3$)	(0.828, 0.95, 0.872)	(0.832, 0.96, 0.874)	(0.995, 0.997, 0.993)
Profit	3297.354	3359.260	5422.079

As shown in Table 2-4, the event-based model is the best approach for product service level and total profit in the generated example, which was coherent because most of the demand will be answered in this approach and the unmet demand and direct purchasing have the lowest value compared to other approaches. It is important to note that according to the literature and previous research, we are aware that using transactions in the BT system will cost the system (Ashraf & Heavey, 2023). Therefore, in the presented system, whenever the smart contract makes the decision and shares it in the system for all the actors, it takes a cost. Table 2-5 and Figure 2-6 depict the affection of this cost on the profit of each approach.

Table 2-5- changes of profit by changing the decision-making cost

Decision-making cost	Basic model	Checkpoint model	Event-based model
0	3297.354	3359.26	5422.079
0.05	3296.897	3296.897	5104.824
0.1	3296.647	3027.814	4821.324
0.2	3296.147	2703.814	4254.324
0.3	3295.647	2379.814	3687.324
0.4	3295.147	2055.814	3120.324
0.5	3294.647	1731.814	2553.324
0.6	3294.147	1407.814	1986.324
0.7	3293.647	1083.814	1419.324
0.8	3293.147	759.814	852.324
0.9	3292.647	435.814	285.324
1	3292.147	111.814	-281.676

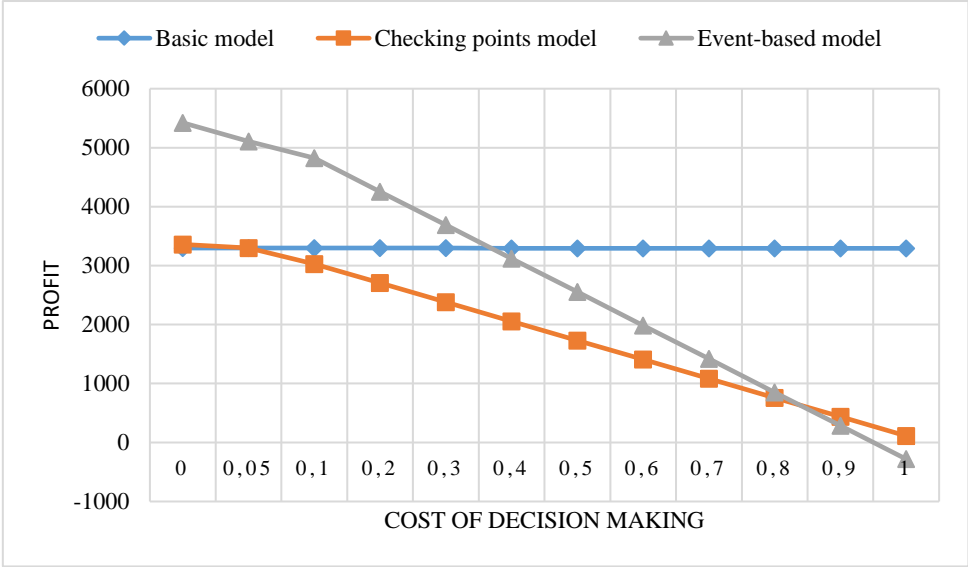


Figure 2-6- Changes of profit by changing the decision-making cost

As it can be seen, by raising the decision-making cost, the event-based approach will be none profitable, and the basic model has the best cost. This analysis shows that in each system consisting of smart decision-making technology, the approaches can be selected toward the events by analyzing the amount of decision-making cost. In the mentioned example, up to the cost between 0.3 and 0.4, it is logical to consider an event-based approach, and when the cost is more, it is crucial to switch to the basic model decision-making approach. This switch can happen automatically or by the predefinitions of the systems. It is important to note that it is just a comparison in the case of reactivity between three different models. Based on the results obtained in this section, it is possible to dig deeper into the practical examples and more strategic discussions. In the next section, the managerial insights regarding the results are discussed.

2.6 Discussion and managerial insights

In this chapter, we are able to manage different types of flows of a SC with the help of smart contract by using the provided data of BT and IoTs. Our smart contract is able to propose different solutions regarding the events happening in the system. These events can be various with different scenarios. The key elements to react according to the events can be the profits and service levels. It should be noted that the definition of the proposed scenarios is based on a discrete event approach and does not depend on the qualification or the number of these events but only on the way to detect it and the desired reactivity. Indeed, from the managerial perspective, different barriers can exist in the context of IT systems and SC. The managers want to increase profit. In this regard, they could, among other possible actions, try to increase their

customers' trust by tracking the products better to stop fake and defected products and remove the damaged and not qualified ones from the system while replacing them with good products to satisfy orders. However, they do not want to have exploding implementation and usage costs (which can quickly become the case with IoTs and BT). Furthermore, from an environmental point of view, the more information are stored (from IoTs and BT), the more energy consumption exists.

The other barrier is making decisions more optimally according to all actors' preferences regarding the system's received data by focusing on the events in the system. To cope with mentioned barriers, it is an opportunity for the managers to implement a system to manage all types of flows in SC. As mentioned in the research gaps, the integrated system of smart contracts, BT, and IoTs can be a useful answer for managers. By using such a system and defining different information retrievals, the manager achieves traceability and trust regarding the related cost of BT as well as selects the approach (event-based, checkpoint, and base model) between the data sharing system and physical actions implementations. Besides, based on our findings, we can suggest several useful managerial insights as follows:

- Considering the key elements, each manager can define the number of connection between the smart contract, IT, and physical systems.
- Managers should be aware of the cost of using IT systems. The change in the cost of these facilities can change the manager's decision for smart contract actions frequency. As an example in our results, the high and low costs of BT rely on the number of events and transactions can change the profit of each approach.
- Events can be different from system to system; in our presented SC, it could be the demand and IoTs fault detections. It is not necessary to approximate all the events in a period, but it is crucial to estimate the frequency and rate of events' occurrences in a period. High frequency and low frequency can completely change a manager's point of view about the balance of the smart contract which can impact on the final risk evaluation of the system.
- Finding the balance, which can be defined as the relationship between using the IT and sharing system with the number of reactions toward events in the physical system, should be considered. To do so, the managers can consider the service level and profit as a target goal and then try to discover the best balance between the systems.

Based on the findings and insights in this section, it is possible to discuss more about the possible lacks that can exist in this chapter and conclude it. In the next section, conclusions and future perspectives are discussed.

2.7 Conclusion and future perspectives

In this chapter, we propose to use a smart contract to cope with defects and decision-making difficulties in a supply chain (SC). The smart contract can collect data using blockchain technology (BT) and Internet of things (IoT) systems. Using the BT and IoT system as data providers make it possible to reach more trust and transparency in the SC between the actors. The smart contract helps decision-makers for managing the material flow and distribution of the products in the SC network by considering a mixed-integer multi-objective problem, integrating the role of suppliers, manufacturers, transporters, DCs, and customers. The proposed mathematical formulation's objectives are cost function, delivery time, and purchasing from qualified suppliers. Besides, three different timing approaches for collecting data and then reactivity toward the events in the SC are considered, namely the basic model, checking point model, and event-based model. Our objective is to define an optimal distribution of the final products to answer the demands relying different events in the system. An example with uniform generated data is considered and the results are presented to compare the mentioned approaches and show the validity of the proposed system. The results considered different cases based on the potential costs of interactions. Then the impacts of these costs are evaluated, and the service level and profit for each decision-making aspect are calculated. Concerning this evaluation, the best moment to change the decision-making approach for the presented example is achievable. Furthermore, when the total number of events is not huge, our results denote that it is of course better to be as reactive as possible when the decision-making system and information-sharing approaches do not have a considerable cost for usage. It means that it is preferable to react and respond at the moment of an event happened.

For future works directions, two main perspectives are important to us based on the findings in this chapter. Firstly, implementing the methods that can help the smart contract algorithm anticipate and prevent problems before the start of the distribution process is so important. It needs to add a better information flow and better assess the actors performances. Regarding the presented system, a dynamic supplier selection method could satisfy this need and improve the final results achieved in this chapter. Furthermore, adding the possibility of interactions and collaborations between actors through the mentioned smart contract can be interesting from

another perspective.

Chapter 3 Dynamic supplier selection strategies for improvement of distribution process

In this chapter, two distinct smart contracts are introduced. The first smart contract uses fuzzy cognitive maps and expert ideas for supplier selection process. The second smart contract is dedicated to the distribution process. The reason of presenting two different smart contracts comes from the different types of inputs for each of them. The principle of fuzzy cognitive map is adapted to identify the main important criteria for a given period of time and then to select suppliers dynamically. It comes from the fact that a given criterion could be described and decomposed by various sub-criteria or factors in the same direction or be contradictory. Furthermore, an important factor for the selection of suppliers at a given period could be less interesting for another period because of dynamical changes and crises. Finally, importance to apply supplier selection to the previous chapter and the advantageous will be mentioned.

3.1 Introduction

In chapter 2, we were able to discuss supply chain (SC) adaptability in the distribution process, but there are other potential developments in addition to adaptable distribution of the products to take into account. These needs can be mentioned as production planning and scheduling, technology integration, supplier selection, and so on. Among all of the needs, the one that will interest us is a dynamic supplier selection process. It comes from the possibility to complete the previous chapter in several aspects, which are mentioned as follows:

- Market conditions and client expectations are continuously changing. A dynamic supplier selection method enables enterprises to regularly evaluate and adapt their supplier base in response to changing market demands. It allows users to choose suppliers who offer the highest value, quality, and responsiveness at any given time.
- The performance of suppliers can fluctuate over time. Changes in management, production capacity, financial stability, and delivery reliability can all have an impact on a supplier's ability to satisfy expectations. Organizations can identify underperforming suppliers and take relevant actions, such as identifying new suppliers or addressing performance concerns, by frequently assessing supplier performance.
- Due to variations in demand, product launches, or growth into new markets, supplier capacity and scalability requirements can fluctuate over time. Organizations can examine suppliers' capacity, scalability, and ability to support business growth through a dynamic supplier selection process. It assures that the selected suppliers will be able to satisfy rising demand while also providing the appropriate resources and capabilities (Sharafi *et al.*, 2022).

Based on the mentioned reasons, it is important to dig into supplier selection procedures and add this option to presented process.

The supplier selection problem involves consideration and qualification of different kind of factors which are characterized by their multiple, conflicting and evolving nature. Furthermore, the supplier selection problem is a complex decision making including the definition of the criteria, their weight and their evaluation (Tavana *et al.*, 2021). It is necessary to propose intelligent and dynamic supplier selection strategies that allow to integrate the various possible changes and uncertainties and thus predict selection criteria. Since the evaluation process is performed by judgement of human experts, fuzzy set theory is generally considered as one of the most efficient tools (Ahmad *et al.*, 2021). Thus, many methods have been proposed by

authors ranging from fuzzy data envelopment analysis to measure efficiency, fuzzy analytic hierarchy process to analyze criteria according to a pairwise comparison scale or fuzzy analytic network process to integrate the existence of interdependences among criteria (Franco & Alfonso-Lizarazo, 2020). All the proposed methods offer interesting and efficient results but unfortunately, they do not always allow to consider the dependencies and the feedback elements nor to predict the potential evolutions.

Moreover, dynamic supplier selection is a rather recent research theme that allows to consider changes in time of some parameters like the demand, prices, lead time, etc. The authors in this case generally solve the problem on the basis of mathematical programming models to allocate to the best suppliers identified for each period of time (Savadkoohi *et al.*, 2018). However, considered criteria are common: quality, cost and time. A dynamic environment is also not considered nor evolution of suppliers' performances. A recent paper (Alavi *et al.*, 2021) proposes the integration of data and machine learning, to obtain suppliers and criteria information. This data analysis is associated with fuzzy best-worst method and fuzzy inference system to weigh the criteria and calculate the final score of suppliers. The proposed method is user-friendly since it allows customization capabilities for supplier selection. However, authors do not consider interdependencies among the selection of criteria. In this chapter, the procedure of the supplier selection will be added to distribution process.

From the literature review, articles just discussed the suppliers' selection and their evaluation approaches from different points of view. Besides, the suppliers' performances after the selection phase and using it for future evaluations is a unique subject previously discussed in a few research articles. Therewithal, the contracting procedure between the suppliers and manufacturers and between manufacturers and warehouses can be a new contribution. After selecting the suppliers, removing the faulted products and deciding to replace the faulted products or lose the demand is an important notice which can be integrated with the decision's timing in our system.

In this chapter, we propose to consider dependencies between criteria with the help of Fuzzy Cognitive Maps (FCMs). Indeed, FCMs allow to connect various and multidimensional concepts with causal reasoning and the definition of fuzzy graphs. Possible changes in criteria and in causal relationships or dependencies among the selection criteria can be discovered from data coming from interviews, media, and so on. Our FCM is integrated with the smart contract presented in previous chapter. The main algorithm of the smart contract presented in the previous section could have some modifications in this chapter regarding the supplier selection

procedures. Besides, it is tried to split the supplier selection strategies and product distribution (which is discussed in the previous chapter). Furthermore, it is vital not to forget that they can be connected in some critical elements. The main innovations of the chapter can be mentioned as follows:

- Introducing a new make use of FCMs
- Adding a supplier selection procedure and accomplish a tool for distribution in SC
- Improve the results of the distribution

Section 2 presents the final scheme of combination of smart contract 1 and smart contract 2. The completed algorithm of the FCM is presented in section 3. Section 4 will discuss about the results and the improvement from the previous chapter. Section 5 concludes the chapter.

3.2 Combination of smart contract 1 and smart contract 2

First, it is necessary to discuss a little about the presented system in the previous chapter. Figure 3-1 presents the considered SC.

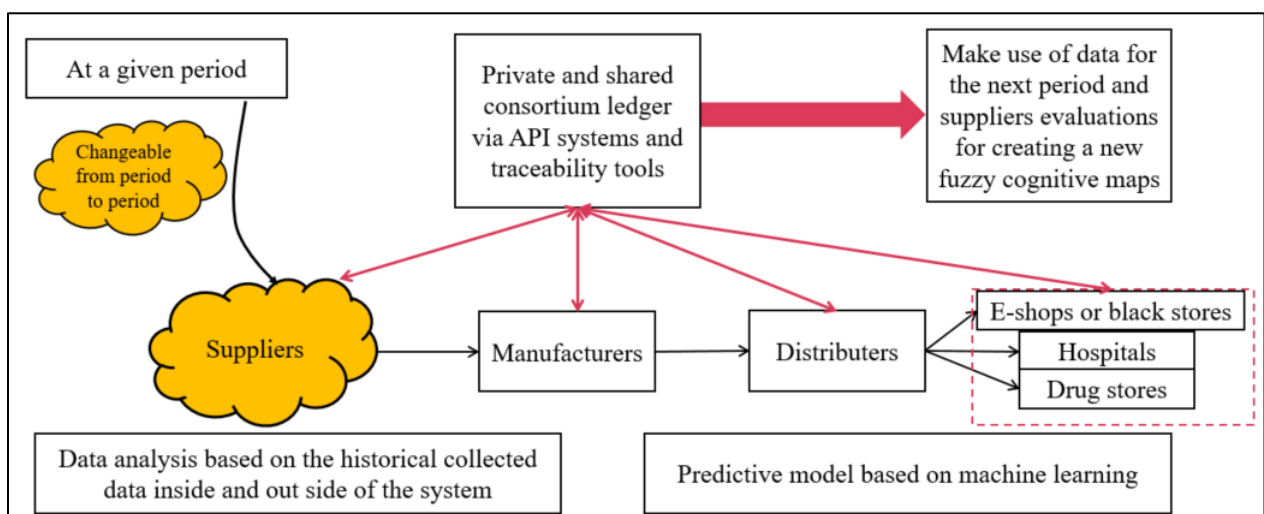


Figure 3-1- Considered SC

This system consists of suppliers, manufacturers, distributors and final customers. The suppliers are changeable from period to period, which is one of the novelties of this chapter. Then, the combination of smart contract 1 and smart contract 2 is presented in Figure 3-2.

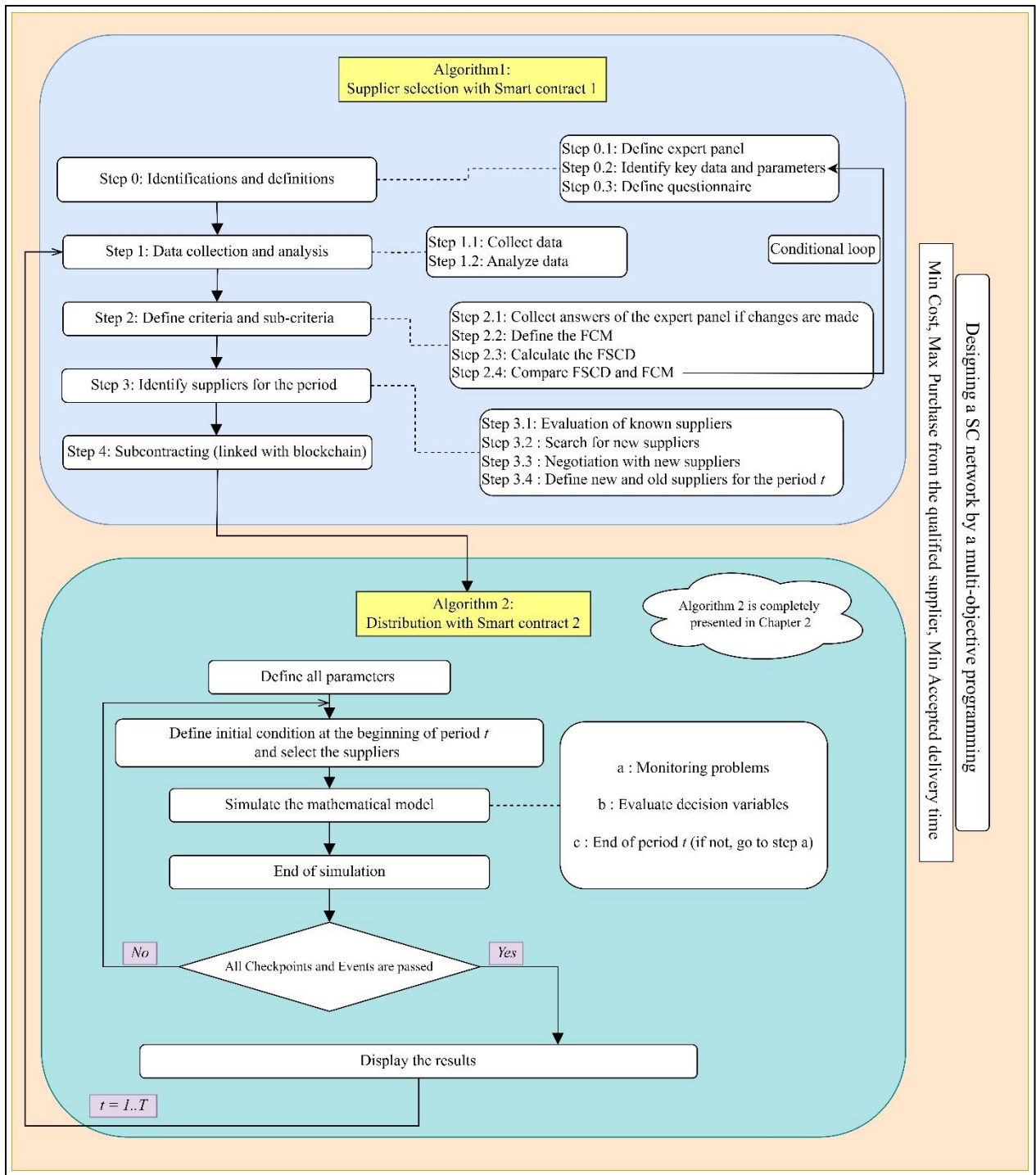


Figure 3-2- The combination of smart contract 1 and smart contract 2

The connection between smart contract 1 and smart contract 2 exists in step 4 of the supplier selection algorithm. This connection happens, when suppliers are added as BT miners and the contract is done between them and manufacturers. The requirement to be added for this connection, is the calculation of the supplier’s weight in smart contract 1. It comes from the need in smart contract 2 for the normalized weight of the suppliers for the optimum distribution

of the products. The suppliers just get the possibility of providing raw materials at the end of period from smart contract 1.

