Operational Research in Engineering Sciences: Theory and Applications
Vol. 6, Issue 3, 2023, pp. 57-85
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta/060303

DESIGNING A FLEXIBLE DISTRIBUTION NETWORK FOR THE DIGITAL SUPPLY CHAIN ENVIRONMENT

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Received: 23 May 2023
Accepted: 28 August 2023
First Online: 29 September 2023

Research Paper

Abstract: *Nowadays, integrated supply chain management has become a serious concern for companies due to the severe competitive market since it is a factor playing a major role in both increasing companies' profitability and creating customer satisfaction. Meanwhile, interest in utilizing information technology in supply chain management and moving towards a digital supply chain to reach a better rank in the industry has rapidly increased. Additionally, the increase in population and the growth of cities leads to the creation of heavy traffic loads bringing difficult challenges to the company's distribution network such as a sharp rise in transportation costs and untimely delivery. On the other hand, having fixed warehouses in the urban area not only is unprofitable for companies but also impossible due to both the increase in costs and the lack of enough space to develop in densely populated and crowded areas. In this paper, a flexible distribution network is designed using the small mobile warehouse's strategy to address the problems raised. Trucks and pickups are considered small mobile warehouses and distribution units in the distribution area, respectively. Wireless sensors are used as an information technology unit in each vehicle to monitor the network condition and make a flexible communication in which all sensors are connected to the processing center located in the organization's building. Consequently, the processing center identifies the optimal points in the distribution area for reloading between small mobile warehouses (trucks) and distribution units (pickups), while minimizing the total cost of network transportation. The applicability of the proposed model is investigated using a case study and sensitivity analyses.*

Keywords: *Digital Supply Chain, Digitalization, Supply Chain Network, Distribution Network, Wireless Sensor Network Technology, Mobile Warehouses.*

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1. Introduction

In recent decades, the influence of supply chain (SC) procedures on the company and worldwide commerce is believed to be unavoidable (Gholian-Jouybari et al., 2023). An SC is a well-organized structure of production segments, depots, and distribution channels that aim to procure commodities as a production input, process them into final commercial materials, and provide them to clients across a vast geographical region. A collection of interrelated activities via the network is referred to as a global coordinate (Chouhan, Khan, & Hajiaghaei-Keshteli, 2021).

The bare bone of business management is supply chain network design (SCND), which influences all other operations associated with the chains and has the greatest impact on the chain's profitability and operating efficiency (Babaveisi, Paydar, & Safaei, 2018). Lately, severe competition and fast-changing client demands, along with the latest technological advancements and global economic integration, have compelled firms to engage as supply chain components rather than stand-alone (Mosallanezhad et al., 2023a). The accomplishment of the SC is dependent on the connection and synchronization of its establishments in order to ensure an effective framework (Kargar, Paydar, & Safaei, 2020). An impactful network reduces operational expenses all over the channel and allows it to react to client requirements more efficiently

As shown in Figure 1, the size of the global SCM market was USD 15.58 billion in 2020, which is supposed to have an increasing trend in 2021 – 2026 so that it will achieve USD 17.41 billion in 2021, and by 2026, it will make USD 30.91 billion. So, supply chain management (SCM) has evolved into a key matter for any organization seeking economic competence, timeliness, and user satisfaction, particularly in a market environment influenced by global commerce and the speed of industrial processes.

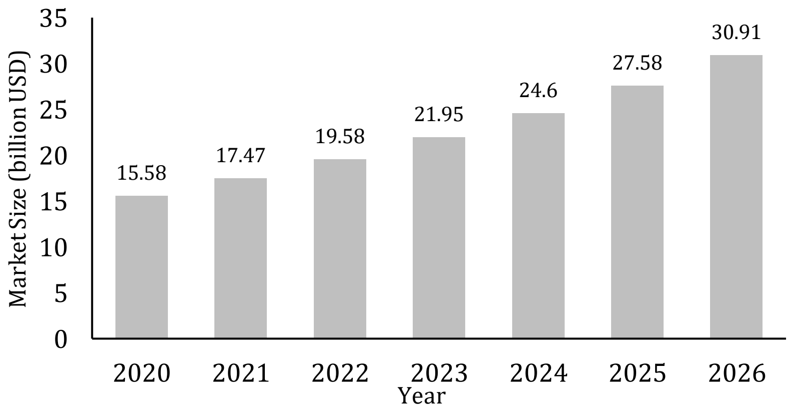

Figure 1. Annual changes in the size of the global SCM market†.

Moreover, digital breakthroughs have altered the way individuals interact and engage with their environment in a way that this phenomenon impacts every business,

† A report by research and market available at: https://www.researchandmarkets.com/reports/5337793/supply-chain-management-market-research-report-by

including the SC. SCs have become more efficient and nimbler due to modern industrial strategies and technological improvements, and modern techniques (Colombaroni, Mohammadi, & Rahmanifar, 2020). As illustrated in Figure 2, the major developments projected to affect SCs by 2023 are technological improvements. Digitalization has the ability to transform the SC by making more valuable, transparent, and cost-efficient services available. According to the findings of a 2021 investigation of different firms throughout the globe, nearly 33% of leaders anticipate digitalization to have a significant and outstanding influence on supply chain efficiency by 20231. The digital supply chain is a smart and innovative, and value-added procedure that involves new methodologies, particularly digitalization using advanced technologies to both establish competitive value and system implications.

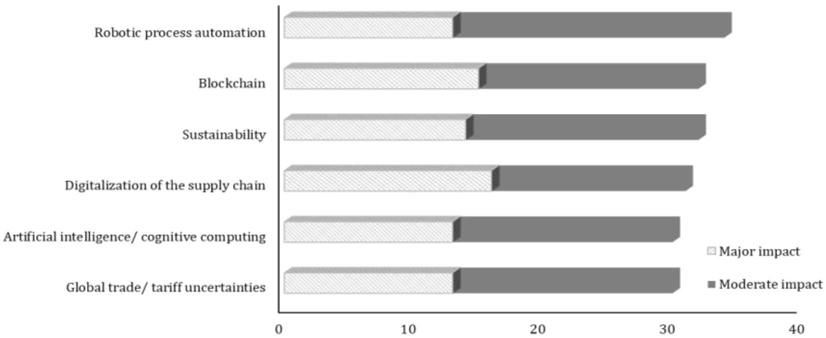

Figure 2. Leading trends anticipated to impact supply chains by 2023‡.

As seen in Figure 3, digital advancements account for the vast proportion of the main trends predicted to impact the SC by 2023. According to report findings, IoT infrastructure is being more extensively used in the logistics business, with 80% of enterprises in their SC profitability by 20232.

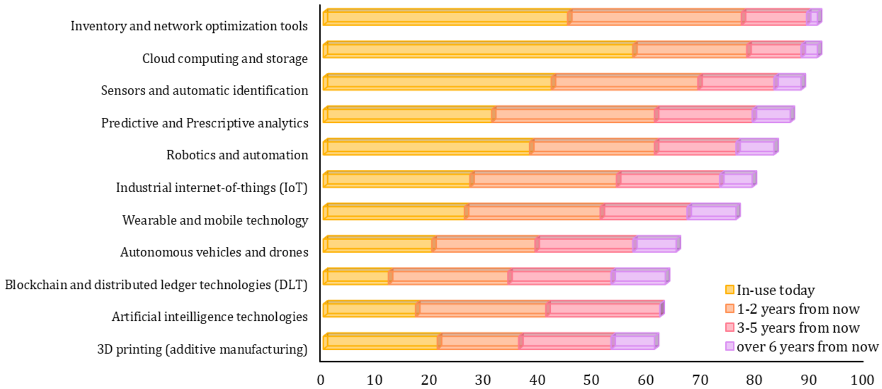

Figure 3. Adoption of technologies by supply chain companies in 2020§.

‡ Supply Chain Management Review: https://www.scmr.com/article/priorities_in_sourcing_and_procurement_for_2021

§ MHI Annual Industry Report by Deloitte available at: https://www.mhi.org/publications/report

The next issue that firms, specifically in the shrinking industry, are dealing with is interacting with digitalization and selecting the appropriate tools in the SC to generate cost reductions. By choosing the appropriate technology for the particular function, the degree of technology and its implementation in logistics may be raised, resulting in speedy classification, information gathering, computing, analysis, and transmission with great precision and dependability (Abdi et al., 2021). The rise and adoption of new advanced technology have significantly influenced the evolution of SCM.

The blockchain platform, mobile applications and data, big data patterns, and the Internet of Things (IoT) are all examples of digital technologies. Most organizations' practices have been transformed by these capabilities, which have increased cooperation and facilitated the creation of new business ideas to increase company competitiveness (Annosi et al., 2021).

To be more precise, the IoT platform is a critical component of successful SCM in a way that it can potentially improve efficiency by minimizing SCs' weaknesses (Mosallanezhad et al., 2023b). The wireless sensor network (WSN), as one of the essential platforms for expanding IoT establishment, offers excellent technological assistance for the maturation of logistics systems (Molka-Danielsen, Engelseth, & Wang, 2018). WSN is a network of wireless sensor modules that can communicate and compute wirelessly and be installed in specified locations. It can perform activities such as detecting and operating a communication system while keeping an eye on the surroundings. Microsensors, integrated information gathering, data analysis, transmission, automation, and other tasks were at the heart of the WSN. WSN is thought to be an application-oriented, info-centric network that may use adaptive management techniques to fulfill the demands of a wide range of activities (Gulati et al., 2022). Thus, information technology has tremendous effects on all aspects of organizations so it needs the consideration of managers to increase the efficiency and effectiveness of the organization and gain various competitive advantages. To delve more into details, one way to achieve a competitive advantage is to focus on the supply chain and use technology to enhance it. Technology also facilitates the improvement of performance within the company and supply chain partners by providing timely, accurate, and reliable information.

As a component of SCND, distribution network design (DND) has a substantial influence on the efficacy and reaction to client expectations and demands. The significance of DND is clearly conceivable from the fact that distribution practices in supply chain networks and logistical processes possess the highest amount compared to other practices (Mosallanezhad et al., 2021a). Therefore, applying SC's digitalization technologies in DND may help firms gain more steady competitiveness by lowering their costs, improving decision accuracy, shortening goods shipping times to clients, and increasing reaction speed to an unanticipated occurrence.

In addition, warehousing and distribution of products are two inseparable members of the supply chain playing an essential role in controlling the company's costs. Accordingly, companies are looking for innovative solutions in order to not only reduce the cost of warehousing but also deliver the final product to the customers in a short time to get their satisfaction (Xing & Liu, 2022). This issue is more apparent in big cities due to both fixed costs including the establishment of a convenient as well as an accessible storage place and side costs such as transportation since most companies are founded around big cities due to environmental and economic issues. As a result of this strategy, the warehousing and distribution costs will increase (de

Oliveira et al., 2020). For instance, the result of research conducted in the U.S. reveals that the average cost to run a warehouse in the United States in 2021 reached $7.91 per square foot. There was a 5.6 percent increase over the average cost a year ago. One of the main and significant reasons for this increase is the reduction of space available for storage in New York, which has had an increasing trend since 2016**,††.

Therefore, business owners are seeking to find creative solutions to choose their warehouses to distribute products in parts of the city with fewer storage costs or to eliminate the limitation of available space to develop a warehouse while increasing customer satisfaction with timely product delivery. Hence, warehouses around the world continue to undergo new innovative solutions and increased investment in automation and supply chain integration (Aravindaraj & Chinna, 2022).

Meanwhile, the use of mobile warehouse strategies using digitization tools can be considered one of the innovative ways that can eliminate the problems of traditional distribution systems for companies by creating flexibility in the supply chain, in other words, applying SC's digitalization technologies in DND may help firms gain more steady competitiveness by lowering their costs, improving decision accuracy, shortening goods shipping times to clients, and increasing reaction speed to an unanticipated occurrence (Rad et al., 2022).

The objective of this study is to propound a mathematical model to leverage WSN technology as a tool for supply chain digitalization and also develop an integrated DND that can lower SC costs while also ensuring client satisfaction. In this matter, the following are the primary features and originalities of the current study:

- Devising a flexible distribution network using a mobile warehousing strategy.
- Utilizing the concept of wireless sensor network technology for flexible communication and monitoring of SC.
- Optimizing the costs of the SC's distribution network by considering the shortages.
- Performing sensitivity analysis to delve further into the model's conclusions and management implications.

In Section 2, a thorough evaluation of prior relevant studies is undertaken and presented. In Section 3, the problem is formulated and defined with respect to the objective function, constraints, and WSN design. The suggested methodological framework is reviewed in Section 4. Also, it describes the case study, reports numerical findings, and explores a genuine issue. To explore the behavior of the objective function and the proposed network, sensitivity analyses are performed in Section 5. Finally, in Sections 6 and 7, the discussion, managerial insights, and conclusions are stated and future directions.