Smart contract 2 has a modification from the previous chapter. In the previous chapter, all the suppliers and initial conditions were set, and the number of suppliers was fixed. In this chapter, smart contract 2 is responsible for the number of final suppliers. Therefore, this number is not fixed and will be chosen based on the optimum distributions. At the end of each period, the calculations of the supplier selection procedures will be done from the beginning (except the definitions). These calculations will impact the number of suppliers and the weights of the suppliers in algorithm 2. The case of the problem is dedicated to pharmaceutical products, and objective functions are defined based on them. However, these algorithms and procedures can have applicability for other types of SC.

The main reasons for separation of these two algorithms are as follows:

- First of all, the inputs of smart contract 1 are mostly linguistic ideas, and they are not quantitative metrics. Therefore, it is necessary to add a procedure to cope with this difficulty in discovering a final numeric value. On the other hand, the input data in smart contract 2 are all quantitative values to optimize the final distribution. As mentioned before, the final results of smart contract 1 are quantitative values that will be added to smart contract 2 for the supplier selection procedures.
- Furthermore, they have different types of output. The output of smart contract 1 is just the final weights, while the output of smart contract 2 is the optimum solution. This differences in the outputs comes from the differences in the process. In the process point of view, smart contract 1 has dynamic evaluation aspects inside the algorithm, while smart contract 2 has optimization schemes.

In the next section, the smart supplier selection process is proposed. These results are useful to add to smart Contract 2 for the final results.

3.3 Smart supplier selection procedures

In this part, the suppliers' evaluation will take into action according to the multiple criteria and sub-criteria that can differ from period to period. It is important to highlight some key points from literatures before introducing the developed algorithm. (Amin & Zhang, 2012) introduced the fuzzy expert system method to evaluate suppliers based on linguistic variables and fuzzy triangular numbers, which are found interesting for the proposed problem in this research. First, it has less complexity than other methods, such as the Fuzzy Analytic Hierarchy Process

(FAHP) (Khalili Nasr *et al.*, 2021). In this research, Fuzzy System for Criteria Definition (FSCD) is used for each product in each period, and from period to period, the number and performance of the suppliers may differ. A method like FAHP would lead to many pairwise comparisons, which exponentially raises the calculations' complexity. Moreover, expert judgments can be more reliable by providing trustable data from blockchain technology (BT) (Völter *et al.*, 2021). Finally, a fuzzy linguistic variable, namely the trend variable “*Tr*”, is introduced to help the experts to highlight the importance of a rising criterion or sub-criteria in a specific period. Therefore, a simpler method is needed to illustrate that idea's impact on the system. However, the expert judgment can be more reliable by using the BT and providing them the trusted data; the room is open to assessing and improving the experts' final evaluations by using the FCM and analyzing the time for introducing a new sub-criteria.

3.3.1 Fuzzy cognitive maps

FCMs can be defined as dynamic systems that allow from an initial state to infer the new states of the systems at each given time step by causal relationships (Borrero-Domínguez & Escobar-Rodríguez, 2023). Thus, FCMs describe different aspects of the behavior of complex systems. Each node represents a concept and these concepts interact with each other showing the qualitative dynamics of the system exploiting the accumulated knowledge of the system (Sharma *et al.*, 2022). FCMs are defined as weighted directed graphs with nodes representing the concepts and edges representing logical and causal relations between concepts. FCMs have become increasingly popular due to the low computational requirements for simulating and to the ease of design (Bevilacqua *et al.*, 2020). Two main methods are defined: i) a deductive approach based on expert judgment from an area of application (for example for diagnosis in medicine, study of failures, waste management, green supply chain management (SCM)); ii) an inductive approach based on historical data and learning (to model perception of changes like for example in climate change and extreme weathers but also for optimal control) (Nair *et al.*, 2019). Based on the examples mentioned, FCMs can be useful for the supplier selection process and bring advantages to our research.

Our basic idea is to use FCMs to evaluate criteria and adjust the evaluation of weights for all criteria (from interdependencies between them) and incorporate new trends as the system changes. These changes can be internal and linked to suppliers which can have a positive or negative evolution in time (the study of the history allows to evaluate this evolution) or to the client (demand), or external and linked to the market and competition, policies and international events (like an economic crisis, a war, new business rules...).

The links between criteria correspond to causal relationships which could be in the same direction, in opposite direction or we could have no relation between two criteria. Then, a change in a criterion will cause a chain effects in the other criteria due to these causal relationships. The causal relationship (the weight) between the criterion C_i and the criterion C_j is denoted by w_{ij} (with i and j in the set of all criteria $\{1 \dots C\}$ and $i \neq j$).

This weight (w_{ij}) could be a fuzzy number which allows defining for each criterion a state value for a given period t . For each causal relationship, 11 linguistic terms are defined: “veryhigh resistance” (which represents a very high negative connection), “high resistance”, “medium resistance”, “low resistance”, “verylow resistance”, “nothing”, “verylow connection”, “low connection”, “medium connection”, “high connection” and “veryhigh connection”, see Figure 3-3.

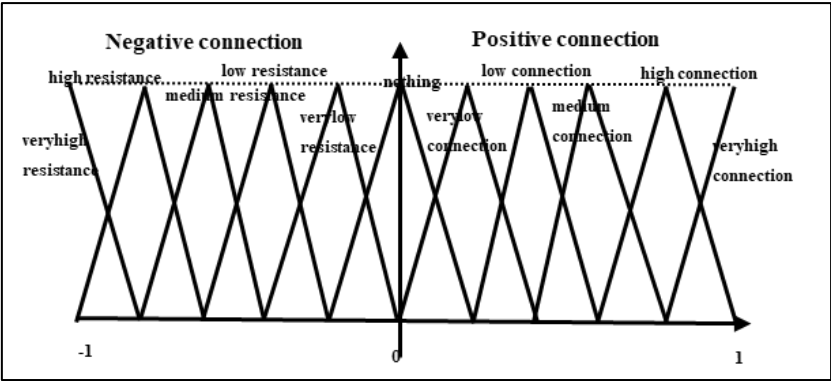


Figure 3-3- Fuzzy sets for the weights w_{ij} .

Furthermore, since we consider manufacturers’ expert and since manufacturers are different with different local objectives, their experts could have divergent judgement, so a learning algorithm will be applied to solve this deviation and obtain appropriate results. The nonlinear Hebbian learning algorithm (NHL) is employed since it is well known and well used for FCMs (*Modeling Implicit Bias with Fuzzy Cognitive Maps - ScienceDirect*, n.d.). The principle is as follows, during the readjustment of the FCM, the weights (w_{ij}) of the criteria change with a first-order learning law that is based on the correlation Hebbian learning law, i.e. criteria which tend to be positive or negative at the same time will have strong positive weights, while those that tend to be opposite will have strong negative weights. In the next subsection, the presented FCM will be discussed based on the definitions in this subsection.

3.3.2 Proposed FCM principles

The principles can be detailed more through several steps. The supplier selection algorithm is given by the following steps.

Step 0: Identification of key parameters and expert system definition

Step 0.1. Establish the experts' panel in function of the main area of expertise and following criteria areas. This panel could be a group of experts that allows avoiding as much as possible subjective evaluations (made by a sum of individual evaluations separately). This panel could be defined for the overall system (all manufacturers and the distribution part). It is composed of at least one expert per manufacturer. The experts will have access to their panels which is predefined with the necessary questions that they have to answer.

Step 0.2. Identify all parameters influencing the supplier selection problem. These parameters could be the main criteria for the problem. At the beginning, these parameters could be defined with the help of experts and a literature review, and after the first period, the data analysis system could help us to identify other key parameters (see also the following step 1). The initial possible criteria and sub-criteria are given in Table 3-1 (given by data from literature).

Table 3-1- Evaluation criteria for suppliers in the SC

Criteria	Sub-criteria	Definition	Ref
Economic	Quality (EC1)	Whether the raw material and services can satisfy the producer and customer requirements	(Stević <i>et al.</i> , 2020), (Ghadimi <i>et al.</i> , 2018), (Kannan, 2018), (Rabbani <i>et al.</i> , 2019), (Tayyab & Sarkar, 2021), (Tavana <i>et al.</i> , 2021)
	Cost (EC2)	The amount of money that should be paid for the raw materials and services	
	On-time delivery (EC3)	The deadline for providing and sending the raw materials by the suppliers	
	Flexibility (EC4)	The ability to respond according to the new orders and adaptative reactions in different situations during a period	
	Reliability (EC5)	The possibility to complete all the assigned tasks	
	Technology capacity (EC6)	The ability to adapt new improvements and features to the raw materials	
	Products diversity (EC7)	Set of products and services that a supplier company can offer at the same time	

Social	Work safety and labor health (SO1)	Measurement facility implementation for the security of laborers' life and health	(M. Zhang <i>et al.</i> , 2017), (Vatovec <i>et al.</i> , 2013), (Daughton, 2014), (Mohammed <i>et al.</i> , 2019), (Rashidi & Cullinane, 2019)
	Employment practices (SO2)	Continuous training and teaching for employment about work safety and security	
	Creating job opportunities (SO3)	Try to employ people from the neighborhood area of the supplier company	
	The right of stakeholders (SO4)	Respect the general idea of the stakeholders at the organizational level	
	Respect for the policies (SO5)	Adopt organizational and managerial procedures according to the legal and other rules to meet the burdens of the supplier	
Environmental	Recycling (EN1)	The raw material can have a reusable characteristic when it is collected as waste	(Ahsan & Rahman, 2017), (Govindan <i>et al.</i> , 2020), (Banaeian <i>et al.</i> , 2018), (H. Li <i>et al.</i> , 2021), (Sadat Hosseini <i>et al.</i> , 2021), (Tong <i>et al.</i> , 2022)
	Pollution control (EN2)	The supplier ability to produce green products and reduce pollution	
	R&D (EN3)	The supplier company section to research and develop green products	
	Environmental management system (EN4)	Implementation ISO 14,001 standard in all organizational level	
	Eco-design (EN5)	Whether the raw material and product packages are compatible with the environment in both protection and service aspects	
	Energy consumption (EN6)	The amount of Energy that the supplier consume to provide the raw materials	
	Resource consumption (EN7)	The amount of resources that the supplier consume to provide the raw materials	

Feedbacks	Customers feedback (FE1)	The customer's evaluation about the product and the supplier which will be obtained in each period	(Ding, 2018), (Rashidi <i>et al.</i> , 2020),(Joakim Larsson & Fick, 2009)
	Experience of the integrated system in the SC (FE2)	The collected data during the time in the integrated system about the performance of a supplier and previous experiences	

Step 0.3. Define the questionnaire (in Appendix A), which will allow us to identify criteria and sub-criteria and capture the experts' viewpoint regarding the existence of causal relationships between the nodes (weights from 0 to 1).

Step 1: Using the data of questionnaire

Remark: Data collection and analysis can be done in future researches (collect internal and external data from IoT network and from market, partners, social networks and analyse these data with a machine learning procedure to identify key parameters and trends for our system). The suppliers' evaluation is based on experts' judgment .

Step 1.1. The collection of internal data.

Step 1.3. Use data for the criteria and sub-criteria selection analysis, and define a data analysis procedure.

Step 2: Define criteria and sub-criteria (Figure 3-4 depicts the whole procedure of step 2.)

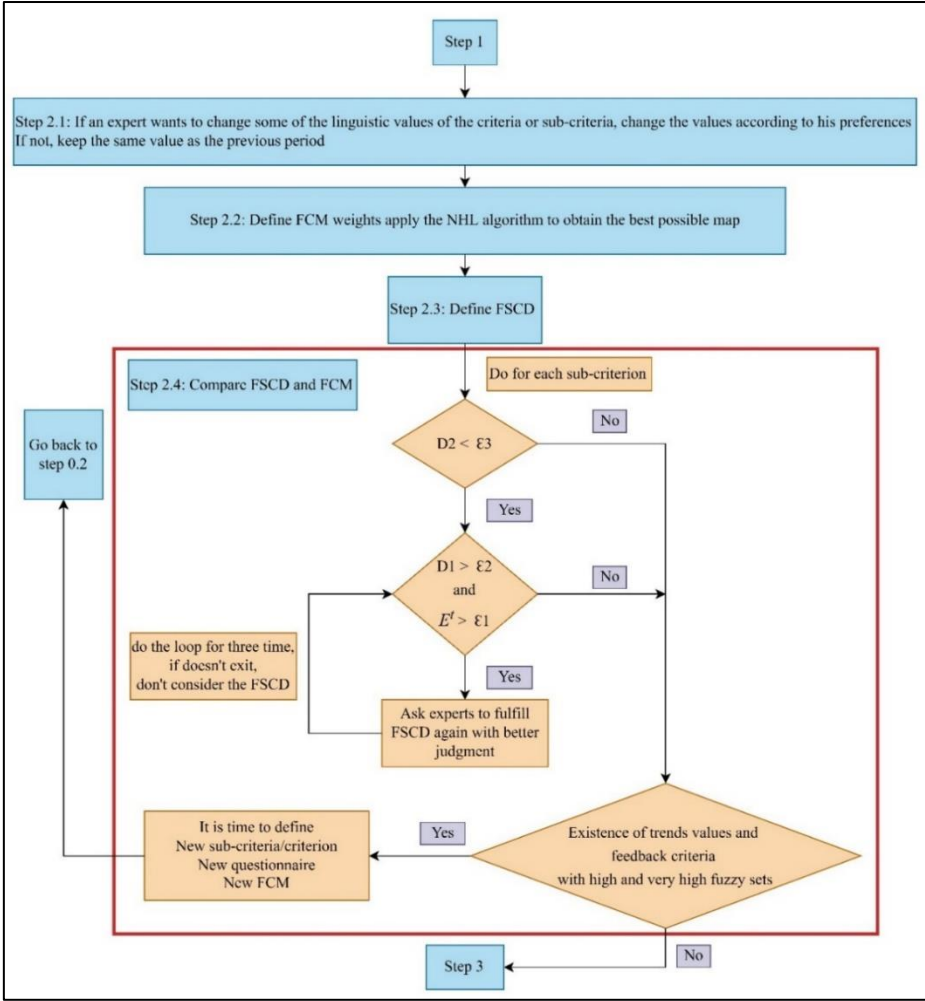


Figure 3-4- the procedure of step 2

Our idea is to propose an evaluation method that allows integrating modifications in the selected criteria and sub-criteria definition. These modifications can be linked to the importance of these criteria for a given period of time, and this importance varies according to the system’s evolution. Besides, new criteria may appear, and the initial criteria may lose importance by raising the new trends. To do this, we propose using and adapting FCM to our problem of sub-criteria. Furthermore, since experts could have a bad judgment, it is tried to adjust with the NHL, which is well known and well used for FCMs to correct the experts’ idea (Kannappan *et al.*, 2011). The expert ideas remains the same up to the time when a change is necessary.

The process is described as follows:

- Step 2.1. Identify all criteria and sub-criteria based on expert opinion from the questionnaire
- Step 2.2. Define the FCM graph. It is represented in Figure 3-5 for time $t=0$ of the presented system.