2. Literature Review

In recent years, authors and scholars in SCM and SCND have performed several studies considering various concepts, formulations, structures, and assumptions. There are several relevant case studies in this field such as Yozgat and Erol (2022),

** https://www.statista.com/statistics/1277919/average-cost-warehouse-united-states/
††https://www.statista.com/statistics/729151/average-construction-costs-warehouse-and-logistic-centers-worldwide-by-key-city/

Aldrighetti et al. (2021), Liao et al. (2020), Sadeghi-Moghaddam, Hajiaghaei-Keshteli, and Mahmoodjanloo (2019), Ben-Daya, Hassini, and Bahroun (2019), and which comprehensively have discussed the most recent studies and research related to supply chain. However, in this section, we concisely examine the most recent studies related to this study while they are categorized into three subsections: "Supply Chain Network Design", "Digital Supply Chain", and "Distribution Network". Furthermore, to meticulously clarify the novelties of the study, a subsection separately is devoted to the "Research Gap".

2.1. Supply Chain Network Design

Indubitably, in the current volatile industrial atmosphere, an efficient SCND leads to competitive advantage, productivity management, and well-structured organizations (Abdi et al., 2020). A considerable number of studies have been done in key industries in this area because of the rising relevance of SCND in major operations and medium and long-term planning.

In one of the recent works, a methodology constructed by Gholamian and Taghanzadeh (2017) to calculate the SCN for wheat crops and their derivatives. The suggested model's goal was to evaluate suppliers, determine the quantity of wheat imported, distribute wheat, and produce wheat products. Jabbarzadeh, Haughton, and Khosrojerdi (2018) proposed a stochastic model that is robust to disruptions of SCN. The suggested approach employs lateral transshipment as a responsive method during the disruption. They devised a Lagrangian relaxation approach to solve this problem.

In another work, Saghaeeian and Ramezanian (2018) proposed an MINLP mathematical modeling for competitive SCN considering multiple products in another research. They used the Stackelberg game to formulate their model and applied Karush-Kuhn-Tucker optimality equations to form a single-level MINLP. The authors' NP-hardness of the proposed model made them develop a hybrid metaheuristic as a solution approach for large-size problems. Moreover, Diabat, Jabbarzadeh, and Khosrojerdi (2019) created a model for essential items in emergencies to manage the humanitarian relief SC. They developed a bi-objective network that tries to optimize the responding duration and the cost of transportation while taking into account potential delays in plants and routes connecting them. To address the problem, they proposed a methodology that relies on Lagrangian relaxation and ε-constraint.

Furthermore, Savadkoohi, Mousazadeh, and Torabi (2018) formulated a pharmaceutical SCN using a unique location framework that took into account the perishability of goods. Also, they incorporated unpredictability in their design and employed a probabilistic method to deal with the inconsistent values. Jahani et al. (2018) attempted to establish a framework that optimizes the model's profitability while also carrying uncertainty of the parameters for demand or costs. They offered an innovative technique to rebuild the SCN while analyzing its existing framework to form the model.

In addition, Zhen, Huang, and Wang (2019) presented a dual-objective SCN model considering environmental impacts and reducing operating costs of the network under the uncertain situation. Nayeri et al. (2020) developed a closed-loop SCN taking into account stability factors with respect to uncertainty conditions. Haghjoo et al. (2020) researched the blood SCN by examining location-allocation facilities and proposed a strong new blood model while considering the risk of disruption and demand uncertainty in a catastrophic situation.

In order to reduce costs in the SCN disaster relief, Mosallanezhad, Hajiaghaei-Keshteli, and Triki (2021b) developed a model involving global medical equipment producers, suppliers, healthcare systems, and donors that aims to manage SC's expenses as well as reduce shortages and meet customer demand is throughout the SCN. Mousavi et al. (2021) considered the sustainability concept in the SCN and designed the blood SC taking into account social and environmental factors. They developed an adaptable, sustainable network that collects blood packets from donation centers and transports them to a test center to produce different blood products. In their model, the effect of the social factor of blood breakdown and the network cost were considered simultaneously.

Also, Zahedi et al. (2021a) developed a closed-loop SCN in which they considered levels for recycling and reconstruction. The results of this study show an increase in the profit of the entire SCN. Darmawan, Wong, and Thorstenson (2021) examined the effect of inventory deployment on the performance of the SCN and the organization's profitability. They proposed a model integrating location-transportation and inventory problems and showed that inventory control can influence network structure. Salehi-Amiri et al. (2021) constructed an SCN for the agri-food industry considering walnut products. In their model, forward and reverse flows of products were considered to respond to the market demand as well as reuse of returned products, thus showing that their extended SCN attempts to optimize the cost of the network.

2.2 Digital Supply Chain

Today, one of the ways to gain the competitive advantage of organizations is to deliberate on the SCN and improve it. By redesigning their SCNs, organizations can create significant cost savings and improve operations (Darmawan et al., 2021).

The use of developing technologies in the SC and the transition to a digital supply chain are two current subjects that have been increasingly discussed. By delivering fast, reliable, and trustworthy information, technology influences the efficiency of enterprises and partners throughout the SC (Balakrishnan & Ramanathan, 2021). Different conventional and developing technologies may contribute to the digitization of businesses, e.g., Cloud Computing (Novais, Maqueira, & Ortiz-Bas, 2019), Internet of Things (IoT) (Ben-Daya et al., 2019), Big Data (Addo-Tenkorang & Helo, 2016), 3D Printing (Mohr & Khan, 2015), Blockchain (Wamba & Queiroz, 2022), Artificial Intelligence (Toorajipour et al., 2021), Radio Frequency Identification (RFID) (Raza, 2022) and Automated Guided Vehicles (AGVs) (Bechtsis et al., 2017).

Cagliano, De Marco, and Rafele (2017) investigated mobile SCM applications. They concentrated on the e-grocery industry and developed a flexible platform for SC's fast, fresh food. The competency of this study is that its model is able to predict how product tracking, digital payments, and scheduled delivery features influence the implementation of an SCM application. Oghazi et al. (2018) presented a generic approach to determine the influence of new technology concepts such as RFID on SCM. They demonstrated how incorporating these techniques into SCM may increase the integration of SC. Kshetri (2018) also explored the influence of the Chinese blockchain platform on SC objectives. The findings indisputably reveal that the proposed platform helps the business SC to achieve its cost, speed, reliability, risk level, stability, and flexibility objectives.

During the last ten years, digital supply chain studies have ignited with different directions. The majority of academic studies focus on how digital technology may affect SC operations. Esmaeilian et al. (2020) presented blockchain as a platform to achieve a sustainable SC, analyzed the benefits and limitations of utilizing this platform, and dubbed it a genuine method for improving sustainability in the SC. Zahedi et al. (2021b) researched the influence of the IoT on the SCN and built a framework for utilizing the IoT system. The influence of digital technology on SC was investigated by Yang, Fu, and Zhang (2021). They developed a three-tier theoretical structure for digitalization in enterprises' SCs, which addressed developing technologies in the SC.

Annosi et al. (2021) incorporated digital technology into food SC procedures to mitigate the negative influences on perishable items. They were able to direct a method to embrace and apply digital technologies in the food supply chain and a methodology for dealing with food SC issues in a technological sense. Beaulieu and Bentahar (2021) developed a digitization plan to enhance the healthcare SC's functionality. Digital revolution was suggested as a trigger to improve SC performance by Hallikas, Immonen, and Brax (2021). They sought how digitized purchasing skills are related to business intelligence and SCN practices and how these competencies lead to higher company performance. The influence of the Industry 4.0 and technical advancements on SC quality was investigated by Fatorachian and Kazemi (2021). Process integration, digitalization, and mechanization abilities, as well as novel advanced analytics, provide substantial quality improvements in SC operations such as purchasing, manufacturing, inventory tracking, and marketing.

2.3 Distribution Network

The distribution network is among the most valuable aspects in creating costs in the SC and will affect the functioning of the network (Cheraghalipour, Paydar, & Hajiaghaei-Keshteli, 2017). The circulation of goods from the manufacturer to the client in the SC is known as distribution (Sahebjamnia, Goodarzian, & Hajiaghaei-Keshteli, 2020). Distribution network design (DND) as a subset of SCND significantly impacts the effectiveness and response to customer demand (Naderi, Govindan, & Soleimani, 2020). DND problems include strategic decisions that affect tactical and operational decisions. In particular, these decisions include the facility location, allocation, transportation routes between centers, and inventory control which affect distribution system costs and customer service quality (Hajiaghaei-Keshteli & Fathollahi-Fard, 2018). Therefore, these decisions are important and the main problem of any organization. Paying enough attention to them is a requirement for survival in today's competitive world (Cao et al., 2018).

Lerhlaly et al. (2016) worked on an inventory location routing problem (ILRP). They designed a bi-objective model, including optimizing cost, risks, and routing. The proposed model determines which depots should be open, how customers allocate to them and how many quantities should be shipped between the allocated depots and the customers per period.

Tavakkoli-Moghaddam and Raziei (2016) outlined a novel bi-objective ILRP problem considering multiple periods, time horizons, and product options. They employed a fuzzy technique to characterize the uncertainty of demands. They employed two objective functions, one for reducing the shipping costs, storage, and locating distribution sites, and the other for lowering shortages in each demand point. Mohammed and Wang (2017) proposed a scheduling model for a multi-tier agri-food SC under fuzzy settings. To implement the more realistic model, the model's parameters are evaluated as uncertain values. The study's approach involves adjusting overall shipping costs, carbon footprint in shipping, and delivery time.

Table 1. Summary of supply chain network studies.

Study	Subject	Model Features	Objective Function	Unsatisfied Demand	Digital Item(s)
Lerhlaly et al. (2016)	DND	MILP	C	No	-
Tavakkoli-Moghaddam and Raziei (2016)	DND	MILP	C, I	Yes	-
Cagliano et al. (2017)	DSC	Sim.	-	No	*
Gholamian and Taghanzadeh (2017)	SCND	MILP	C	No	-
Jabbarzadeh et al. (2018)	SCND	MILP	C	No	-
Mohammed and Wang (2017)	DND	MILP	C, T, E, DV	Yes	-
Diabat et al. (2019)	SCND	MILP	C, T	No	-
Jahani et al. (2018)	SCND	MILP	P	No	-
Kshetri (2018)	DSC	Conc.	-	No	Blockchain
Oghazi et al. (2018)	DSC	Conc.	-	No	RFID
Savadkoohi et al. (2018)	SCND	MILP	C	No	-
Wang, Gunasekaran, and Ngai (2018)	DND	MILP	C	No	-
Akgün and Erdal (2019)	DND	MILP	C, R	No	-
Mogale, Cheikhrouhou, and Tiwari (2020)	DND	MILP	C, E	No	-
Zhen et al. (2019)	SCND	MILP	C, E	No	-
Esmaeilian et al. (2020)	DSC	Conc.	C	No	Blockchain
Haghjoo et al. (2020)	SCND	MILP	C	No	-
Mohamed, Klibi, and Vanderbeck (2020)	DND	MILP	C	No	-
Nayeri et al. (2020)	SCND	MILP	C, E, J	No	-
Vafaei et al. (2020)	DND	MILP	C, E, J	No	-
Wang et al. (2020)	DND	MILP	C, DV	No	-
Annosi et al. (2021)	DSC	Conc.	-	No	*
Beaulieu and Bentahar (2021)	DSC	Conc.	-	No	*
Darmawan et al. (2021)	SCND	MILP	C	No	-
Fatorachian and Kazemi (2021)	DSC	Conc.	-	No	*
Hallikas et al. (2021)	DSC	Conc.	-	No	*
Mosallanezhad et al. (2021b)	SCND	MILP	C, D	Yes	-
Mousavi et al. (2021)	SCND	MILP	C, S	No	-
Salehi-Amiri et al. (2021)	SCND	MILP	C	No	-
Yang et al. (2021)	DSC	Conc.	-	No	*
Zahedi et al. (2021a)	SCND	MILP	P	No	-
Zahedi et al. (2021b)	DSC	MILP	T	No	IoT
Alizadeh et al. (2022)	SCND	MILP	C, RE, CU	No	-
Kordi et al. (2022)	SCND	MILP	C	No	-
Hashemi-Amiri, Ghorbani, and Ji (2023)	SCND	MILP	C, RL	No	-
Goli, Ala, and Hajiaghaei-Keshteli (2023)	SCND	MILP			
This Study	DND/DSC	MINL	Cost	Yes	WSN

Supply Chain Network Design (SCND); Distribution Network Design (DND); Digital Supply Chain (DSC); Linear (L); Non-linear (NL); Mixed Integer Linear (MIL); Mixed Integer Non-Linear (MINL); Simulation (Sim.); Conceptual (Conc.); Cost (C); Profit (P); Time (T); Emission (E); Job Opportunities; Demand (D); Social Impact (S); Inventory (I); Delivery (DV); Risk (R); Recovery (RE); Casualty (CU); Reliability (RL) .

* *These studies discussed the application digital technologies regardless of any spesific digital architecture.*

In another study, to predict the optimal quantity of storage in SCN, Wang et al. (2018) devised a mathematical model. Also, in this model, the regional markets were allocated to the nearest warehouse to optimally handle the cost of the distribution network. Finally, they examined big data to solve real SC problems. Mogale et al. (2020) developed an optimization model for agri-food distribution purposes. Their model considered the sustainability parameters of reducing carbon dioxide emissions in transportation. Akgün and Erdal (2019) presented a model for determining the number and locations of warehouses in the ammunition distribution network by considering risk levels.