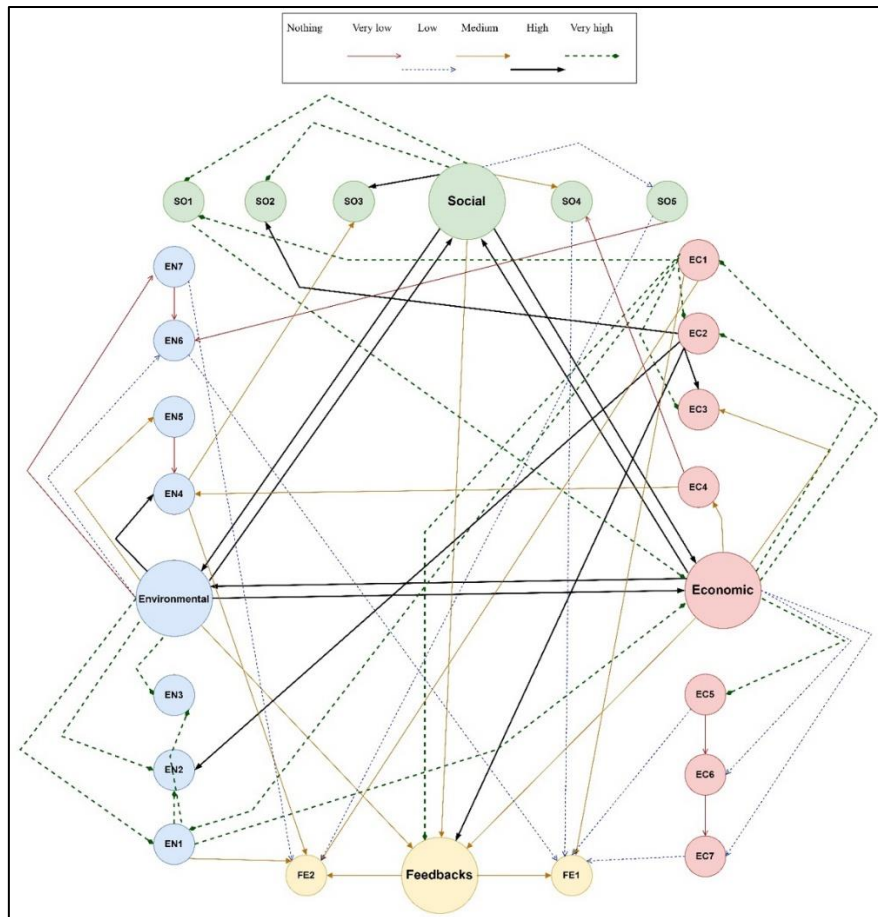


Figure 3-5- FCM of the $t=0$ in the system according to the literature background

To have such figure, several sub-steps are necessary as follows:

- Analyze the questionnaire and define casual relationships between criteria and sub-criteria.
- Calculate the value of each criterion and sub-criterion according to the interactions between criteria and sub-criteria causal-effect relationships.
- Define causal relationships with the help of fuzzy numbers (qualitative evaluation) in six linguistics terms: nothing (Nothing), very low connection (VL), low connection (L), medium connection (M), high connection (H), and very high connection (VH) in Figure 3-6 (a).
- Define C_{FCMi}^t as the state value of criterion i at time t and C_{FCMi}^{t+1} as the state value of criterion i at time $t + 1$ (when t is representative of the periods). Then, define C_{FCMj}^t as the state value of criterion j at time t and w_{ij} as the weight between criterion i and j .
- If $w_{ij}=1$ then C_{FCMj}^t causes C_{FCMi}^t in its direction (it is proportional, the more we have C_{FCMj}^t the more we will have C_{FCMi}^t) which means very high. If $w_{ij}= 0$ then there is no

causal relationship between C_{FCMi}^t and C_{FCMj}^t which means nothing. We C_{FCMi}^{t+1} is given in equation (1):

$$C_{FCMi}^{t+1} = f \left(\sum_j C_{FCMi}^t w_{ij} + C_{FCMi}^t \right) \quad j \neq i \quad (1)$$

- Define $f(.)$ as the threshold function, used to transform the sum of causal effects on the criterion C_i and the previous value of this criterion C_i . $f(.)$, could be the sigmoid function given in equation (2):

$$f(x) = sig(\alpha x) = \frac{1}{1 + e^{-\alpha x}} \quad (2)$$

Where α determines the slope of the function, it is greater than 0 and is defined based on empirical study. This sigmoid function represents the fact the causal relationships could have the same or opposite direction in $[0,1]$.

- Then, NHL algorithm obeys the equation (3):

$$w_{ij}^k = sgn(w_{ij}^{(k-1)}) (\mu |w_{ij}^{(k-1)}| + \pi C_{FCMi}^{(k-1)} (C_{FCMj}^{(k-1)} - sgn(w_{ij}^{(k-1)}) w_{ij}^{(k-1)} C_{FCMi}^{(k-1)})) \quad (3)$$

Where μ and π are the learning parameters of weight reduction and $w_{ij}^{(k)}$ is the updated weight at k th iteration. μ and π will be calculated by trial and error, and they can guarantee coverage toward the optimal solution.

According to the literature presented in the first chapter, the most effective values are: $0 < \mu < 0.1$ and $0.9 < \pi < 1$ that are obtainable by simulation (Khodadadi *et al.*, 2019). Besides, the termination condition happens when the differences of two iterations are less than a small considered value.

Triangular fuzzy number, one of the most practical fuzzy numbers, is used to assign the values to the linguistic sets. The fuzzy set is employed to solve real-world complicated systems interactions with humans by designing robust and flexible models (Inuiguchi *et al.*, 1990).

It has to be noticed that the weight (causal relationships) could be fuzzy numbers or crisp values. At the end of this part, we have a FCM. In the next part, a supplementary method is defined to compare with the results of the FCM and for better validation of the final results of supplier selection method.

Step 2.3. Define fuzzy expert system (FSCD). Several necessary sub-steps are as follows:

- Define a fuzzy linguistic value for each criterion and sub-criterion based on manufacturers' experts. This fuzzy linguistic value is defined on a larger scale than FCM which allows us to obtain more accurate (if judgement of experts is good) and precise values.
- It is important to note that a value of trending to these linguistic values is added to express the importance and sudden rise of a criterion. Therefore, the set of θ can be defined as: $\theta = \{\text{Very Low(VL), Low(L), Medium Low (ML), Medium(M), Medium High(MH), High(H), Very High(VH), Trend (Tr)}\}$ see also Figure 3-6 (b).

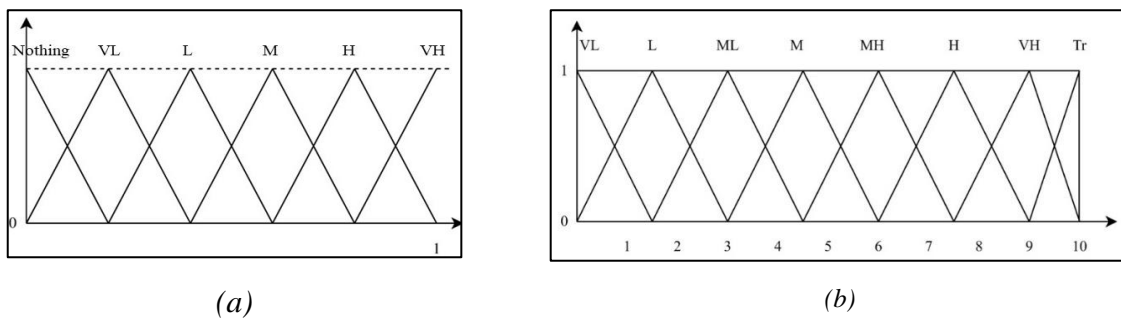


Figure 3-6- (a) Fuzzy sets for the weights w_{ij} in the FCM
(b) Linguistic scale of FSCD

- Define CW_{Ci}^t as the mean value of manufacturers' experts ideas. It can be obtained by using fuzzy triangular numbers where CW_{Cij}^t is the weight of criteria C_i in the period t according to the manufacturer j decision maker (with j from 1 to M) in equation (4).

$$CW_{Ci}^t = \frac{CW_{Ci1}^t + CW_{Ci2}^t + \dots + CW_{CiM}^t}{M} \quad \forall t \in \{1 \dots T\} \quad (4)$$

- For each possible sub-criterion, the mean value defined by the manufacturers' experts will be calculated. RW_{CijN}^t depicts the weight of sub-criterion k in criterion C_i in the period t according to manufacturer j decision-maker (with j from 1 to M). It can be obtained according to the equation (5):

$$RW_{kCi}^t = \frac{RW_{kCi1}^t + RW_{kCi2}^t + \dots + RW_{kCiM}^t}{M} \quad \forall t \in \{1 \dots T\} \quad (5)$$

In the next steps, we will compare FCM and FSCD to validate our experts' judgements.

Step 2.4. Compare FCM and FSCD

After obtaining the weight from point of view of both methods, it is time to compare them. Several important notes for comparing these two algorithms and the reasons are mentioned in the sub-steps as follows:

- The main procedure checks the differences between the FCM and FSCD in each period. If the gap is huge and the differences of each one of them from the previous period value of themselves is notable, it will bring the idea of adding new criteria to mind. This huge gap can be different from system to system based on the importance of the criteria.
- Using the trend value of the fuzzy linguistic values and customer feedback lead to a considerable gap between the FCM and FSCD values that display it is time to formulate new criteria in the system.
- The weights will be recalculated by introducing a new criterion, and the new FCM will be introduced. It is important to note that at the beginning of the system, the main reliable weights are the FCM, and each time the FSCD will be compared with the FCM values.
- This comparison improves the final weights because these two approaches have a different point of view. FCM focus on the relationships between criteria, and the fuzzy expert system focuses on the manufacturers' perspectives.

The way we calculate these differences are mentioned in the sub-steps as follows:

- Calculation of the difference between the two methods

$$E^{t+1} = \max_i \left| 10 * C_{FCMi}^{t+1} - C_{FSCDi}^{t+1} \right| \quad (6)$$

where C_{FCMi}^{t+1} is the value obtained with the FCM for a given sub-criterion at time t+1 (it is included in [0;1]) and C_{FSCDi}^{t+1} the value obtained with the FSCD for the same sub-criterion at time t+1.

- The calculation for each method of the deviations obtained between two periods to readjust the values if necessary

$$D1 = \max_i \left| C_{FSCDi}^{t+1} - C_{FSCDi}^t \right| \quad (7)$$

$$D2 = \max_i \left| C_{FCMi}^{t+1} - C_{FCMi}^t \right| \quad (8)$$

Experts are responsible for fulfilling the questionnaire in the first period. In the next period, they just do the modifications if they think it is necessary. Then the related FCM will be calculated, and then NHL will be applied. The reason is that after the implementation of the NHL, we have a correct value of weights of criteria and sub-criteria to rely on it. Then, we start to compare the differences in the FCM value with the previous period. Therefore, the complete version and definitions for the all possible occasions that can happen for this comparison can be mentioned as follows:

- Suppose no considerable differences exist with the last period while there are considerable differences in FSCD values with the last period or between the value of the two methods. In that case, it means that the FSCD has been done miss correctly. Then, there are a maximum of three times (based on the experimental results) of correcting the judgment of FSCD to remove this gap; otherwise, the FSCD method will be ignored to calculate the criteria and sub-criteria. For mentioning it again, the reason is that we are confident in the correctness of the FCM values after applying NHL.
- In all other conditions, in the next phase, we check the existence of trends values and feedback criteria with high and very high fuzzy sets. If yes, we can have several new definitions such as sub-criteria and criteria questionnaire and FCM from the beginning, which means step 0.2 regarding the system condition and obtained values. If not, we go to the next stages. By making these loops, we assure that we can dynamically update the state of the algorithm (1) and be sure about the judgment of experts.

In the next step, the way to identify the suppliers have been mentioned.

Step 3: Evaluate suppliers for the period

The evaluation of known and new suppliers is then defined by three sub-steps. To evaluate suppliers according to the criteria and sub-criteria mentioned in Step 2. It is important to note that this evaluation happens in each period, and a new or multiple sub-criterion can be added in different periods. The sub-steps are as follows:

- Each supplier will be assessed according to the specific raw material p' . Let us define $PW_{kCiSp'j}^t$ that depicts the weight of supplier s to supply raw material p' based on sub-criterion k in criteria Ci in the period t according to the manufacturer j decision-maker (with j from 1 to M). $PW_{kCisp'}^t$ depicts the mean value of the weight of supplier s to

supply raw material p' based on sub-criterion k in criteria C_i in the period t . It can be obtained according to the equation (9):

$$PW_{kCisp'}^t = \frac{PW_{kjsp'1}^t + PW_{kjsp'2}^t + \dots + PW_{kjsp'M}^t}{M} \quad \forall t \in \{1 \dots T\} \quad (9)$$

- All the previous phases' values will multiply according to equation (10) to obtain $A_{sp'M}^t$ (a,n,b). Then by using equation (11), $B_{sp'M}^t$ is the defuzzified value of $\alpha_{sp'M}^t$ (a,n,b) (Perry & Greig, 1975).

$$A_{sp'M}^t = \sum_k \sum_m \sum_j CW_{km}^t RW_{kjm}^t PW_{kjsp'}^t \quad \begin{array}{l} \forall t \in \{1 \dots T\}, \\ \forall p' \in \{1 \dots P\}, \\ \forall s \in \{1 \dots S\} \end{array} \quad (10)$$

$$B_{sp'M}^t = \frac{a + n + b}{3} \quad \forall t \in \{1 \dots T\} \quad (11)$$

- In this phase, the normalized value ($es_{st}^{p'}$) of each supplier s_t will be calculated by using equation (12):

$$es_{st}^{p'} = \frac{B_{sp'M}^t}{\sum_s B_{sp'M}^t} \quad \forall t \in \{1 \dots T\} \quad (12)$$

After discovering the normalized weights, it is possible to discuss about the contracting parts in the mentioned system.

Step 4: Subcontracting

After evaluating suppliers, they will be added to the system as the BT's miners and can be possible suppliers of the raw material. Besides, even if the supplier supplies zero raw material, it will be a miner of the BT. The reason is that the data of the supplier will be shared through BT. The contract will be made between the manufacturers and suppliers in this step. In each period, the new suppliers can be new miners in the BT system. Besides, the selection will happen according to the mathematical formulation, and the normalized weight of the suppliers will be the co-efficient of the purchasing from qualified suppliers' objective function. It is important to note that smart contract 2 will select the suppliers.

Based on the findings in this section, the results improvement by adding the supplier selection procedure from the previous section is presented.

3.4 Results

Based on the results obtained from the FCM (in Appendix A), it is possible to compare the impact of better supplier selection in the distribution part. We defined an expert panel composed of 4 experts (one expert per manufacturer). The final FCM is given in Figure appendix B-1. In this chapter, we do not present all possible cases but only consider the obtained values for one supplier and one product. In Table 3-2, the results for sub-criteria were obtained with the FSCD (first period). For this case, no changes are necessary. The obtained values are closed for both FCM and FSCD for each criterion and sub-criterion.

Table 3-2- Importance of criteria, sub-criteria, and suppliers

$A_{sp'M}^t = (1345.883203, 3381.064453, 6746.708531)$ $B_{sp'M}^t = 3824.552063$					
$eS_{st1}^{p'}$					
p' / s_t	1	2	3	4	5
1	0.21	0.19	0.20	0.20	0.20
2	0.20	0.24	0.19	0.17	0.20
3	0.18	0.18	0.23	0.20	0.21

Therefore, we repeat this procedure for each period to obtain the weight of the suppliers. The suppliers will know their chance of selection to supply raw materials. If we consider a problem with three periods, ten different suppliers are available for the considered time horizon. Besides, the number of them can vary from period to period. Four manufacturers, five DCs, three products and raw materials, three sets of routes between all actors, and three different vehicles. All the notations and data are exactly same as the previous chapter, but the only thing is changed is the supplier selection procedure. Therefore, the comparison of the results is presented in Table 3-3.

Table 3-3- Comparison of the impact of the suppliers selections in the final results

Objectives in the basic model	With supplier selection	Without supplier selection
Final cost (Z1)	11802.801	11905.964
Purchasing from qualified supplier (Z2)	850.320	716.983

Based on the improvement in the final cost and qualified supplier selection, it can be proven that the mentioned procedure is validated. In the next section, we will conclude the chapter based on the findings.

3.5 Conclusion and future perspectives

In this chapter, the algorithm of the presented smart system is completed. This system consists of two different smart contracts. The first smart contract is dedicated to dynamic supplier evaluation, and the second smart contract is dedicated to the distribution of the products (discussed in the previous chapter). This chapter exclusively highlights the importance of the first smart contract and the improvement that can happen for the distribution of the products which is discussed in the previous chapter. Then, the final system has been introduced, and the reasons for using two different smart contracts have been provided.

Furthermore, a fuzzy cognitive map is proposed for the dynamic supplier selection problem. The dynamic aspect considered here is not related to the operational dynamics of the supply chain (SC) during a period but to the changes that can occur in the environment of the SC. For example, the market demand may affect the supplier's selection. Of course, in our fuzzy cognitive map the prices, quality, lead times and other suppliers' criteria are considered. The interests of the use of the fuzzy cognitive map are firstly to allow taking into account the interdependencies between the criteria and secondly to be able to define a system allowing to link the criteria with potential changes and thus to integrate the evolutions of the system. Our approach is deductive on the basis of a questionnaire proposed to purchasing and raw material supply managers and inductive on the basis of the results provided by data analysis (the latter not being studied in the document). We apply our approach to the case of a pharmaceutical SC whose producers and non-final customers (hospitals, pharmacies). The fuzzy cognitive map is proposed for this case. Moreover, to ensure the consistency of our results, the fuzzy cognitive map is associated with the non-linear Hebbian algorithm in order to ensure the adequacy between the obtained results and the reality. It should be noted that not all the criteria have been presented in this chapter.

For future works, we have to validate our approach by interviewing more actors (in Europe but also in other geographical areas) to complete and refine our results. The data collection and analysis part must also be fleshed out by testing different machine learning algorithms and verifying the results obtained. This part is important since we have developed also an inductive method to be sure to consider new trends. In the pharmaceutical industrial sector, many data

are increasingly available but their heterogeneity does not facilitate the implementation of tools that are easily adaptable according to the type of drugs, marketed products and patients. We have applied our approach to pharmaceutical supply chains (PSCs), but a generalization to other industrial sectors would also be interesting. More important for the future direction can be adding the possibility of actors collaborations directly in our integrated system. By using this system, possible necessary infrastructure may exist for the actors to present their expectations and preferences to each other. In this manner, it seems that many possible collaboration strategies can be found in the material flows and information flows of the system which we will discuss in the next chapter.

Chapter 4 Potential enhancement based on collaborative proposals

Rely on the described system in the previous chapters, we may be able to improve the distribution process by suggesting collaborative approaches among different actors and stages. For this, sharing reliable data and traceable information is crucial to execute the appropriate actors' actions. We propose several collaboration approaches through our proposed system using information exchange among actors. By this approach, it is expected to remove third parties from the collaboration strategies. The collaboration activities are integrated with a mathematical formulation based on mixed integer programming. The combination of our proposed system and collaboration strategies may significantly contribute to the automation of the distribution process and facilitate actors interaction. Finally, through these interactions, the room might be opened for more sustainable development perspectives.

4.1 Introduction

The SC's collaborative and inter-firms relationships methods have become a more widely studied subject in recent years since they allow value exchanging (Lindsey Hall *et al.*, 2022). These strategies call for collaboration and planning among numerous SC participants, including suppliers, manufacturers, distributors, retailers, and customers. The collaboration aims to improve customer satisfaction, optimize the SC, and cut expenses while increasing efficiency. Numerous applications, such as collaborative planning, forecasting, and replenishment; vendor-managed inventory; collaborative transportation management; collaborative outsourcing; collaborative product development; and collaborative risk management have been proposed in the concept of SC with different resolution approaches (Malacina & Teplov, 2022). The resolution approaches are brought up to highlight the impact of the collaborations and assess the performance of the SC elements. These different approaches can be based on mathematical resolution, interviews and surveys, best practices and guidelines and SC mapping. Among many different approaches, mathematical resolution has been used extensively in the area of collaboration to model and optimize processes. Furthermore, it allows to highlight goal achievements based on preferences (Settanni *et al.*, 2017). Mathematical models such as game theory and mixed-integer programming (MIP) can be used to represent the different mechanisms in the context of collaboration and to assess the effects of that collaboration on the performance of the SC (Ivanov, 2010). Most of existing articles have modeled and analyzed collaborative SCs using game theory (Hudnurkar *et al.*, 2014). In this chapter, we would rather use MIP instead of game theory (Leng & Parlar, 2005). In game theory, it is preferred to discuss actors' strategies and their preferences to increase their own profit (Gao *et al.*, 2022). We would rather focus on a more operational level, focusing on satisfying the demands and introducing a tool for collaborative approaches using MIP.

Several examples of using MIP in the collaborative approaches of SC can be mentioned as follows. (Kalantari *et al.*, 2023) uses the potential of drivers to diffuse information in the purchase of transportation services to create an optimization technique employing a multi-objective model. By assigning shipping orders to drivers, the objectives include time, cost, and the appropriateness of the drivers. Based on a mathematical formulation, the interaction between drivers is highlighted to show the collaboration. In order to better serve consumers, (Vaziri *et al.*, 2019) provides a vehicle routing problem with fair carrier collaboration that divided multi-pickup and delivery services. By taking into account the reduction of travel time, a MIP model is built to maximize the overall profit and the equitable distribution of profit

among the carriers. The presented problem is solved using a genetic algorithm. According to the results of the sensitivity analysis, raising the fairness collaboration coefficient between the carriers may result in a drop in the overall profit made. In general, MIP is used to formalize the collaboration activities.

The research gaps and novelty of this chapter based on collaborative approaches in the SC are mentioned in Table 4-1.

According to the scanty literature study, generally authors discussed collaborative approaches separately and their advantages for each actor in the system, and they highlighted IT systems benefits and added value toward the collaboration strategies. In this chapter, for the first time, we consider the most possible types of collaborations that can exist in a SC and highlight the scenarios that can improve the global interests of collaborations based on primary agreements and reliable data. The pre-agreements could be developed in the smart contract for more reliable and autonomous execution of the final results of the global system. The smart contract actions are integrated in the form of MIP. BT and IoT can be data providers for the system. Although we are not highlighting the BT and IoT data collection strategies and discussions, we emphasize their roles within the architecture of the presented system and highlight their negative and positive impacts on the proposed MIP and SC network. Therefore, the main contributions of this chapter (which are added to the previous chapters' contributions) are as follows:

- Introducing collaboration strategies between the SC actors, highlighting the different types of collaborations based on material and information flows and automating the collaborative procedures through the presented smart contract.
- Solve the presented MIP with an exact method. Solving the problem in different types of examples and cases based on real-world use cases and analyzing the results with regard to collaborative strategies.

Table 4-1- Literature background in Collaborative approaches in SC

References	Types of collaborative approaches				Types of mathematical Formulation	Global approach	Objectives		Smart contract integration	Data providing tools	SC characteristics		Resolution approach
	Collaborative forecasting	Collaborative inventory	Direct purchasing	Undeliverable demand			Cost function	Demand satisfaction			Multiple products type	Multiple periods	
(Pibernik <i>et al.</i> , 2011)	✓				Game theory		✓				✓		Inverse optimization
(Aloui <i>et al.</i> , 2021)	✓			✓	MIP	✓	✓				✓	✓	CPLEX
(Chan <i>et al.</i> , 2004)	✓			✓	MIP		✓				✓	✓	Combination of analytic hierarchy process with genetic algorithms
(T. K. Agrawal <i>et al.</i> , 2022)	✓		✓	✓	-			✓	✓	✓	✓		Ethereum BT
(Guo <i>et al.</i> , 2022)	✓	✓			MIP	✓	✓				✓	✓	CPLEX
(Chen & Chen, 2005)		✓			MIP		✓				✓		Mathematica
(Al-Ashhab, 2023)		✓	✓		MIP	✓	✓	✓			✓	✓	Mosel language
This chapter	✓	✓	✓	✓	MIP	✓	✓		✓	✓	✓	✓	CPLEX

The rest of chapter is organized in the following way. The problem and system are described in the section 2. Section 3 addresses possible collaborations strategies that can exist in the system. Section 4 presents the mathematical formulation of the collaborations and presented smart contract. In section 5, the experimental results based on several cases and scenarios are surveyed. Section 6 is dedicated to possible sustainable development in the collaborative strategies. Finally, conclusions and future perspectives are represented in section 7.

4.2 Problem description

The proposed SC consists of four main stages: suppliers, manufacturers, distribution centers (DCs), and customers. Between stages, the transporters are responsible for conveying the products. (Figure 4-1)

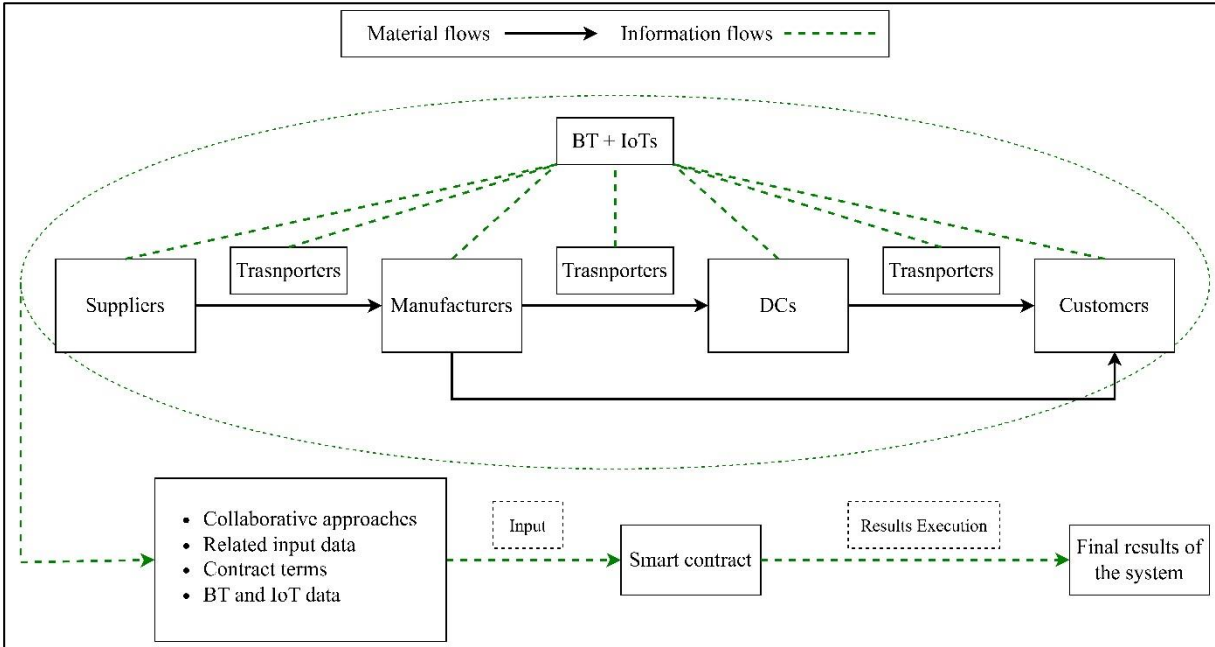


Figure 4-1- Graphical abstract of the problem

The roles are as follows:

An introduced smart contract based on a mathematical formulation using the input data of the related information of the physical system and the possible collaborative approaches will propose the solutions. The proposed results of the smart contract are the actions that should be done by the actors to optimize the cost function related to the pre-agreement. The results are possibly the most optimal solution but only based on the predefined scenarios. The limits of the smart proposed system can be inability to take an action out of the pre-defined scenarios.

In the concept of SC, multiple barriers exist for more negotiations and counter-offers for achieving a higher profit for an actor. These barriers consist of governments regulating for trading and selling the products at a reasonable price and quality. This regulation can have a great impact on all SC actors' strategies that can make the exchange a challenging task. The other barrier is related to the occasions that are happening related to the human beings lives. Sometimes with a disaster such as floods and earthquakes, there is no other choice than a fast collaboration between the SC actors to reach a solution to supply the products for the community. For example, at the beginning of COVID-19, they were just a collaborative approach between multiple countries' laboratories to find a solution. The last barrier can be mentioned as the human being's ethics and morals for producing a pharmaceutical product by better supplying the final customers with lower cost and better quality. Therefore, regarding the barriers, the collaboration in the presented system will be considered as "let's win together with a few possible compromises to have better final results for the global system."

All the collaborations will be described in a mathematical formulation integrating the smart contract scripts. In the next section, we will discuss the possible collaborations in the presented system and its impact on actors and the global system.

4.3 Possible collaborations and their purposes

First, we will define four different collaborations and discuss main counterpart and example of each. Then, the interests, limits, and impact of collaborations on each actor will be discussed.

Figure 4-2 represents the collaborations relations between the actors for a system consisting of three suppliers, two manufacturers, two DCs and three customers.

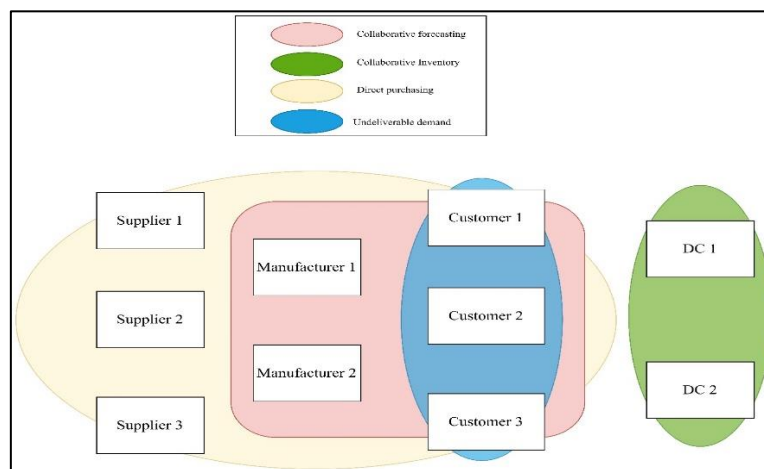


Figure 4-2- Collaborative relations between the actors

The collaborations are as follows:

1. Collaborative forecasting of demand and devising production plans using a decision-making tool. Relying on a system based on BT and trusted information-sharing protocols connected to the smart contract, it can be possible to share the market demand and impact forecast tools for future production planning of manufactures in the collaborative mode. In the non-collaborative mode, they obey to a fixed production planning procedure. In this collaborative mode, an important counterpart exists. Several producers, retailers, and customers have problem with sharing some private and strategic data. This counterpart increase a well-definition of data sharing procedure between entities.
2. Collaborative inventory management. In non-collaborative mode, final products are stored in the DCs, and each DC is responsible for its own customers' demands. In collaborative mode, DCs can start sharing their resources and support each other to answer the customers' demands. Multiple limits can be considered such as the distance and range of collaboration on the roads between DCs. These two modes are defined based on the definition of each DCs customer in the smart contract scripts. This definition consists of two possible sides. One of them is the owned customers, and the other one is the non-owned customers. Owned customers are the ones who are directly related to the DC, and it is responsible for them. Non-owned customers are the others DCs' customers. It means that before finalizing and deploying the smart contract, each DC informs others about its collaboration level based on several important parameters such as geological distances. This level comes from the number of non-owned customers for which the DCs take responsibility in the collaborative mode. For example, several permanent blood centers can be considered. Each blood center is responsible to answer the demand of its region and centers are in different regions, while the blood products can have a high rate of perishment. Therefore, by collaboration between centers, it may be possible to answer better the demand as the shared goal of the entities (Manupati *et al.*, 2021). The main counterpart of such collaboration can be sharing the level of inventory between the DCs. Each DC may have limited capacity to answer the demand of its customer and a number of products to share. The amount and timing of sharing the resources are dynamically changing and it is important to consider it in the collaboration modes.

3. Acceptance of direct purchasing of final products by manufactures. In the collaborative mode, some or all manufacturers try to answer the demand of the markets, when the DCs are not able to do. In this regard, with a “higher cost”, they start sending the products directly to the customers. The “higher cost” is representative of more distances, more time, more packaging cost, more human resources cost and so on. The manufacturers could be competitors but we do not consider this case in this article. The DCs can lose some of their demands because the manufacturers will directly do it. In non-acceptance mode, the direct purchasing is considered as not possible. The proposed smart contract just ask the possibility of the collaborative mode from each manufacturer to each customer. The decision-making will be made according to the final production and transportation cost. The main counterpart will be the acceptance of DCs to let such collaborations happen because there is the possibility of losing some of their customers.
4. Acceptance of undeliverable demand for customers. In the collaborative mode, all or some customers accept not to receive the final product when needed. This option can have an important cost in the system such as losing the customers, time of answering the demand and so on. In the non-collaborative mode, the undeliverable demands are expected not to happen in the markets. It is important to note that when a demand is undeliverable, it can be supplied by delay or by an external entity. The acceptance of undeliverable demands for a product come from two main reasons. Firstly, there are many alternative products and brands for a specific product in the market. Furthermore, some products are not crucial enough to be supplied right at the moment to prevent the undeliverable demands. As an example, blood is a vital product that should be supplied right at the moment of the demand, and there will be no collaboration for the undeliverable demands of such a product. However, a pain reliever product such as Paracetamol medicines like Doliprane can be supplied by other alternatives. In the smart contract, when the undeliverable demands are possible, in the script, the smart contract can consider between the selection of undeliverable demand and other possible material flows based on costs. The main counterpart can be the shipping time and receiving products for the customers.

Based on these options, the mathematical formulation of the presented collaborations integrated into the smart contracts is presented in the next section.

4.4 Mathematical formulation

This section consists of model assumptions, notations, objective function and constraints.

4.4.1 Model assumptions

The model assumptions are as follows.

- The costs are constant and known
- The total number of periods, suppliers, manufacturers, DCs, customers, roads and transporters are given
- The time horizon is finite
- The inventory level of DCs at the beginning is equal to zero
- The periods are constant

4.4.2 Notations

The notations are as follows.

Notations	Definitions
Sets	
t	Set of periods from 1 to T
K	Set of all possible suppliers in each period with $k \in \{1 \dots K\}$
M	Set of manufacturers m with $m \in \{1 \dots M\}$
S	Set of DCs s with $s \in \{1 \dots S\}$
Pr, Pr'	Set of raw materials Pr' and final products Pr with $pr' \in \{1 \dots Pr'\}$ and $pr \in \{1 \dots Pr\}$
I	Set of roads i between manufacturers m and DCs dc with $i \in \{1 \dots i\}$
J	Set of roads j between suppliers k and manufacturers m with $j \in \{1 \dots j\}$
E	Set of transporters e between manufacturers m and DCs S with $e \in \{1 \dots E\}$
C_s	Set of customers of the DC s from 1 to C_s , $\forall c_s \in \{1 \dots C_s\}$ and $C_{s'}$ means the customer of other DC s'
Parameters	
pcm_{mt}^{pr}	Cost of producing product type pr in the manufacturer m at period t (per unit)
$qc_{kmeit}^{pr'}$	Cost of transferring raw material pr' from supplier k to the manufacturer m with transporter e in rout i at period t (per unit)
pc_{msejt}^{pr}	Cost of transferring product type pr from manufacturer m to the DC s with transporter e in rout j at period t (per unit)
h_{st}^{pr}	Holding inventory cost of product type pr in the DC s at period t (per unit)

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$cund_{c_s t}^{pr}$	Cost of undeliverable demand of product type pr for the customer c_s at period t (per unit)
$cdp_{mc_s e j t}^{pr}$	Cost of direct purchasing of product type pr that should send from manufacturer m to the customer c_s with transporter e in rout j at period t (per unit)
$\theta_{kt}^{prpr'}$	The needed percentage of raw material pr' to produce product type pr by purchasing from the supplier k at period t (per unit)
$esdem_t^{pr}$	Estimated demand of the product pr at period t
$cap_{kt}^{pr'}$	The capacity of the supplier k to supply the raw material pr' at period t
$dem_{c_s t}^{pr}$	The demand for the product type pr of the customer c_s at time t
qc_{mt}^{pr}	The possible percentage of detected product type pr in manufacturer m at time t by sensors during the quality control of the production
fsf_{mt}^{pr}	The possible percentage of detected product type pr in manufacturer m at time t by sensors before sending toward the DCs
tf_{ejt}^{pr}	The possible percentage of detected product type pr with transporter e in rout j at time t by sensors during transportation
$tr_{eit}^{pr'}$	The possible percentage of detected raw material type pr' with transporter e in rout i at time t by sensors during transportation
$df_{s jt}^{pr}$	The possible percentage of detected product type pr in DC s that come from rout j at time t by sensors at the time they arrived to the DCs
BM	A very big number
$dmaxmd_{mst}^{pr}$	The maximum accepted delivery time for product type pr from manufacturer m to the DC s at period t
$dmaxsm_{s_t m t}^{pr'}$	The maximum accepted delivery time for raw material pr' from the supplier k to manufacturer m at period t
$dismd_{msj}$	The distance between manufacturer m and DC s in the route j
$dissm_{kmi}$	The distance between supplier k and manufacturer m in the route i
$aspm_{msej}$	The average speed of transporter e to transfer products from manufacturer m to DC s in the route j
$aspsm_{kmei}$	The average speed of transporter e to transfer raw materials from supplier k to manufacturer m in the route i
$coou_{sc_s t}^{pr}$	Cost of transferring final products of product type p from DC s' to customer c_s at period t to answer the demand
$cblcm_{mc_s t}^{pr}$	The cost of using BT for sharing the data for product type pr between manufacturer m and customer c_s at period t
$psli_{ss' t}$	Cost of collaboration and resource sharing between DC s and s' at period t
$Colu_{c_s t}^{pr}$	$\begin{cases} 1 & \text{if the undeliverable demand of the product type } pr \text{ is accepted by the customer } c_s \text{ at period } t \\ 0 & \text{otherwise} \end{cases}$
$Cold_{mc_s t}^{pr}$	$\begin{cases} 1 & \text{if the direct purchasing of the product type } pr \text{ produced is accepted by manufacturer } m \text{ to} \\ & \text{customer } c_s \text{ at period } t \\ 0 & \text{otherwise} \end{cases}$