Mohamed et al. (2020) designed a distribution network in a two-tier state and used secondary warehouses to deliver products to customers to meet customer needs in a minimum time. They used a stochastic state to deal with demand uncertainty. Vafaei et al. (2020) developed a DND model for multi-channel distribution in which sustainability parameters were considered. Wang et al. (2020) evoked a network framework for reducing DND's costs as well as the number of vehicles by considering the time window.

2.4 Research Gap

The distribution network costs in the supply chain are among the main component of the total cost, so the factors affecting it must be managed. One surefire way to deal with the optimization of distribution costs is to frame it as mathematical modeling, taking into account the constraints and strategies that can meet the network's goals. Previous studies in the field of supply chain distribution network discussed in Section 2.3 shows that a mobile warehousing strategy has not been used to help managers or policy-makers in the industrial environment in a way that they control fixed warehouse costs in the lowest possible amount, taking into account unsatisfied demands' penalties and costs associated with the entire distribution network.

Moreover, the literature review revealed that the majority of studies in this area have focused on location and allocation, inventory control, and routing in different modes and industries. On the other hand, the digitalization of the distribution network adds flexibility and monitoring capabilities to the network, which has not been considered in previous studies related to the supply chain. Furthermore, most studies on flexible distribution networks consider the digital supply chain and mobile warehousing strategy. At the same time, it attempts to minimize the total cost of the distribution network and unmet demands. This model can help organizations manage and reduce the costs of the supply chain distribution network and increase customer satisfaction by satisfying their needs at the right time.

3. Problem Definition and Formulation

In developed companies, the size of the company its distribution network are highly associated with transportation costs and also the company's profitability (Cheng & Wang, 2021). This problem forces companies to focus on reducing their transportation costs. On the other hand, with the rise of competition, punctual delivery can increase customer satisfaction (Arabsheybani & Arshadi Khasmeh, 2021). These challenges demonstrate the need for companies to have a flexible and optimal distribution network. Therefore, this paper attempts to design and model a distribution network in the supply chain using a wireless sensor network and manage the financial aspects of the network while reducing the costs to the lowest possible amount.

As we know, the cost of establishing warehouses in large cities is extremely expensive. However, trucks can add mobility features to warehouses as they move throughout the SCN. If the trucks act as mobile warehouses they can have a significant advantage and distribution units (pickups) instead of going to the main warehouses for reloading purposes, which are usually out of reach, could provide their required quantity of products from these trucks. This strategy reduces the cost, wasted time, and distance traveled by the pickups and undoubtedly results in higher satisfaction among customers. In the current study, all existing vehicles, including both trucks and pickups, are equipped with wireless sensors that can locate the vehicles and count the number of available products in each vehicle while they can send and receive information messages.

To organize and make decisions based on the received messages from the vehicles, it is necessary to have a processing center in the company. The purpose of this center in the company is to organize and make decisions on the received messages. These messages are sent to the processing center in form of information packets. It is worthwhile to mention that the messages pickups and trucks are distinguishable. The information packet for each pickup contains the current vehicles coordinate (x, y), vehicle ID, reload flag (F_{rl}: 1 if the pickup is required for reload; otherwise, is 0), next customer ID, and for each truck encompasses the current coordinates, vehicle ID, and reload flag. The information packets are denoted as(x, y, j, ID, F_{rl}) (information packet that is sent to the processing center by pickup j) and $p_k(x, y, k, F_{rl})$ (information packet that is sent to the processing center by truck k).

The processing center uses messages from the network to determine how to load pickups. For reloading activities, it is assumed that there are predetermined points in the city called Transfer Points (TPs). The processing centers' main task is to determine the best TP for reloading, which has the lowest cost of transportation. It is assumed that an RFID tag is installed on all products in the network. The sensor implemented in each vehicle alternately counts the number of items in the vehicle. So, suppose the number of goods in each vehicle reaches less than 30% of its capacity. In that case, the vehicle's sensor automatically sends the reloading message to the processing center.

After applying the proposed model to the information received from the distribution units, the processing center sends the response in form of an information packet to the desired distribution units and the relevant containers. It should be noted that the processing center calculates the model based on the requests received from pickups and trucks. Considering that their information packet is frequently reported (sent) to the processing center. Also, the center knows their requests and the exact location of pickups and mobile warehouses and disregards the recalculation of the model until it receives a message from the pickups with a reload flag of 1. Since it is not cost-effective to load only one pickup and due to the high cost of trucks and traffic load usually the number of trucks in the distribution network is less than the number of pickups, therefore the processing center must allocate the trucks so that each truck deals with a reasonable number of pickups. For this purpose, after receiving the reload message from the first pickup, the center waits for a certain time (this time can be adjusted) until other pickups are added to the group. Thus, if other pickups declare the need for reloading within this time period, it allocates them simultaneously.

Finally, the processing center calculates the model and sends them the adjusted locations for the pickups and trucks.

After receiving the message, the distribution unit moves to the corresponding TP to reload. It should be noted that after several loading processes by trucks, their load will be reduced and as a result, they will need to be reloaded. They express the situation through their information packet to the processing center. After receiving the message, the processing center permits to reload of the truck. Then, the truck sends an exit message to the processing center. The processing center removes the truck ID number from the list of potential trucks during this time. For this purpose, the company has one or more main warehouses. After reloading, the truck will declare its entry to the processing center and re-enter the list of potential trucks.

3.1. Nomenclature

In this section, notation and indices used for mathematical modeling are presented. All the notations are summarized in Table 1.

Table 1. *Notation of the mathematical modeling.*

	Indices
$i \in I$	Index of the TP.
$j \in J$	Index of the pickup.
$k \in K$	Index of the truck.
	Parameters
d_{ij}	Distance between the pickup's (j) current customer and the TP (i).
d'_{ij}	Distance between the pickup's (j) next customer and the TP (i).
dc_{ik}	Distance between the truck (k) to TP (i).
C_p	The maximum number of pickups can be present simultaneously in each TP.
C_T	The maximum number of trucks can be present simultaneously in each TP.
K_k	The amount of truck (k) load when entering the TP.
D_j	Amount of pickup (j) 's demand for reloading.
w_1	Cost of distance traveled by each pickup per kilometer.
w_2	Cost of distance traveled by each truck per kilometer.
w_3	Setup cost for each truck.
$w_4{}^j$	Cost per unit of pickup shortage (j).
	Variables
ud_j	Unsatisfied demand of pickup (j).
ac_j	The amount allocated to pickup (j) at the TP
z_{ij}	If the pickup (j) assigned to the TP (i) equals 1; otherwise, 0.
x_{ik}	If the truck (k) assigned to the TP (i) equals 1; otherwise, 0.