$Coli_{sc_s,t}$	$\begin{cases} 1 \text{ if the link of sharing resources exist between DC } s \text{ and} \\ \text{customer } c_{s'} \text{ while } s' \neq s \\ \text{and for } s' = s \text{ at period } t \\ 0 \text{ otherwise} \end{cases}$
$Colcm_{mc_s,t}^{pr}$	$\begin{cases} 1 \text{ if the the data sharing for product type } pr \text{ exist between by BT the manufacturer } m \text{ and} \\ \text{customer } c_s \text{ at period } t \\ 0 \text{ otherwise} \end{cases}$
$dplim_{mc_s}$	Based on the distances between the manufacturer m and the customer c_s it is the possibility to not be able to directly supply the demand in a period of times
$limitdc$	The maximum number of the products can be transferred from DCs to customers
$cunw_{c_s,t}^{pr}$	Cost of unwilling unmet demand of product type pr for the customer c_s at period t (per unit)
Variables	
pm_{mt}^{pr}	Number of produced product type pr in the manufacturer m at time t
$qr_{kmeit}^{pr'}$	Number of transferred raw material pr' from supplier k by the manufacturer m with transporter e in the route i at time t
pdc_{msejt}^{pr}	Number of transferred product type pr from manufacturer m to the DC s with transporter e in the route j at time t
inv_{st}^{pr}	Inventory level of product type pr in DC s at time t
$und_{c_s,t}^{pr}$	Number of undeliverable demand of product type pr in customer c_s at time t that can collaborate on it
$tun_{c_s,t}^{pr}$	Total number of unprocessed demand of product type pr in customer c_s at time t
$unw_{c_s,t}^{pr}$	Number of unwilling unmet demand of product type pr in customer c_s at time t
$dp_{mc_s,ejt}^{pr}$	Number of direct purchased product type pr from manufacturer m to send to the customer c_s from route j at time t
x_{msejt}^{pr}	$\begin{cases} 1: \text{ If the product type } pr \text{ transfer from manufacturer } m \text{ to the DC } s \text{ with transporter } e \text{ in route } j \text{ at ti} \\ 0: \text{ Otherwise} \end{cases}$
$y_{kmeit}^{pr'}$	$\begin{cases} 1: \text{ If raw material type } pr' \text{ transfer from supplier } k \text{ to the manufacturer } m \text{ with transporter } e \text{ in rout} \\ 0: \text{ Otherwise} \end{cases}$
$oui_{sc_s,t}^{pr}$	Number of transferred final products of product type pr from DC s to the customer $c_{s'}$ at time t to answer the demand with $s' \in S$
Z	Cost objective function

4.4.3 Objective function

Equation (1) is the objective function based on economic costs.

$$\begin{aligned}
 \text{Min } Z = & \sum_t \left(\sum_{pr} \sum_m p c m_{mt}^{pr} p m_{mt}^{pr} + \sum_{pr'} \sum_k \sum_m \sum_e \sum_i q c_{kmeit}^{pr'} q r_{kmeit}^{pr'} \right. \\
 & + \sum_{pr} \sum_m \sum_s \sum_j \sum_e p c_{msejt}^{pr} p d c_{msejt}^{pr} + \sum_{pr} \sum_s h_{st}^p \text{inv}_{st}^p \\
 & + \sum_{pr} \sum_m \sum_{c_s} c b t l c m_{mc_s t}^{pr} C o l c m_{mc_s t}^{pr} + \sum_s \sum_{s'} \sum_{c_{s'}} p s l i_{ss't} C o l i_{sc_s't} \\
 & + \sum_{pr} \sum_{pr'} \sum_m \sum_s \sum_j \sum_{c_s} c d p_{mc_s e j t}^{pr'} C o l d_{mc_s t}^{pr} d p_{mc_s e j t}^{pr} \\
 & + \sum_{pr} \sum_s \sum_{c_s} c u n d_{c_s t}^{pr} C o l u_{c_s t}^{pr} u n d_{c_s t}^{pr} \\
 & \left. + \sum_{pr} \sum_s \sum_{c_{s'}} c o o u i_{sc_{s'}t}^{pr} o u i_{sc_{s'}t}^{pr} + \sum_{pr} \sum_s \sum_{c_s} c u n w_{c_s t}^{pr} u n w_{c_s t}^{pr} \right) \quad (1)
 \end{aligned}$$

It consists of ten different parts.

- 1) Costs of producing final products,
- 2) Cost of transferring raw materials from the suppliers to the manufacturers,
- 3) Cost of transferring the final products from the manufacturers toward the DCs,
- 4) Inventory holding cost,
- 5) Cost of collaborative forecasting which come from the data using BT (Based on the number of transactions),
- 6) Cost of collaborative inventory management which come from sharing resources (Based on the number of products exchanging between inventories),
- 7) Direct purchasing cost from manufacturers which comes from acceptance of direct purchasing,
- 8) Cost of undeliverable demands which is related to acceptance of undeliverable demand,
- 9) Cost of transferring products to the demands,
- 10) Cost of unwilling unmet demand (Based on the none defined unmet demand quantities),

The constraints are presented in the next sub-section.

4.4.4 Constraints

The constraints are as follows:

$$\sum_k \sum_e \sum_i \theta_{kt}^{prpr'} q_{kmeit}^{pr'} (1 - tr_{eit}^{pr'}) = pm_{mt}^{pr} \quad \begin{array}{l} \forall pr' \in \{1 \dots Pr'\}, \\ \forall pr, \in \{1 \dots Pr\}, \\ \forall m \in \{1 \dots M\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (2)$$

$$\sum_m pm_{mt}^{pr} = esdem_t^{pr} \quad \begin{array}{l} \forall pr \in \{1 \dots Pr\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (3)$$

$$\sum_m \sum_e \sum_i q_{kmeit}^{pr'} \leq cap_{kt}^{pr} \quad \begin{array}{l} \forall pr \in \{1 \dots Pr\}, \\ \forall k \in \{1 \dots K\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (4)$$

$$pm_{mt}^{pr} (1 - (qc_{mt}^{pr} + fsf_{mt}^{pr})) = \sum_s \sum_e \sum_j pdc_{msejt}^{pr} \quad \begin{array}{l} \forall pr \in \{1 \dots Pr\}, \\ \forall m \in \{1 \dots M\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (5)$$

Constraint (2) shows the relationship between raw materials and products. Constraint (3) depicts the amount of production according to the data from the BT. Constraint (4) describes the capacity of the suppliers. The products that are ready to send to the DCs should pass from the sensors, and the quality of them during the production should be checked as well. This aspect is represented in constraint (5).

$$inv_{dt}^{pr} = inv_{st-1}^{pr} + \sum_m \sum_e \sum_j pdc_{msejt}^{pr} (1 - (tf_{ejt}^{pr} + df_{sjt}^{pr})) - \sum_{c_s t} Coli_{sc_s t} oui_{sc_s t}^{pr} \quad \begin{array}{l} \forall pr \in \{1 \dots Pr\}, \\ \forall s \in \{1 \dots s\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (6)$$

$$dem_{c_s t}^{pr} = \sum_s Coli_{sc_s t} oui_{sc_s t}^{pr} + tun_{c_s t}^{pr} + \sum_m \sum_e \sum_j Cold_{mc_s t} dp_{mc_s ejt}^{pr} (1 - (tf_{ejt}^{pr})) \quad \begin{array}{l} \forall pr \in \{1 \dots Pr\}, \\ \forall c_s t \in \{1 \dots C_s\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (7)$$

$$tun_{c_s t}^{pr} = Colu_{c_s t}^{pr} und_{c_s t}^{pr} + unw_{c_s t}^{pr} \quad \begin{array}{l} \forall pr \in \{1 \dots Pr\}, \\ \forall c_s \in \{1 \dots C_s\}, \\ \forall t \in \{1 \dots T\} \end{array} \quad (8)$$

Constraint (6) is the inventory level controller. Constraint (7) illustrates that the inventory or direct purchasing will answer the demands; otherwise, they will be unprocessed. Constraint (8) represent that the unprocessed demands have two elements, collaborative undeliverable demands and the unwilling unmet demands.

$$pdc_{msejt}^{pr} + dp_{msejt}^{pr} \leq BM x_{msejt}^{pr}$$

$$\begin{aligned} \forall pr &\in \{1 \dots Pr\}, \\ \forall m &\in \{1 \dots M\}, \\ \forall s &\in \{1 \dots S\}, \\ \forall e &\in \{1 \dots E\}, \\ \forall j &\in \{1 \dots J\}, \\ \forall t &\in \{1 \dots T\} \end{aligned} \quad (9)$$

$$\left(\frac{dismd_{msj}}{aspm_{msj}} \right) x_{msejt}^{pr} \leq dmaxmd_{msjt}^{pr}$$

$$\begin{aligned} \forall pr &\in \{1 \dots Pr\}, \\ \forall m &\in \{1 \dots M\}, \\ \forall s &\in \{1 \dots S\}, \\ \forall e &\in \{1 \dots E\}, \\ \forall j &\in \{1 \dots J\}, \\ \forall t &\in \{1 \dots T\} \end{aligned} \quad (10)$$

$$qr_{kmeit}^{pr'} \leq BM y_{kmeit}^{pr}$$

$$\begin{aligned} \forall pr &\in \{1 \dots Pr\}, \\ \forall k &\in \{1 \dots k\}, \\ \forall m &\in \{1 \dots M\}, \\ \forall e &\in \{1 \dots E\}, \\ \forall i &\in \{1 \dots I\}, \\ \forall t &\in \{1 \dots T\} \end{aligned} \quad (11)$$

$$\left(\frac{dissm_{km}}{aspsm_{km}} \right) y_{kmeit}^{pr} \leq dmaxsm_{kmt}^{pr}$$

$$\begin{aligned} \forall pr &\in \{1 \dots Pr\}, \\ \forall k &\in \{1 \dots K\}, \\ \forall m &\in \{1 \dots M\}, \\ \forall e &\in \{1 \dots E\}, \\ \forall i &\in \{1 \dots I\}, \\ \forall t &\in \{1 \dots T\} \end{aligned} \quad (12)$$

Constraints (9) and (10) depict sending the products less than the maximum accepted time to the DCs. Constraints (11) and (12) do the same task for the maximum accepted time for the manufacturers.

$$\sum_{pr} \sum_t Cold_{mc_s t}^{pr} \leq dplim_{mc_s}$$

$$\begin{aligned} \forall t &\in \{1 \dots T\} \\ \forall C_s' &\in \{1 \dots C_s\} \end{aligned} \quad (13)$$

$$oui_{sc_s' t}^{pr} \leq limitdc$$

$$\begin{aligned} \forall pr &\in \{1 \dots Pr\}, \\ \forall s &\in \{1 \dots S\}, \\ \forall C_s' &\in \{1 \dots C_s\}, \\ \forall t &\in \{1 \dots T\} \end{aligned} \quad (14)$$

Constraint (13) illustrates the limitation of direct purchasing in a given period based on the distances. Constraint (14) represent the limit of transportations from the DCs toward the

customers.

In the next section, the proposed model will be simulated and solved using an exact method.

4.5 Experimental results

4.5.1 Considered scenarios

Regarding Table 4-2, 54 possible cases based on the different collaborations are presented. The possible actions are considered "always happening", "sometimes happening", and "not happening" for undeliverable demand, direct purchasing, and collaborative inventory, as well as "yes" or "no" for collaborative forecasting. Among all the cases, cases 1 and 53 represent respectively the minimum and maximum levels of collaboration while collaborative forecasting exists, and cases 2 and 54 respectively represent the minimum and maximum levels of collaboration while collaborative forecasting does not exist. Because, the collaborations are more important in this chapter, we select cases 1 and 53 as minimum and maximum level of collaborations. Alongside cases 1 and 54, we selected eleven cases based on the possible level of collaboration and their importance for the experimental results. The thirteen selected cases are named as scenarios to make them easier to distinguish in the next sub-sections.

Table 4-2- Possible scenarios in the collaboration

Cases	Undeliverable demand (Blue in Fig. 3)		Direct purchasing (Yellow in Fig. 3)		Collaborative Inventory (Green in Fig. 3)		Collaborative forecasting (Red in Fig. 3)
	Always accepted	Sometimes accepted	Always accepted	Sometimes accepted	All collaborate	Some of DCs collaborate	
Case 1 (Scenario 1)							Yes
Case 2							No
Cases 3/4				✓			Yes / No
Case 5 (Scenario 2)			✓				Yes
Case 6			✓				No
Cases 7/ 8						✓	Yes / No
Case 9 (Scenario 3)					✓		Yes
Case 10					✓		No
Cases 11/12				✓		✓	Yes/No
Cases 13/14				✓	✓		Yes/No
Cases 15/16			✓			✓	Yes/No

Chapter 4: Potential enhancement based on collaborative proposals

Cases 17/18			✓		✓		Yes/No
Cases 19/20		✓				✓	Yes/No
Cases 21/22		✓			✓		Yes/No
Cases 23/24		✓		✓		✓	Yes
Case 25 (Scenario 4)		✓		✓	✓		Yes
Case 26		✓		✓	✓		No
Cases 27/28		✓	✓			✓	Yes/No
Case 29 (Scenario 5)		✓	✓		✓		Yes
Case 30		✓	✓		✓		No
Cases 31/32		✓					Yes/No
Cases 33/34		✓		✓			Yes/No
Case 35 (Scenario 6)		✓	✓				Yes
Case 36		✓	✓				No
Cases 37/38	✓					✓	Yes/No
Cases 39/40	✓				✓		Yes/No
Cases 41/42	✓			✓		✓	Yes/No
Case 43 (Scenario 7)	✓			✓	✓		Yes
Case 44	✓			✓	✓		No
Case 45 (Scenario 8)	✓		✓			✓	Yes
Case 46	✓		✓			✓	No
Case 47 (Scenario 9)	✓						Yes
Case 48	✓						No
Case 49 (Scenario 10)	✓			✓			Yes
Case 50	✓			✓			No
Case 51 (Scenario 11)	✓		✓				Yes

Case 52	✓		✓				No
Case 53 (Scenario 12)	✓		✓		✓		Yes
Case 54 (Scenario 13)	✓		✓		✓		No

Note: If undeliverable demand and direct purchasing are accepted then $Colu_{c_s t}^{pr}=1$ and $Cold_{mcst}^{pr} = 1$. If unmet demand and direct purchasing are sometimes accepted, it means that their value are generated uniformly $\{0,1\}$. In collaborative inventory, all collaborate means that they are all sharing the resources together, and some DC collaborate means they can be several groups of several DCs that collaborate together. In the end, if there is no “✓” it means that no collaboration exists. The collaborative forecasting is denoted by yes and no. Besides, sometime generation for all the collaboration can vary from period to period. It means an actor can collaborate in one period and decide not to collaborate in the other period, and the values are completely random.

The presented scenarios can have different impacts in SC, which will be discussed in the next section and will be evaluated based on different examples.

4.5.2 Experimental Analysis

A problem with 10 suppliers ($s = 10$), 12 periods ($t = 12$), five manufacturers ($m=5$), ten DCs ($d = 10$), four products ($p = 4$), three different roads ($i,j = 3$), three different transporters ($v = 3$) and ten customers ($c = 10$) is generated. Table 4-3 depicts the generated data. The notable point is that all parameters are generated based on uniform generation, and the cost of direct purchasing, undeliverable demand and unwilling unmet demand are exponentially generated. The reason is based on the nature of the problem. When we have no other choice than to do direct purchasing (the time that the undeliverable demand is not accepted and there is no available inventory), it is probable to pay a higher cost for the products. In this regard, the same procedure exists for the undeliverable demand and unwilling unmet demand. The generated values are presented in Table 4-3.

Table 4-3- Data generation of parameters

Parameter	Value	Parameter	Value
pcm_{mt}^{pr}	Uniform(5,10)	$df_{s jt}^{pr}$	Uniform(0.001,0.002)
qc_{kmeit}^{pr}	Uniform(2,4)	$dmaxmd_{mst}^{pr}$	Uniform(10,30)
pc_{msejt}^{pr}	Uniform(1.5,3)	$dmaxsm_{s_t mt}^{pr}$	Uniform(10,30)
h_{st}^{pr}	Uniform(2,5)	$dismd_{msj}$	Uniform(10,1000)
$cund_{c_s t}^{pr}$	Exp(Uniform(2,5))	$dissm_{kmi}$	Uniform(10,1000)
cdp_{mcsejt}^{pr}	Exp(Uniform(2,5))	$aspm_{msej}$	Uniform(20,40)
θ_{kt}^{prpr}	Uniform(0.9,0.95)	$aspsm_{kmei}$	Uniform(20,50)

$esdem_t^{pr}$	Uniform(700,1700)	$cooui_{sc_s't}^{pr}$	Uniform(0.5,10)
cap_{kt}^{pr}	Uniform(100,500)	$cbtlcm_{mc_s't}^{pr}$	Uniform(5,10)
$dem_{c_s't}^{pr}$	Uniform(50,200)	$psli_{ss't}$	Uniform(2,10)
qc_{mt}^{pr}	Uniform(0.01,0.02)	$dplim_{mc_s}$	Uniform(2,20)
fsf_{mt}^{pr}	Uniform(0.005,0.01)	$limitdc$	Uniform(80,120)
tf_{eit}^{pr}	Uniform(0.004,0.01)	$cunw_{c_s't}^{pr}$	Exp(Uniform(1.5,5.5))
tr_{eit}^{pr}	Uniform(0.004,0.01)		

The presented values and problem is solved based on six different examples as represented Table 4-4. In each example, all the mentioned selected thirteen scenarios of Table 4-2 have been solved. All generated values are same for all examples and the only differences of the examples are mentioned in Table 4-4. Besides, it is important to mention that scenario 13 has higher inventory holding costs that comes from lack of collaborative forecasting.

Table 4-4- Generated examples

Name of example	Generated values
EX1	Same as Table 4-3.
EX2	The costs of undeliverable demand are reduced by 50% from EX1.
EX3	The costs of undeliverable demand are reduced by 50% from EX1 and the sharing resources costs are higher by 50%.
EX4	Higher cost of undeliverable demand by 50% and higher cost of inventory by 50% and less possible transportations from DCs by 50% from EX1.
EX5	Higher cost of direct purchasing by 50% from the EX1.
EX6	Lowest possible cost of unwilling demand by 80% from EX1.

Based on the examples in Table 4-4, the results are presented in Figure 4-3. Each result presented in Figure 4-3 is an average value. This average value comes from multiple generation (5 times based on experiences) of Table 4-3 parameters and solving them based on the Table 4-4 presentation. Therefore, each point is the average value, and the low standard deviation of results makes them reliable for further discussion. Besides, the color of columns in the Figure 4-3 is same as the color of scenarios in Table 4-2.