3.2. Assumptions

For this paper, the following assumptions are considered:

- All vehicles send their information packet to the processing center at a specified time interval.
- There will be no lost packet in transmission.
- If a pickup needs to be reloaded, the parameter in its packet is considered equal to one; then, the processing center notices the pickup needs to be reloaded.

After receiving each reload message, the processing center waits for a td minute if other pickups in the short run declare a need to reload. Afterward, they will consider them simultaneously to reduce their additional truck allocation.

- The maximum number of pickups that can simultaneously be reloaded is M, so the maximum waiting time for the first pickup that needs to be reloaded is (M-1) × td.
- The location of the TPs is predetermined.
- The order of customers and the route of each pickup are predetermined.

3.3. Flexible Distribution Network Model

Based on the parameters, assumptions, and problem statement expressed in the previous sections, the proposed model is presented in Equations (1)-(8).

$$Min\ Z = \sum_i \sum_j w_1 \times (d_{ij} + d'_{ij}) \times z_{ij} + \sum_i \sum_k w_2 \times dc_{ik} \times x_{ik} + \sum_i \sum_k w_3 \times x_{ik} + \sum_j {w_4}^j \times ud_j \quad (1)$$

$$\sum_j z_{ij} \le C_P \quad \forall i \quad (2)$$

$$\sum_k x_{ik} \le C_T \quad \forall i \quad (3)$$

$$\sum_i z_{ij} = 1 \quad \forall j \quad (4)$$

$$\sum_k x_{ik} \le 1 \quad \forall k \quad (5)$$

$$\sum_j ac_j \times z_{ij} \le \sum_k x_{ik} \times K_k \quad \forall i \quad (6)$$

$$ac_j \le D_j \quad \forall j \quad (7)$$

$$ud_j \ge D_j - ac_j \quad \forall j \quad (8)$$

Equation (1) represents the objective function of the problem, which consists of four terms. The first term represents the cost of the distance traveled by the pickups. The distance traveled for each pickup is divided into two parts: d_{ij} is the distance between the current pickup's customer and the TP and d'_{ij} is the distance between the TP i and the next pickup customer. The pickup (j) goes to deliver the order to its next customer after reloading at the TP (i); therefore, in order to choose the optimal TP, the distance of the TP to the next customer must be considered for pickup (j). The processing center is assumed to be aware of pickup customers' orders and places of them and the routes. The processing center can choose the optimal TP with the lowest cost for reloading using this information. The second part of the objective function represents the cost of the truck's distance (k) traveled. Given the fact that the presence of each truck in a network has a fixed cost to set up (such as driver's costs), the third part considers the setup cost. In this paper, the possibility of shortage occurrence is also considered. If pickup (j) arrives at the TP with a specific quantity of demand for reloading; however, its demand does not be completely satisfied, then the amount of shortage equivalent to ud_j is considered for pickup (j), and its cost is considered in the fourth part of the objective function. As the cost of a possible shortage is different for each pickup (For example, the customer is one of the permanent customers with high demand or the customer is one of the branches of a chain store), the cost of the shortage for each pickup is considered separately by the fourth term of the objective. As the number of TPs in large cities is practically limited, the number of pickups and trucks that can simultaneously be available for reloading in each area will also be limited. As can be seen in Equations (2) and (3), the total number of pickups and trucks at each TP is limited to specific numbers C_P and C_T. Equation (4) expresses that each pickup can only be assigned to one TP. Equation (5) gives us this freedom to prevent sending extra trucks to the TPs if sufficient loads are provided. If the pickup (j) moves to the TP (i), the load amount assigned to it is equal to ac_j. The total amount of allocated loads to pickups is always less than or equal to the truck's amount transported to that TP; this is expressed in Equation (6). Equation (7) illustrates that the amount of load assigned to a pickup (j) is always smaller or equal to its demand for loading. And finally, the amount of shortage of each pickup is obtained from Equation (8), which is the difference between the pickup demand and the amount allocated to it.

4. Solution Methodology

The literature review on network design models is sound in applying several solution methods, including exact, heuristic, metaheuristics, and hybrid approaches. In this study, the solution methodology is exact, and we use GAMS software and BARON solver to cope with the nonlinearity of the model. We provide more details on case description, sensitivity analysis, and managerial insights.

4.1. Case Description

In this section, the applicability of the proposed model is investigated using empirical examples. Also, to examine the model in the real world, a real case is provided in Tehran, Iran. As shown in Figure 4, Tehran has 22 districts, among which district 1, namely Shemiranat, is selected to implement the model. Although the prevalent currency in Iran is the Iranian Rials (IRR), the cost parameters are converted to United States dollars (USD) for a better understanding of the problem.

Table 2. Parameters of the problem.

Parameters	Value	Unit
Number of TPs (i)	5	#
Number of pickups (j)	15	#
Number of trucks (k)	3	#
W_1	2	USD
W_2	3/5	USD
W_3	20	USD
C_p	5	#
C_K	2	#

Table 3. Demand for each pickup (D_j).

Pickup (ID)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Demand (*box*)	71	81	72	85	72	80	86	80	81	70	81	79	90	73	73

Table 4. The initial amount of each truck's load.

Truck (ID)	1	2	3
Initial amount (*box*)	370	391	377

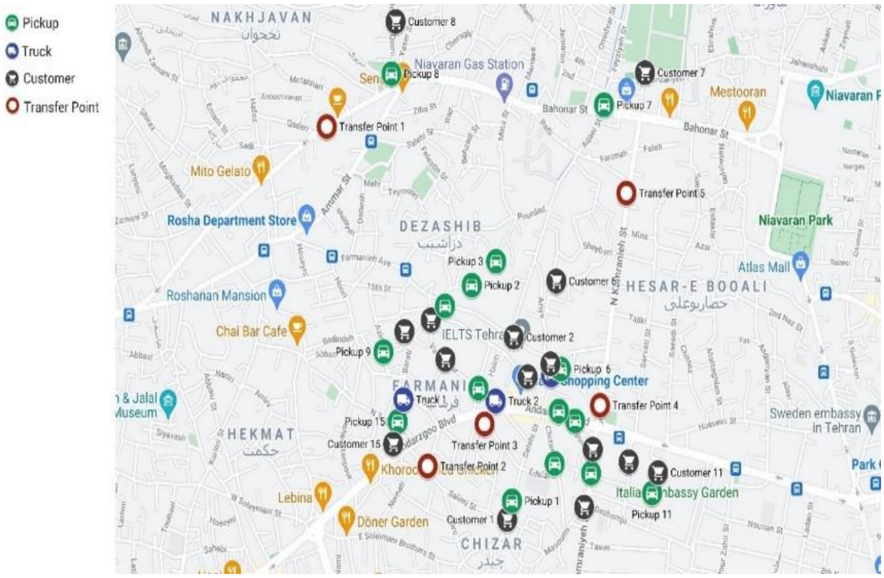

Figure 5. Supply chain distribution network of the case study.