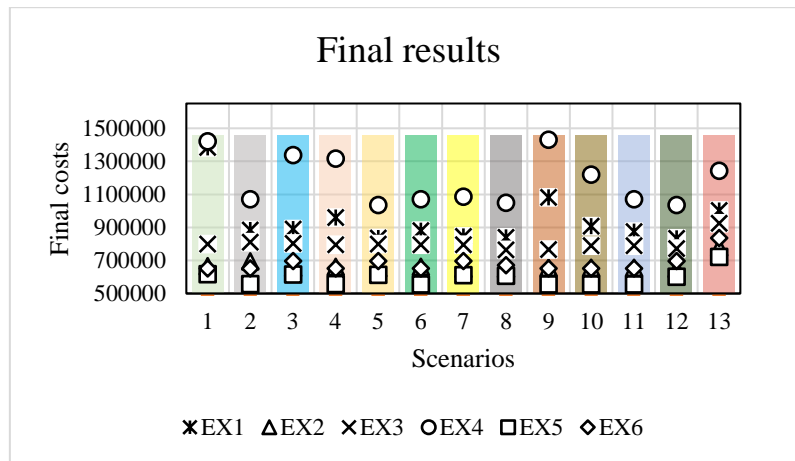


Figure 4-3- Final results

The results can be discussed as follows:

EX 1: The generated data are tried to be close to the PSC's products with few alternatives in this example where the cost of undeliverable demands is high. Scenarios 5, 8 and 12 have the lowest costs. It exists because they represent a high level of collaboration based on the number of generated nodes in the problem. Scenario 9 has the high cost due to the occurrence of numerous undeliverable demands and scenario 1 based on lack of collaboration has the highest cost. In scenario 13, the cause of higher cost of lack of forecasting increases the final costs compare to scenario 12. This behavior exists in all the examples.

EX 2: We consider a product with multiple alternatives in the market, so we reduce the undeliverable demand cost. These products can be inferred to be ordinary products in all drug stores. The lower cost of undeliverable create an equality between all scenarios, and scenario 9 has improved from the previous example because of this impact. The worst cases exist on scenarios 2 and 13 where the unmet demand does not much impacts on the system.

EX 3: It refers to a pandemic, while sharing resources seems costly and difficult. In this case, acceptance of undeliverable demand plays a pivotal role. As it is depicted in the results, scenarios 8, 9, and 12 are the best choices because they had better supply of products without consideration of collaborative inventory.

EX 4: It represents critical vaccines as the final products with a huge cost of undeliverable demand and little possibility of storage. As it is depicted, scenarios 1 and 9 compared to other scenarios can drastically affect the PSC. It can be implied that, in such a condition, the relevance of production planning and market demand for preventing undeliverable demand is the most important factor that does not represented well in these two scenarios.

EX 5: It can be inferred as the locations when there is a far distance between the manufacturers or suppliers from the final customers. As can be seen, whenever a direct purchasing exists, the cost of the system will raise. It can be inferred as a time when a new product wants to be distributed in an external market for the other PSC. The only scenario that has a more cost than other is scenario 13. It means that in such occasions, just collaborative forecasting is an important collaboration that should be taken into actions.

EX 6: It points to a PSC with less important types of products in the market. The cost of collaborating and sharing resources will be more costly. It happens when a market share of a product is low and a lot of alternative products exist for a product type. In such case, scenarios 12, 7, 5 and 3 can have the worst outcomes.

In the next section, we will discuss more about the findings of the problem based on the results.

4.5.3 Findings

In Table 4-5, the possible finding of each collaboration based on the integrated system are listed. The results are based on the findings in the experimental results, and they highlight the impact of each collaborative approach by their respective limits and interests and different kinds of input data and material flows.

Table 4-5- Possible finding of each collaboration

Collaboration	Inputs from material and information flows	Interest	Limits
Collaborative forecasting	<ol style="list-style-type: none"> 1. Data of customer and manufacturers 2. Manufacturers production schedule 	<ol style="list-style-type: none"> 1. Demand prediction 2. Production planning 	<ol style="list-style-type: none"> 1. BT data sharing 2. Data privacy
Collaborative inventory management	<ol style="list-style-type: none"> 1. Inventory level 2. Market demand 3. Transportation status 	<ol style="list-style-type: none"> 1. Customer satisfaction 2. Less inventory cost 	<ol style="list-style-type: none"> 1. Distance 2. Inventory privacy

Acceptance of direct purchasing	<ol style="list-style-type: none"> 1. Market demand 2. Related costs and limits 3. Transportation status 	<ol style="list-style-type: none"> 1. Customer satisfaction 2. Prevent unmet demand 	<ol style="list-style-type: none"> 1. Higher cost 2. DCs acceptance
Acceptance unmet demand	<ol style="list-style-type: none"> 1. Inventory level 2. Possible Direct purchasing 3. Market demand 	<ol style="list-style-type: none"> 1. Possible cheaper costs for the DCs and manufacturers 	<ol style="list-style-type: none"> 1. Shipping the product 2. Late demand answer 3. Losing customer

Based on the findings in Table 4-5, for implementing each collaborative approach, the importance of advantages and disadvantages should be considered and discussed before taking any further actions. In the next section, we will discuss about the sensitivity analysis of the proposed model.

4.5.4 Sensitivity analysis

By analyzing the sensitivity of various parameters on the developed model, it is possible to find the effects of each one of them separately. This sensitivity analysis can affect different parts of the model as follows:

4.5.4.1 Changes of demands

The reduction in percentage of demand and its impact on the cost is presented in Figure 4-4.

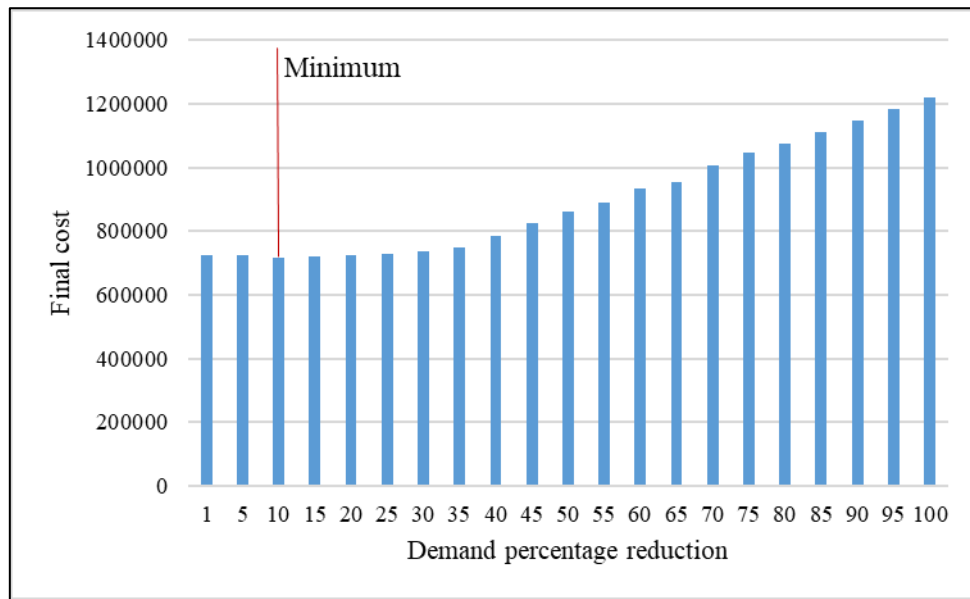


Figure 4-4- Demand changes based on cost

It follows that the minimum value of the final cost is at 10 percent reduction. These alterations demonstrate the applicability of the suggested model. Because when demand declines in the actual world, the system will incur additional costs for inventory and will not be able to sell the products. The model is valid because the value of the goal is deteriorating as demand declines. The changes of demand could have impact on the final value of collaborations but the behavior of the model is same for all scenarios exactly same as in Figure 4-4.

4.5.4.2 Changes of estimated demand

Based on the changes in the estimated demand in Figure 4-5, several important points can be investigated. First, the cost of production and supply in the material handling system is more than the cost of undelivered demand and direct purchasing. It can be seen that when the production level is lower than the estimated demand, the final cost of the system is reduced, which can be up to 50%. Further, the estimated demand is approximately close to the final real demand in the generated problem. If the cost of not supplying products were higher, it was more important to be close to zero or a little more.

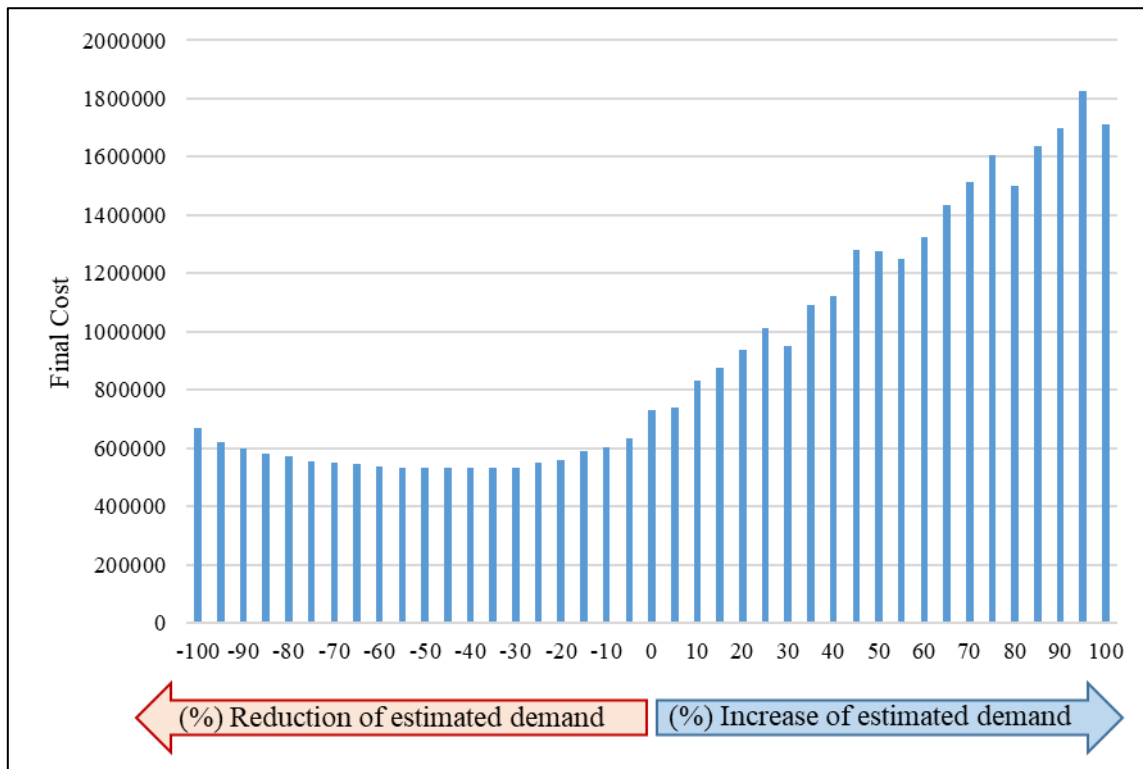


Figure 4-5- Changes of estimated demand

Based on the findings in this section, the next section will propose the conclusions and future perspectives.

4.6 Toward sustainability

Based on the previous sections, it is possible to discuss more about the aspiration and needs of the actors to develop more sustainable metrics in the mentioned system and through the collaborative activities. The main needs and motivations can be mentioned as follows:

- For all the actors in the SC, we have local objective while some of them could be global objectives. In the presented smart contract, it may be then interesting to integrate them for the decision-making scheme and not only as an economic function. Other objectives can be connected to sustainability metrics in the environmental and social aspects (Kheybari *et al.*, 2023).
- Sustainable practices in SCs can also result in long-term cost reductions. Adopting energy-efficient technologies, optimizing transportation routes, and minimizing waste can reduce energy consumption, transportation costs, and material expenditures, for instance. Implementing sustainable practices can mitigate risks associated with resource scarcity, price volatility, and regulatory compliance (Al-Ashhab, 2022).

In our presented system, several examples based on the needs can be given. For instance, actors can start collaborating using renewable materials and recyclable packaging as an environmentally friendly activity while adding costs to their final system. It is clear that actors have to find a balance between economic and environmental metrics. Another environmental goal in the collaborative approach could be dedicated to reduce the greenhouse gas and hazardous waste emissions. Mostly, various distinct social sustainability practices exist which two of them are more common. First, the implementation of measures to ensure the health and safety of employees, such as proper training, protective equipment, and routine inspections. In addition, implementing systems to monitor and track the working conditions and social practices of suppliers and subcontractors. This approaches are mainly targeted about the educations of the employees. Therefore, social responsibility approaches could be taken into account as well.

Based on several needs and the importance of sustainable development, our proposition toward sustainability can be displayed in Figure 4-6.

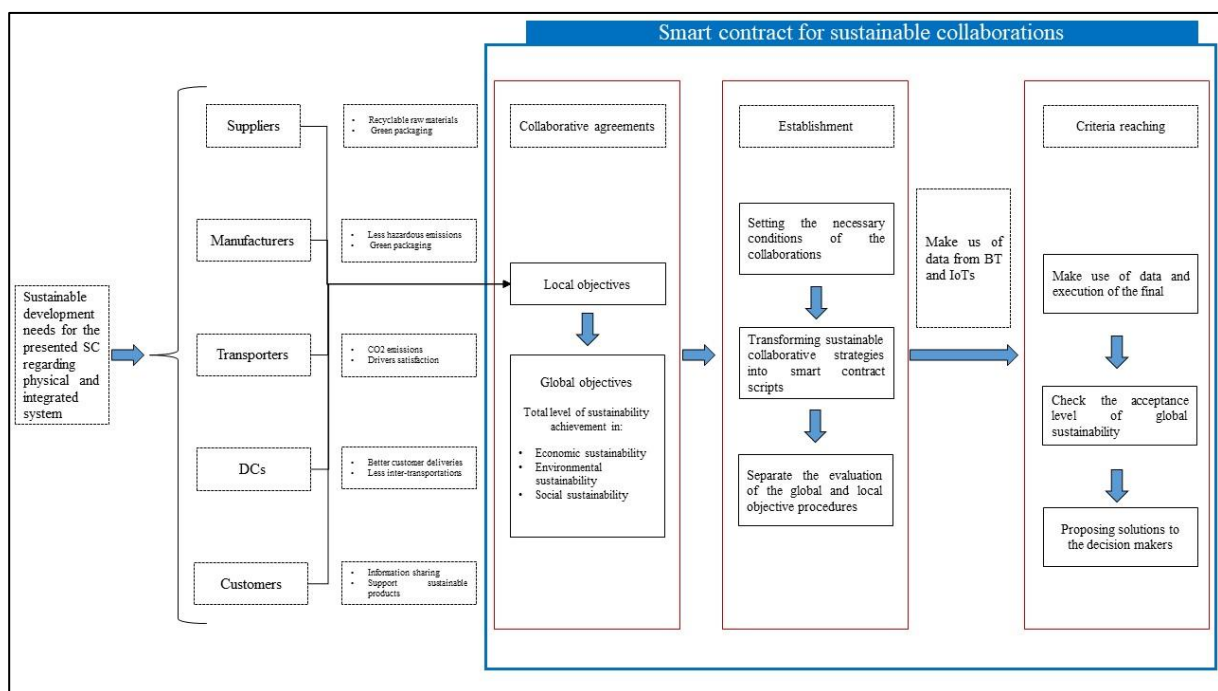


Figure 4-6- Toward sustainability procedures based on the presented system

The main research gaps and possibilities toward sustainable development based on the presented system in this thesis can be mentioned as follows:

- I. At the first step, it is important for the actors of the presented SC to identify their needs and local objectives for sustainable development, as well as discover the elements that

can affect their final customers. As an example, for the suppliers, recyclable raw materials and green packaging could be helpful toward sustainable development. Other examples can exist for the suppliers as well as the other actors in the SC. The second step could then be done by the smart contract. The basic idea is to find which local objectives are common to all actors and could become global objectives.

- II. To overcome this challenge, several possible developments may exist. First, it is possible to collect data by asking questions from experts in the sustainability domain and discovering the importance of local objectives in the global process by using several methods such as fuzzy expert systems, fuzzy cognitive maps (FCM), fuzzy analytic hierarchy process (FAHP), and so on. Secondly, implementing machine learning algorithms to predict the importance of sustainable elements through the time could be the other solutions.

Based on the prior discussions, one of the solutions can be found in this thesis. Based on our previous findings about the criteria and sub-criteria evaluations, a FCM for the importance of each sustainable criteria and sub-criteria is achievable rely on the data in Table appendix B-1. Smart contract can have the role of distinguishing the importance of each local objective in the global process. The global process consists of three pillars of sustainability, which is connected by the local objectives of each actor in the system. Therefore, categorizing each local objective and discovering the weight of each one of them in the final global system can be a gap for more development in the presented smart contract.

Based on the findings in this thesis and using the data based on the literature, the FCM can be achievable in Table 4-6 and Figure 4-7.

Table 4-6- Possible FCM for sustainable developments

Criteria	Sub-criteria	Weight
Economic C_{eco}		0.40
	Profitability C_{eco1}	0.22
	Market Share C_{eco2}	0.14
	Return on Investment C_{eco3}	0.15
	Revenue from Sustainable Products/Services C_{eco4}	0.10
Environmental C_{env}		0.30
	Resources consumption C_{env1}	0.14
	GHG emission C_{env2}	0.48
	Green manufacturing C_{env3}	0.21
	Green research and development C_{env4}	0.17
	Environmental management system C_{env5}	0.56
Social C_{soc}		0.30
	Employment practices C_{soc1}	0.25
	Occupational health and safety C_{soc2}	0.34
	Ethical Sourcing C_{soc3}	0.10
	Employee Diversity and Inclusion C_{soc4}	0.15

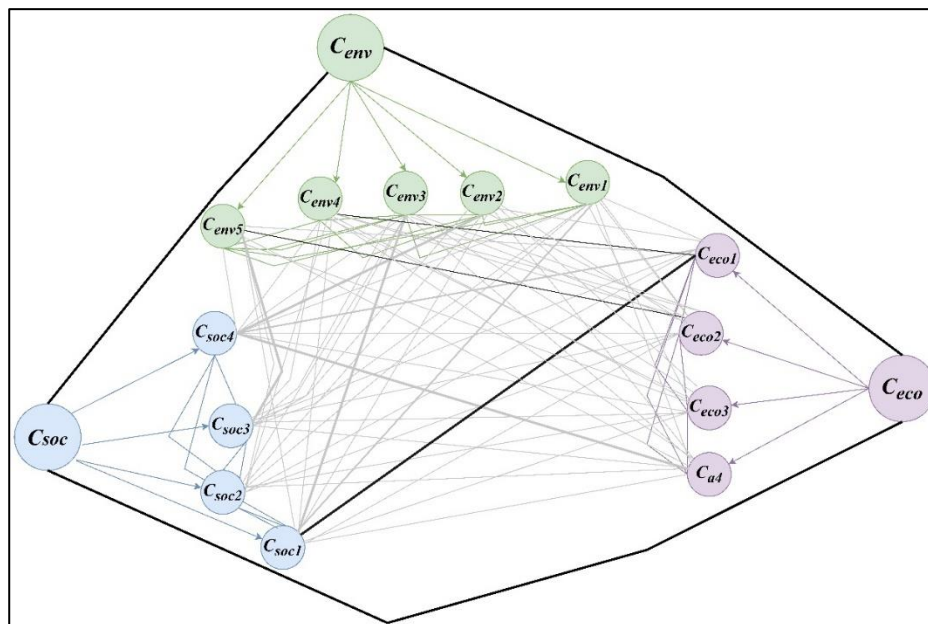


Figure 4-7- Possible FCM for sustainable developments

- III. Then, the global objective(s) could be defined in the form of a mathematical formulation using the weight of the sustainable metrics given in the presented FCM. The objective function can be defined as a multi-objective optimization linearized problem with a maximization of the sustainable metrics. A binary variable based on the sustainable selection metric to assess the usage of the local objectives in the global process are defined as Sus_{ij} . This variable means that if the criteria i of the sub-criteria j is selected for the global process or not. One other parameter name as $Wsus_{ij}$ will define the weight of sub-criteria j in criteria i . Then the objective function Z is defined as follows:

$$Z = \max Wsus_{ij} * Sus_{ij} \quad (15)$$

- IV. In the process of establishment, another improvement from the previous section toward the sustainability may exist. It is probable to integrate other external actors in each stage of the presented SC that may be more suitable for the system's preferences. It means that the smart contract can evaluate and consider the best possible actors among pools of candidates during each period of time taking to account collaborative strategies. Which is out presented solution in the previous chapters. Finally, the smart contract can propose global solutions to the decision makers by proposing different possible actions in the physical system and material fellows. The actors of the SC are the decision-makers, and this process can happen in each period.

In the next section, the conclusion of the whole chapter based on findings in this chapter is represented.

4.7 Conclusion

In this chapter, a supply chain (SC) and an IT system composed of blockchain technology (BT) and Internet of things (IoTs) are considered. The collaborations between several potential SC actors are considered based on data sharing, resource sharing, undeliverable demand, and direct product purchasing. The thoroughly observed collaboration and its effects on each actor are

discussed. Based on the challenges that exist in the collaborative approaches for removing third parties and the automation of the process, a smart contract in the form of mixed integer programming (MIP) has been introduced. In this chapter, for the first time, MIP is used to formalized BT and IoT with the smart contract for collaborative approaches of SC to highlight the operational activities happening in the system. The objective of the suggested model is represented by a cost function that includes the cost of products, the cost of moving materials, and the cost of collaborations. The cost function that is being provided does not just concentrate on the economic factors. The human ethical implications of SC are highlighted by a number of factors, including preventing undeliverable demand and better satisfying customer needs. Using uniform random data generation, the proposed model was examined, and various options were discussed. The final results have been discovered by the optimization simulation based method in several examples to discuss different possible scenarios and their impacts. According to the results, it is advised to enhance collaborations as much as possible in a system where the cost of IT and collaboration is low in order to better serve customer demand and lower the overall cost of the system. Collaboration is not always the greatest option for a system, though, because of things like the high level of data privacy, the distance between actors, and the existence of sensitive medicine items.

General conclusion

In this thesis, we were able to highlight the role that smart contracts could play in different problems related to the supply chain distribution process. The smart contracts are connected with blockchain technology and the Internet of things for better transparency and traceability of the system (Ouyang *et al.*, 2022). Our approach relied on smartness and discussing the automation possibilities at the operational level. Besides, different parts of the smart contract algorithm were defined by such methods as fuzzy logic, mixed integer programming, and so on. Therefore, by having such a system, we had enough motivation to dig into different problems and challenges that may exist for better management of the supply chain system and discuss possible roles of the smart contract to better propose solutions to the decision makers. The decision makers are the actors of the supply chain, which consist of suppliers, manufacturers, distribution centers, warehouses, and transporters.

Motivated by the mentioned aspects, we tried to tackle several different problems and help with the better management of the supply chain. Our focus was dealing with the distribution process; therefore, the different problems were as follows:

- We make use of the interest of blockchain technology and Internet of things. Create a smart contract that is interconnected with blockchain technology and Internet of things to help decision-makers. It can help to set the moment for taking actions in response to potential events and system problems prior to occurrences of any of them. The provided smart contract uses a multi-objective approach to lower costs, increase purchases from verified suppliers, and shorten the anticipated time for product delivery.
- Then we added the dynamic supplier selection algorithm inside the presented smart contract. We integrated fuzzy cognitive maps and expert ideas into the problem. Through this dynamic development, we were able to improve the results of the presented system in the distribution process, focusing on economic gains.
- Using the aforementioned system, we added more collaborative interactions between the actors. We provided numerous strategies for collaborations that rely on the potential for actor-to-actor information exchange. The collaborative activities are modeled mathematically using a mixed integer programming formulation. The proposed system may significantly aid in the automation of the distribution process and make actor interaction easier. These interactions might open the door for ideas for more sustainable development.

In this research work and based on analyzes of the state of the arts, we defined our system consisting of a physical and integrated system to better control and optimize supply chain activities. To do so, we have presented three distinct problems in the distribution process of the supply chain related to time interval approaches, supplier selection approaches, and collaborative strategies. In our presented problems, smart contracts help the decision-makers for better management of the system through its propositions regarding the data that exists in different flows of the supply chain. In this regard, we were able to propose solutions that can improve the final performance of the system based on its economic function and service levels. However, there can be other developments that can be considered in future studies to improve our defined system in multiple directions. Therefore, we propose the following research directions that we deem necessary to address in the future:

- First and foremost, we tried to consider a smart system for our studies. We refer to smartness as efficient and effective operations, and our focus was just on operational levels. In this regard, we were able to introduce our smart contract. However, there is a good opportunity to go toward intelligence in the presented system. It involves the use of business intelligence tools, predictive analytics, machine learning algorithms, and artificial intelligence to extract meaningful information from large volumes of data from Internet of things and blockchain technology. This implementation may enable actors in the supply chain to gain a deeper understanding of market trends, customer behavior, supplier performance, and internal operations. It helps in identifying patterns, predicting future outcomes, and optimizing supply chain activities based on data-driven insights.
- Furthermore, integrating other principles of programming into the present smart contract algorithm can be interesting. We made use of mixed integer programming in our system for operational purposes. Other methods, such as dynamic programming, multi-agent systems, and event-based methods, for considering different events in the system could be interesting. Besides, presenting game theory methods to integrate different collaboration and negotiation possibilities through the smart contract can be interesting as well. Another application of game theory can be dedicated in deciding whether to implement and invest on the presented integrated system or not.
- Finally, developing more sustainable development metrics and objectives can be an interesting direction. In this thesis, we discussed the possibilities of sustainable development in our system. However, there is still room for development by integrating

more objectives dedicated to sustainable development in our system and thoroughly discussing their impacts on the collaborative strategies of the preset SC actors.

The above-mentioned suggestions are just a few of the possible directions, and there can be more development in the future. These developments can be the result of the integration of new technologies and new tools into the presented system.

Appendix A

Five different questions were asked from different supply chain experts in industries. The question are as follows:

1. What are the most important criteria and sub-criteria to select a supplier?
2. How would you evaluate the performance of your suppliers during this time?
3. What were the possible critical red lines for you to remove a supplier from your system and try to find a new supplier?
4. What is your idea about the impact of sustainable development on your supplier selection?
5. What were the impacts of the war between Russia and Ukraine on your system?

The answers of the experts collectively are synthesized as follows to each question:

1. Mainly, several important criteria exist for selecting a supplier, depending on the type of SC. They can be mentioned as quality, delivery, price, reputation, and reliability. In this regard, the quality of final products, lead-time, and positions in the market were the most important sub-criteria.
2. Mainly, it depends on the performance of the risk factors and their adaptability toward new technologies, which would be the most important aspect for long-term communication. Of course, being on time, reliable, and cost-effective are the main evaluation techniques during this time for most enterprises.
3. It depends on the level of relationship with the supplier and the volume of products it supplies. If the majority of the products are coming from a supplier, it means that we are not going to remove them, but we will try to reduce our share and refine our relationship. If the supplier is short-term, it can be easily removed if he cannot obey the trend and crucial factors. It can be named the environmental certifications and final services.

4. Sustainable development may require different methods. Two main examples exist in this manner. First, companies try to select suppliers who have a certificate of sustainable development for their products because they are aware of the market demand for such products. Besides, shifting polluted industries from Europe to other continents creates more boundaries for several industries.
5. This war increases costs and makes it harder for several industries. Especially the industries that were related to more energy consumption and food. Besides, many suppliers, because of geopolitical reasons, have been eliminated from the supply chain network.

Appendix B

The presented FCM is a specific case of PSC by interviews. To identify all parameters influencing the suppliers' selection problem, we conduct a literature review to point out criteria and sub-criteria proposed for this problem and we interview in parallel supply managers. The literature review is made not only for PSCs but for supplier selection in general (the characteristics of PSCs are close to other SCs like in agro-food with an important reglementary pressure, humanitarian SCs with vital human issues and of course more classical industrial sectors from fashion to automobile industry). We also analyse researches made for risk management and uncertainties, and sustainable SCs to pick out elements which could affect criteria. More than 50 papers have been studied carried out in relevant databases during the last two decades. Then, a list of factors influencing the decision making has been defined. Correlated with this list, a resume of the list of criteria and sub-criteria has been established, see Table appendix B-1.

Table appendix B-1 Criteria and sub-criteria for suppliers in the considered PSC

Criteria	Sub-criteria	Weight	Criteria	Sub-criteria	Weight
Quality C_A		0.69	Reputation C_I		0.41
	Quality features C_{A1}	0.72		Professionalism C_{I1}	
	Production quality C_{A2}	0.07		Position in the market C_{I2}	
	Quality system C_{A3}	0.34	Environmental C_J		0.33
Delivery C_B		0.71		Resources consumption C_{J1}	0.14
	Lead time C_{B1}	0.58		GHG emission C_{J2}	0.48
	On-time performance C_{B2}	0.8		Green manufacturing C_{J3}	0.21
	Returns management C_{B3}	0.32		Green research and development C_{J4}	0.17
Price C_C		0.6		Environmental management system C_{J5}	0.56
	Unit price C_{C1}	0.78	Social C_K		0.29
	Discount C_{C2}	0.05		Employment practices C_{K1}	0.25
Service C_D		0.34		Occupational health and safety C_{K2}	0.34
	Customization C_{D1}	0.4	Smartness C_L		0.22

Appendix

	Response to change C_{D2}	0.12		Artificial intelligence C_{L1}	0.16
Performance history C_E		0.21		Big data analysis C_{L2}	0.12
Communication system C_F		0.07		IoT, cyber-system C_{L3}	0.29
Risk factor C_G		0.23		Cloud technology C_{L4}	0.21
Reliability C_H		0.46	Resilience C_M		0.21
	Financial stability C_{H1}	0.54		Vulnerability C_{M1}	0.08
	Number of partners C_{H2}	0.15		Agility C_{M2}	0.27
	Diversity of ownership C_{H3}	0.02		Flexibility C_{M3}	0.34
				Adaptability C_{M4}	0.15

From this list and feedback from managers, we define the FCM (see Figure appendix B-1). To calculate the weights (w_{ij}), we simply defuzzify the resulting fuzzy set for each criterion. However, since supply managers may have different points of view due to their experience and the problems they have encountered, a readjustment is necessary. It is done with the help of the NHL algorithm. For the NHL algorithm, we test different values for μ and π , the best values for our SC are: $\mu=0.05$ and $\pi=0.97$. These results correspond to the first study period for our supplier selection problem. In this case, our approach is purely deductive. For the other periods, the identification of key factors and the definition of criteria and sub-criteria will be made with the help of data analysis and experts. Then, the approach will be also inductive based on results on the first period.

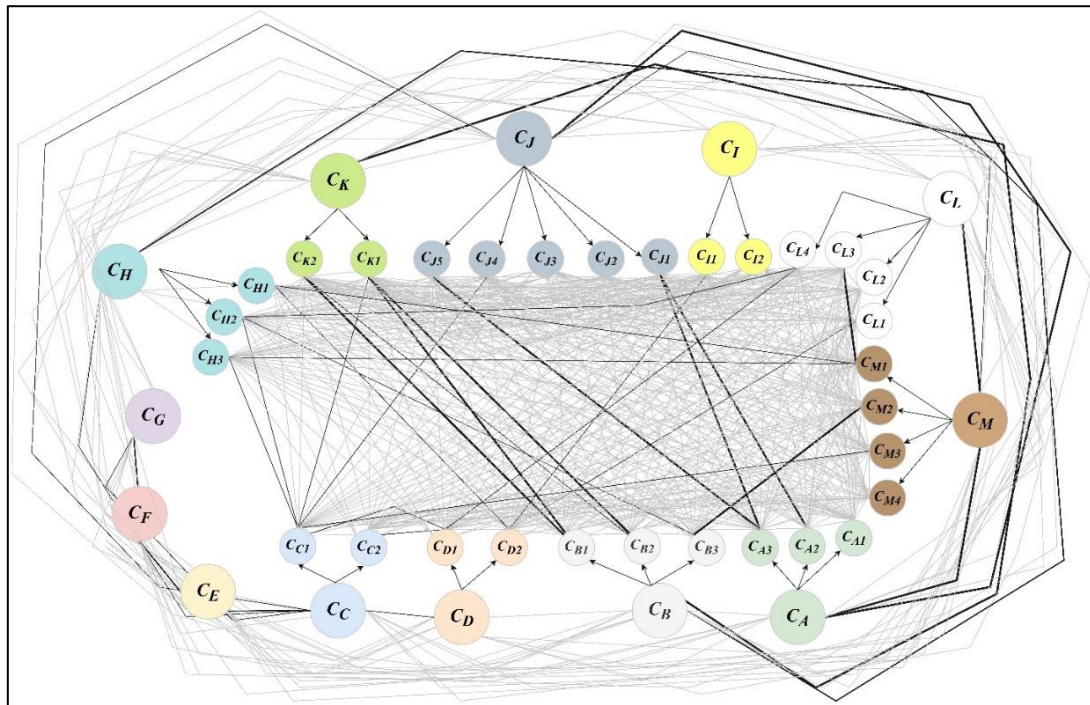


Figure appendix B-1- Resulting FCM

The obtained results show the interest of our method since various factors could be taken into account. Of course, the resulting weights (w_{ij}) reflect the fact that we find classic criteria (cost, quality, service, reliability of the supplier) with an important weight and that other criteria seem for the moment less important. This is the case for certain criteria related to sustainable development and it is all the more true with the current situation (continuation of the pandemic and war in Ukraine) which encourages managers to make habitual and recognized choices. However, the pressure of younger customers and of the international community, the ever more intense impacts of climate change will perhaps modify the weights obtained.

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Chapter 5 French Résumé

5.1 Introduction

La distribution et la commercialisation de produits est soutenue par des réseaux complexes qui facilitent la circulation des produits et les services des producteurs aux consommateurs. Ce système complexe est connu sous le nom de chaîne logistique, et il est essentiel au succès et à la compétitivité des entreprises dans l'économie mondiale interconnectée d'aujourd'hui. La distribution est cruciale pour la chaîne logistique car elle implique le mouvement efficace et la livraison des produits aux clients finaux. De plus, l'intégration de nouvelles technologies s'est révélée être une force propulsive majeure, révolutionnant les processus de distribution et facilitant l'amélioration la performance globale de la chaîne logistique. Dans cette thèse, nous examinerons l'atour dans une chaîne logistique, en mettant particulièrement l'accent sur la distribution, de l'intégration d'une technologie pour optimiser les opérations et découvrir des opportunités commerciales inédites.

L'intégration de nouvelles technologies a transformé les techniques de distribution ces dernières années, propulsant l'industrie de la chaîne logistique vers une nouvelle ère d'efficacité et de créativité. L'Internet des objets, l'intelligence artificielle, la robotique et la technologie de la blockchain ont révolutionné les anciens paradigmes de distribution, permettant aux organisations de résoudre des difficultés et de capitaliser sur des opportunités auparavant. Parmi toutes les technologies, nous nous intéressons davantage à l'Internet des objets et à la technologie de la blockchain. Les entreprises peuvent gérer et suivre les expéditions en temps réel, améliorer les itinéraires et l'utilisation des véhicules, et obtenir des informations importantes sur leurs opérations de distribution en intégrant les objets connectés en réseau. La technologie de la blockchain améliore la transparence et la sécurité des transactions de la chaîne logistique, réduisant le risque de fraude et de contrefaçon tout en maintenant la traçabilité et l'authenticité des produits. Cependant, il peut y avoir d'autres besoins pour aider les décideurs à mieux gérer le processus de la chaîne logistique dans tous les aspects des flux de matériaux, financiers et d'information.

Parmi les nouvelles technologies, les smart contrats sont des accords auto-exécutables encodés sur des plateformes qui appliquent automatiquement les termes et conditions contractuels. En intégrant les smart contrats dans le processus de distribution, les décideurs peuvent obtenir plusieurs avantages. En effet, les smart contrats permettent l'automatisation et la numérisation

de diverses tâches et processus, réduisant les erreurs manuelles et améliorant l'efficacité opérationnelle.

Nous appuyant sur les nouvelles technologies, les principales motivations de cette thèse sont les suivantes :

- avoir une approche intégrant les acteurs a visant les moyens issus des technologies de la blockchain et de l'Internet des objets comme source de données sécurisée et fiable ;
- introduire une nouvelle utilisation des smart contrats pour l'aide à la prise de décision ;
- étudier l'impact des dates/moments de traitement des données de la chaîne logistique (matériel, information et financier) aux décideurs ;
- considérer la possibilité de sélection dynamique des fournisseurs et l'évaluation des performances des fournisseurs (Chapitre 3).
- introduire des stratégies de collaboration différentes entre les acteurs et étudier leurs impacts ;

Ces éléments et nos motivations sont discutés dans quatre chapitres différents. Les chapitres sont organisés comme suit.