Moreover, Table 3-8 shows a list of selected parameters based on real case settings. These parameters are the demand of each pickup, the initial amount of the truck's load, the distance between each component of the network

Table 5. Distance between pickup's current customer and TPs (d_{ij}) (Kilometers).

Pickup		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TP	1	5.20	2.80	3.25	5.34	4.18	3.80	3.76	2.66	2.75	4.95	6.15	3.15	5.33	5.88	3.52
	2	2.55	4.51	2.80	6.36	3.33	3.43	4.97	5.61	5.14	4.32	4.07	2.59	3.57	2.23	3.69
	3	2.91	5.23	4.80	5.85	3.49	5.31	5.78	5.14	3.42	2.43	2.51	5.21	4.73	2.16	5.96
	4	2.36	2.88	4.63	5.75	2.89	2.17	4.93	5.11	3.95	3.79	3.22	3.23	2.65	6.67	3.90
	5	5.92	3.50	2.63	5.74	2.35	3.01	2.03	3.35	4.50	2.76	2.87	3.65	3.58	3.61	6.82

Table 6. Distance between trucks and TPs (dc_{ik}) (Kilometers).

Truck		1	2	3
TP	1	2.6870	5.3731	4.2015
	2	3.2046	3.1688	2.8962
	3	3.3993	5.4251	2.2685
	4	4.0008	5.9925	4.3149
	5	5.9645	5.0490	2.5228

Table 7. The distance between the TPs and the pickup's next customer (d'_{ij}) (Kilometers).

Next Customer		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TP	1	6.30	1.83	1.51	1.21	4.79	3.13	3.38	1.37	1.49	4.35	5.40	2.48	5.30	2.35	3.84
	2	1.86	3.49	3.64	3.54	4.13	4.70	6.92	5.80	3.82	4.16	4.85	3.13	3.63	3.25	2.10
	3	3.29	1.76	1.97	2.01	2.81	2.91	5.15	4.31	2.13	2.67	3.57	1.33	2.73	1.46	2.81
	4	5.04	2.60	2.88	3.31	0.62	1.58	4.18	4.80	2.87	0.16	1.04	2.09	1.61	2.16	5.60
	5	6.87	2.71	2.82	3.26	2.71	1.05	2.21	3.61	2.68	2.24	2.78	2.70	3.71	2.63	6.44

Table 8. The unsatisfied demand cost of each pickup ($w_4{}^j$).

Truck	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost (USD)	25	26	25	25	30	28	25	26	30	27	28	26	28	25	27

As previously stated, the proposed model has been implemented in GAMS software. According to the non-linearity of the model, the BARON solver has been used to solve it. Table 9-10 shows the result of the solved model and even how the model assigned the pickups and trucks into TPs. In Table 9, if pickup j is assigned to TP i, output in row i and column j is one otherwise is zero. For example, pickup No. 3 is assigned to TP No. 1, so the output value equals one. Figure 6 illustrates the supply chain distribution network environment in a real case and shows the result of the allocation of the proposed model.

Table 9. Result of variable decision assignment of pickups to TPs (z_{ij}).

	Pickup	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TP	1	0	1	1	0	0	0	0	1	1	0	0	1	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	1	0	0	0	1	0	0	0	0	1	1	0	0	0	1
	5	0	0	0	1	0	1	1	0	0	0	0	0	1	1	0

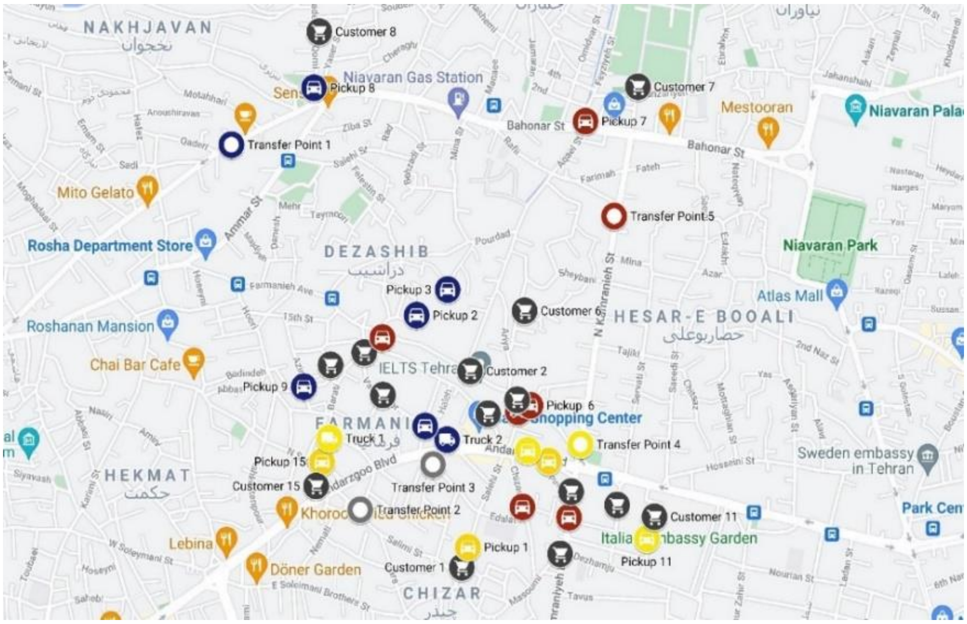

Figure 6. Allocation of vehicles in the case study.

Table 10. The result of trucks allocation to TPs.

Truck		1	2	3
TP	1	0	1	0
	2	0	0	0
	3	0	0	0
	4	1	0	0
	5	0	0	1

As shown in Figure 6, the same-colored vehicles will observe the same color TP to reload. As it is clear, TPs 2 and 3 are not selected for reloading according to the conditions of the real case. The results of the allocation of trucks indicate that truck No. 1 has been assigned to TP No. 4 and truck No. 2 to TP No. 1, as well as to truck No. 3 to TP No. 5.

Table11. The amount allocated to each pickup in the loading process (ac_j).

Pickup	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Allocated Load	71	81	70	80	72	80	84	80	81	70	81	79	90	38	73

In Table 11, the amount of load assigned to each pickup after loading has been determined by considering the load amount of the truck. The proposed model allocates goods (loads) between pickups based on the cost of unsatisfied demand for each pickup in order to minimize the cost of unsatisfied demand in the model. For example, of the 70 units required for the third pickup, 68 units have been assigned, therefor the third pickup is facing two unsatisfied demand units. The shortage of demand for each pickup is given in Table 12. The total shortage of this example is 39 units and the value of the objective function of the numerical example is 1242.12.

Table 12. The amount of unsatisfied demand for each pickup.