- Le premier chapitre encadre et contextualise le travail de recherche proposé. Une vue d'ensemble du contexte de cette thèse est présentée en abordant plusieurs termes liés à la chaîne logistique et aux défis de l'industrie du futur. Un résumé illustre les différentes technologies, en mettant l'accent sur les paradigmes modernes. Ensuite, nous nous concentrons sur les différents concepts utilisés dans le processus de distribution de confiance dans la chaîne logistique. Parmi ces concepts, nous rappelons l'importance de la technologie de la blockchain, de l'Internet des objets et des smart contrats. À la fin de cette synthèse, nous proposons une description générale de notre problème de recherche et le positionnons par rapport aux éventuels défis.

- Le deuxième chapitre introduit notre nouvelle approche dans l'utilisant des smart contrats pour aider les décideurs à faire face aux difficultés du processus de distribution en utilisant des dispositifs connectés (capteurs, outils de traçabilité, etc.) pour être plus réactifs, et la technologie de la blockchain pour apporter transparence et confiance entre les participants de la chaîne logistique. De plus, le smart contrat fourni aide les décideurs à définir les moments d'action en réponse à d'éventuels événements et problèmes dans le système avant qu'ils ne surviennent. Le smart contrat utilise une méthode multi-objectifs pour réduire les coûts, augmenter les achats auprès de fournisseurs certifiés et réduire le temps de livraison prévu des produits. Enfin, les résultats sont résumés et comparés en termes d'avantages économiques et de taux de service.
- Le chapitre trois met l'accent sur une des lacunes identifiées dans le deuxième chapitre. Il introduit un nouveau smart contrat. Pour le smart contrat, des cartes cognitives floues et les point de vue d'experts sont utilisées pour aider à la sélection des fournisseurs. Le processus de distribution reste au centre du deuxième smart contrat. Les différentes entrées pour chaque smart contrat sont la raison de la présentation de deux smart contrats différents. L'idée des cartes cognitives floues est modifiée pour trouver les critères les plus essentiels pour une certaine période de temps, puis pour choisir dynamiquement les fournisseurs. Enfin, les résultats, les modifications potentielles et l'amélioration du système présenté ont été discutés.
- Le chapitre quatre s'intéresse à une deuxième lacune présentés dans le deuxième chapitre, traitant des interactions et des moyens de collaboration entre les différents acteurs et étapes. Il présente de nombreuses scenarios de collaboration qui exploitent la possibilité d'échange d'informations entre les acteurs. Une formulation mathématique basée sur la programmation en nombres entiers mixtes est utilisée pour modéliser les activités de collaboration. Le système proposé combiné aux tactiques de coopération

peut contribuer considérablement à l'automatisation du processus de distribution et faciliter l'interaction entre les acteurs. Enfin, ces interactions peuvent ouvrir la voie à des idées de développement plus durables.

Enfin, nous concluons cette thèse avec quelques remarques et des pistes pour des recherches futures.

5.2 Défis de la gestion des chaînes logistique dans le contexte de l'industrie 4.0

Le premier chapitre est dédié aux enjeux et défis des chaînes logistiques dans un contexte d'industrie 4.0. Ainsi, plusieurs termes liés à la chaîne logistique et à l'industrie du futur sont présentes, un accent étant mis sur apports des nouvelles technologies. Ensuite, nous nous concentrons sur les différents concepts utilisés dans le processus de distribution dans la chaîne logistique. La notion confiance étant un élément clé, nous rappelons l'importance de la technologie de la blockchain, de l'Internet des objets et des smart contrats.

Nous mettons ainsi en évidence qu'une première lacune concernant l'utilisation des outils transparents et traçables existe dans les systèmes logistiques. Cela nous permet également de discuter de leurs impacts sur les approches de prise de décision des différents acteurs (Hasan et al., 2019). Pour faciliter la prise de décision, il est possible d'introduire des outils algorithmiques qui proposent des solutions applicables par les acteurs de la chaîne logistique (Dolgui et al., 2020). À cet égard, l'outil algorithmique présenté peut jouer le rôle d'un éliminateur de tiers. Avoir la possibilité d'agir face aux événements avant leur survenue peut être un point intéressant. Pour cela, il est évidemment nécessaire de bien définir le problème. En fin de compte, évaluer les performances de la chaîne logistique en fonction de différents critères et selon les acteurs dans une perspective dynamique reste un écart scientifique peu traité dans la littérature.

Il est important de mentionner que les initiateurs des smart contrats peuvent être les fournisseurs, les fabricants et les entrepôts de distribution. Ils sont en effet à l'origine de la prise de décision qui assurera la satisfaction des clients. Ils seront donc les décideurs dans les propositions de smart contrats.

Tout d'abord, nous proposons un réseau de chaîne logistique en tenant compte des perspectives des acteurs et en intégrant des approches de partage de données en utilisant la blockchain et l'Internet des objets comme source sécurisée et fiable de données. Ensuite, nous introduisons une nouvelle approche pour les smart contrats en formalisant une partie des scripts sous forme de programmation en nombres entiers mixtes et en distinguant leurs rôles en tant qu'aide à la prise de décision. Dans notre approche algorithmique des smart contrats, nous définissons différentes réactions possibles en fonction du retour d'information. Nous évaluons leurs impacts sur les objectifs finaux du système nous proposons également une évaluation dynamique dans le smart contrat pour mettre à jour et évaluer les performances des fournisseurs dans la chaîne logistique en fonction des données réelles. Enfin, nous proposons d'introduire des stratégies de collaboration entre les acteurs de la chaîne logistique en présence de la blockchain, mettant en

évidence les différents types de collaborations basées sur les flux de matériaux et d'informations. Ces stratégies de collaboration seraient automatisées dans les procédures grâce au smart contract proposé.

5.3 Adaptabilité de la distribution de la chaîne logistique

Le deuxième chapitre introduit un nouveau type de smart contrat permettant d'aider les décideurs à faire face aux difficultés du processus de distribution en utilisant les dispositifs connectés (capteurs, outils de traçabilité, etc.) pour être plus réactifs et la technologie de la blockchain pour apporter transparence et confiance entre les participants de la chaîne logistique. De plus, le smart contrat donné assiste les décideurs dans la définition des moments où agir en réponse à des événements potentiels et des problèmes dans le système avant leur survenue.

Trois approches différentes correspondant à trois niveaux de récupération d'informations sont considérées. La réactivité du système provient du nombre et des moments auxquels le smart contrat propose des décisions possibles dans le système. Mais, cette réactivité a un coût qui ne peut être négligé. Les trois approches sont les suivantes.

5.3.1 Approche initiale

Dans cette approche, toutes les décisions seront prises au début et à la fin de chaque période par le smart contrat. Pendant la période, le système intégré stockera les données et enverra les informations nécessaires au smart contrat, et la meilleure solution sera proposée pour satisfaire les demandes à la fin des périodes. Il est important de noter que cette approche est censée être plus pratique et efficace lorsque le système est plus stable et que peu de problèmes peuvent survenir au cours d'une période.

5.3.2 Approche par point de contrôle

Le smart contrat divisera chaque période en un nombre spécifique de points de contrôle. Les données seront collectées à partir du système intégré à chaque point de contrôle. Si un problème est détecté dans le système, les décisions seront alors prises au moment du point de contrôle. Le nombre de points de contrôle est défini en fonction des préférences du décideur, des données du système intégré et d'autres éléments du système d'information. Ils peuvent varier d'une période à l'autre. Cette approche permet une surveillance plus fréquente et aide à avoir un aperçu régulier de l'état du système. Le choix des moments pour les points de contrôle pourrait être défini en fonction de l'expérience et de l'analyse des données (non présentées dans cette thèse). Elle pourrait également être dynamique.

5.3.3 Approche basée sur les événements

Dans ce scénario, chaque fois qu'un changement se produit dans le système, le smart contrat peut réagir. Les événements peuvent être des alarmes de capteurs dans les différentes étapes de la chaîne logistique ou l'augmentation de la demande pour un produit spécifique au cours d'une

période à un moment donné. Au début de chaque période, la demande peut être considérée comme un événement de ce point de vue. Il est important de noter qu'au moment d'un événement, toutes les données collectées du système intégré seront vérifiées pour d'éventuels problèmes dans les autres étapes de la chaîne logistique. Cette approche permet au système de réagir aux problèmes importants. De plus, nous disposons d'une meilleure indication de la demande réelle du marché par rapport aux autres approches ; cependant, s'il y a trop de problèmes (événements), le smart contrat pourrait avoir des difficultés à fournir des réponses efficaces. Les conflits et les arrivées d'évènements conjointes ne sont pas traités.

Le smart contrat donné utilise une méthode multi-objectifs pour réduire les coûts, augmenter les achats auprès de fournisseurs certifiés et réduire le temps de livraison prévu des produits. Enfin, les résultats sont résumés et comparés en termes d'avantages économiques et de taux de service.

5.4 Stratégies dynamiques de sélection des fournisseurs pour l'amélioration du processus de distribution

Le troisième chapitre met l'accent sur un manque dans le deuxième chapitre concernant l'approvisionnement. Pour y répondre, il introduit deux smart contrats différents. Pour le premier smart contrat, des cartes cognitives floues et des idées d'experts ont été utilisées pour sélectionner les fournisseurs. Le processus de distribution reste au cœur du deuxième smart contrat. Les différentes formes d'entrée pour chaque smart contrat sont la justification de la présentation de deux smart contrats différents. L'idée de la carte cognitive floue est adoptée pour trouver les critères essentiels pour une période donnée, puis sélectionner dynamiquement les fournisseurs.

L'aspect dynamique considéré ici ne concerne pas la dynamique opérationnelle de la chaîne logistique pendant une période, mais les changements qui peuvent survenir dans l'environnement de la chaîne logistique. Par exemple, la demande du marché peut influencer la sélection des fournisseurs. Dans notre carte cognitive floue, les prix, la qualité, les délais de livraison et d'autres critères des fournisseurs sont pris en compte. Les avantages de l'utilisation de la carte cognitive floue sont tout d'abord de permettre de prendre en compte les interdépendances entre les critères, et deuxièmement de pouvoir définir un système permettant de relier les critères aux changements potentiels et ainsi d'intégrer les évolutions du système. Notre approche est déductive sur la base d'un questionnaire proposé aux responsables des achats et de l'approvisionnement en matières premières, et inductive sur la base des résultats fournis par l'analyse des données (cette dernière n'étant pas traitée dans le mémoire). Nous appliquons notre approche au cas d'une chaîne logistique pharmaceutique. De plus, pour garantir la cohérence de nos résultats, la carte cognitive floue est associée à l'algorithme non linéaire de Hebbian afin d'assurer l'adéquation entre les résultats obtenus et la réalité. Il convient de noter que tous les critères n'ont pas été présentés dans ce chapitre.

Enfin, les résultats de ce chapitre obtenus par la méthode de sélection des fournisseurs ont été comparés avec le chapitre précédent, et des améliorations ont été constatées en termes de coûts et de niveau de service. Sur la base de l'amélioration du coût final et de la sélection de fournisseurs qualifiés, il est possible de prouver que la procédure mentionnée est valide.

5.5 Amélioration potentielle basée sur des propositions de collaboration

Le chapitre quatre est une continuité du chapitre deux. Permettant d'introduire davantage d'interactions et de moyens de collaboration entre les différents acteurs et étapes. Il présente de nombreux scénarios de collaboration utilisant pleinement l'informations issues des IoT et de la blockchain. Une formulation mathématique basée sur la programmation en nombres entiers mixtes est utilisée pour modéliser des activités de collaboration. Le système proposé, combiné aux scénarios de coopération, peut contribuer de manière significative à l'automatisation du processus de distribution et faciliter l'interaction physique entre les acteurs.

Un smart contrat sous forme de programmation en nombres entiers mixtes a été introduit. Dans ce chapitre, pour la première fois, la programmation en nombres entiers mixtes est utilisée pour formaliser la technologie blockchain et l'Internet des objets avec le smart contrat pour des approches collaboratives de la chaîne d'approvisionnement afin de mettre en évidence les activités opérationnelles se déroulant dans le système. L'objectif du modèle proposé est représenté par une fonction de coût qui comprend le coût des produits, le coût du déplacement des matériaux et le coût des collaborations. La fonction de coût qui est fournie ne se concentre pas uniquement sur les facteurs économiques. Les implications éthiques humaines de la chaîne d'approvisionnement sont mises en avant par plusieurs facteurs, notamment la prévention de la demande non satisfaite et la meilleure satisfaction des besoins des clients. Quatre types de collaborations différents, tels que la prévision collaborative de la demande et l'élaboration de plans de production à l'aide d'un outil de prise de décision, la gestion collaborative des stocks et le partage des ressources, l'acceptation de l'achat direct de produits finaux par les fabricants et l'acceptation d'une demande non satisfaite a un instant donne pour les clients, ont été présentés et discutés. En utilisant la génération de données aléatoires uniformes, le modèle proposé a été examiné et différentes options ont été discutées. Selon les résultats, il est conseillé d'améliorer autant que possible les collaborations dans un système où le coût de l'IT et de la collaboration est faible afin de mieux servir la demande des clients et de réduire le coût total du système. Cependant, la collaboration n'est pas toujours la meilleure option pour un système en raison de facteurs tels que le niveau élevé de confidentialité des données, la distance entre les acteurs et l'existence d'articles médicaux sensibles.

Enfin, ces interactions peuvent ouvrir la voie à des idées intégrant le concept de développement durable. Les possibilités en matière de développement durable basées sur le système présenté dans cette thèse ont été discutées en vue de futures propositions.

5.6 Conclusion

Dans cette thèse, nous avons pu mettre en évidence le nouveau rôle que les smart contrats pourraient jouer dans différents problèmes liés au processus de distribution et d'approvisionnement de la chaîne logistique. Les smart contrats sont connectés à la technologie de la blockchain et à l'Internet des objets pour une meilleure transparence et traçabilité du système (Ouyang *et al.*, 2022). Notre approche s'est centrée essentiellement sur les possibilités d'automatisation au niveau opérationnel. Ainsi, une partie des scripts automatise des smart contrats a été définie à l'aide de méthodes telles que la logique floue, la programmation en nombres entiers mixtes. En proposant ces ajouts et en utilisant matière, nous avons les données collectées pour le système numérique, pour aborder différents problèmes pouvant exister. Notre idée est discuter des rôles possibles des smart contrats pour mieux proposer des solutions aux décideurs. Les décideurs sont les acteurs de la chaîne logistique, qui se composent de fournisseurs, de fabricants, de centres de distribution.

Motivés par les aspects mentionnés, nous avons tenté de résoudre plusieurs problèmes différents et d'aider à une meilleure gestion de la chaîne logistique. Notre focus paraît sur le processus de distribution ; par conséquent, les différents problèmes étaient les suivants :

- Comment améliorer la prise de décision en distribution la technologie de la blockchain et de l'Internet des objets ? Utilisant notre solution est de créer un smart contrat adosse à la technologie de la blockchain pour aider les décideurs. Il peut contribuer à définir le moment d'agir en réponse à des événements potentiels et des problèmes survenus. Le smart contrat fourni améliore les performances pour une approche multi-objectifs.
- Comment améliorer le choix des fournisseurs ? Nous avons ajouté un algorithme de sélection dynamique des fournisseurs à l'intérieur du smart contrat présenté. Sur la base de cognitives floues et des retours d'experts. Grâce à ce développement dynamique, nous avons pu améliorer les résultats économiques du système présenté dans le processus de distribution.
- En utilisant le système mentionné ci-dessus, nous avons également agir sur l'interactions entre les acteurs. Nous avons proposé de nombreuses stratégies de collaboration qui reposent sur la possibilité d'échange d'informations d'acteur à acteur. Les activités

collaboratives sont modélisées mathématiquement à l'aide d'une formulation de programmation en nombres entiers mixtes. Le système proposé peut considérablement contribuer à l'automatisation du processus de distribution et faciliter l'interaction entre les acteurs. Ces interactions pourraient ouvrir la voie à des idées d'améliorant dans un cadre développement plus durables.

Dans ce travail de recherche et sur la base de l'analyse de l'état de l'art, nous avons défini notre système composé d'un système physique et intégré pour mieux contrôler et optimiser les activités de la chaîne logistique. Les smart contrats peuvent aider les décideurs à mieux gérer le système en fonction des données collectées dans la chaîne logistique. À cet égard, nous avons pu proposer des solutions susceptibles d'améliorer les performances ceci est une première proposition du système et de ses niveaux de service. D'autres développements sont à envisager pour améliorer notre système être dans plusieurs directions.

- Tout d'abord, nous avons cherché à envisager un système 'intelligent' dans notre démarche. Nous entendons par intelligence des opérations efficaces et efficaces. À cet égard, nous avons pu présenter une adaptation des smart contrats. Cependant, il existe une bonne opportunité d'aller vers l'intelligence dans le système présenté. Cela implique l'utilisation d'outils d'intelligence commerciale, d'analyses prédictives, d'algorithmes d'apprentissage automatique et d'intelligence artificielle pour extraire des informations significatives à partir de grandes quantités de données l'Internet des objets et vis les réseaux sociaux et de la technologie de la blockchain. Cette mise en œuvre permet trait aux acteurs de la chaîne logistique de mieux comprendre les tendances du marché, le comportement des clients, les performances des fournisseurs et les opérations internes et cela de manière plus dynamique.
- En outre, l'intégration d'autres principes de programmation dans l'algorithme actuel du smart contrat peut être intéressante. Nous avons fait usage de la programmation en nombres entiers mixtes dans notre système à des fins opérationnelles. D'autres méthodes, telles que la programmation dynamique, les systèmes multi-agents et les

méthodes basées sur les événements, pourraient être intéressantes pour prendre en compte différents événements dans le système. De plus, la présentation de méthodes de théorie des jeux pour intégrer différentes possibilités de collaboration et de négociation à travers le smart contrat peut également être intéressante. Une autre application de la théorie des jeux peut être dédiée à la décision d'implémenter et d'investir ou non dans le système intégré présenté.

- Enfin, le développement de mesures et d'objectifs de développement plus durables peut être une direction intéressante. Dans cette thèse, nous avons discuté des possibilités de développement durable dans notre système. Cependant, il y a encore de la place pour le développement en intégrant davantage d'objectifs dédiés au développement durable dans notre système et en discutant en détail de leurs impacts sur les stratégies de collaboration des acteurs de la chaîne logistique.

Les suggestions mentionnées ci-dessus ne sont que quelques-unes des directions possibles, et il reste davantage de développements à mener. Ces développements peuvent résulter de l'intégration de nouvelles technologies et de nouveaux outils dans le système présenté, de bonnes pratiques et d'éthique.

5.7 Références

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