Pickup	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Unsatisfied Demand	0	0	2	0	0	0	2	0	0	0	0	0	0	35	0

As earlier mentioned, 15 test problems, a real case, and 14 experimental examples are provided to examine the model's applicability.

5. Sensitivity Analysis

The proposed network aims to manage the total costs and unsatisfied demand optimally. Based on these two targets, optimizing the unsatisfied demands may lead to an increase in the total costs of the network and vice versa. Considering these two targets in the modeling of the proposed network, a balance is required to have both of them at their optimal level. In this section, we conduct a sensitivity analysis on the main parameters of the model, such as the amount of trucks' load, the distance between the pickups and TPs, the distance between trucks and TPs, the amount of pickup demand and penalty of unsatisfied demands of pickups. This framework helps us examine the model's behavior based on the variation of parameters.

5.1. Effect of the Amount of Truck's Loads

Due to the fact that the load of each pickup is supplied by the trucks, it may cause difficulties for the pickups in case their load becomes insufficient. Also, it has other consequences, such as adding extra costs to the whole distribution network. Here, we examine the sensitivity of the cost of the distribution network to a load of trucks by changing their load. Table 13 and Figure 7 demonstrate the effect of trucks loads on the behavior of total distribution cost and unsatisfied demand for all pickups. Loads of trucks are decreased 20 percent from the normal problem, and the results are reported in Table 13. The results show that the lower the amount of truck loads get, the higher the total cost and unsatisfied demands. This variation is because the demand for pickups could not be satisfied with a lower level of truck loads, increasing the total cost and unsatisfied demand.

Table 13. The sensitivity analysis for the amount of truck's loads.

Test Problem	Truck Load	Active TPs	(Pickup No.) Unsatisfied Demand	Unsatisfied Demand	Objective Function
1	-20 %	(1,2,5)	(1) 15, (4) 49, (7) 32	96	3304.221
2	-40 %	(1,2,5)	(1) 35, (4) 69, (7) 52	156	4804.221
3	-60 %	(1,2,5)	(1) 55, (3) 4, (4) 85, (7)72	216	6304.221
4	-80 %	(1,2,4)	(1) 02, (3) 24, (4) 85, (7) 86, (10) 6, (14) 73	276	7788.807
5	-100 %	(1,2,4)	(1) 36, (3) 44, (4) 85, (7) 86, (10) 6, (14) 73	336	9315.558
Original		(1,2,5)	(1) 16, (4) 8, (7) 12	36	1832.800

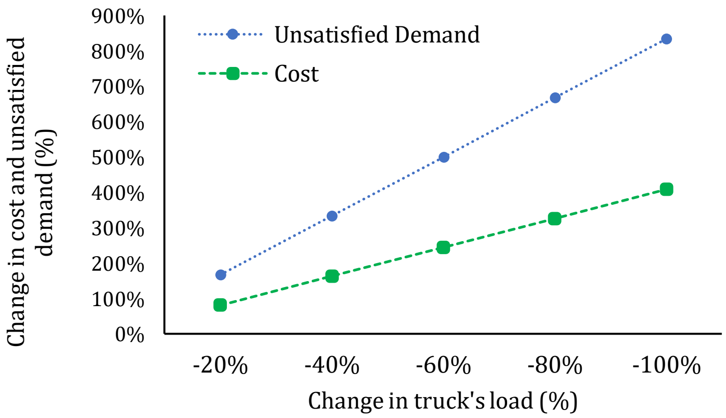

Figure 7. Changes of unsatisfied demands and cost for the amount of truck's loads.

5.2. Effect of the Distance of the Pickups to the Transfer points

The next parameter is the distance pickups to the TPs. In this part, we vary the distance of pickups to TPs by 20% in each step compared to the normal amount and form 5 different problems. As Table 14 and Figure 8 imply, the distance variations between the pickups and the transfer points affect the total cost. However, the unsatisfied demands do not follow the variation of distances. As shown in Figure 8, the pickup distance increases by 50%, the total cost of the distribution network increases from 1832,800 to 1999,476 (about 10%).

Table 14. The sensitivity analysis for the distance of the pickups to the transfer points.

Test Problem	Pickup Distance	Active TPs	(Pickup No.) Unsatisfied Demand	Unsatisfied Demand	Objective Function
1	+10%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1866.135
2	+20%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1899.470
3	+30%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1932.805
4	+40%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1966.141
5	+50%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1999.476
Original		(1,2,5)	(1) 16, (4) 8, (7) 12	36	1832.800

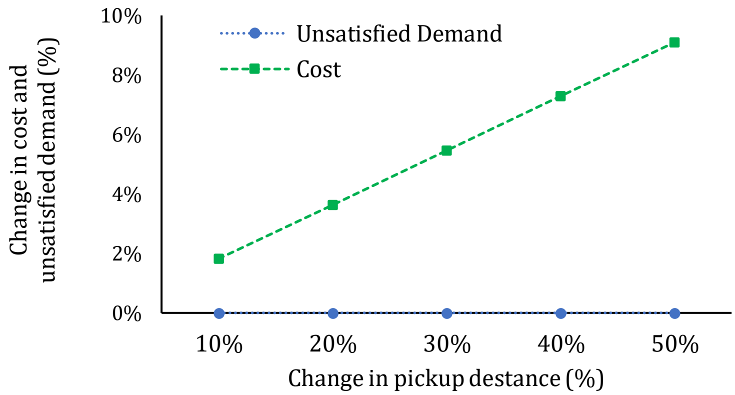

Figure 8. Changes of unsatisfied demands and cost for the distance pickups to the transfer points.

5.2. Effect of the Distance of the Trucks to the Transfer points

As in the previous section, we analyze the behavior of total cost and unsatisfied demands based on the distance of trucks to the TPs. Hence, the distance of trucks is changed from 10 to 50% in five problems. The result of each problem is obtained and reported in Table 14 and Figure 8. It can be reckoned that changes in the distance of trucks bring about increases in the total cost of the distribution network; however, similar to the previous section, they do not impact the amount of unsatisfied demands.

Table 15. The sensitivity analysis for the distance of the trucks to the transfer points.

Test Problem	Truck Distance	Active TPs	(Pickup No.) Unsatisfied Demand	Unsatisfied Demand	Objective Function
1	+10%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1832.800
2	+20%	(1,2,5)	(1) 3, (4) 29, (7) 4	36	1843.171
3	+30%	(1,2,5)	(1) 3, (4) 29, (7) 4	36	1851.968
4	+40%	(1,2,5)	(1) 3, (4) 29, (7) 4	36	1860.766
5	+50%	(1,2,5)	(1) 3, (4) 29, (7) 4	36	1869.563
Original		(1,2,5)	(1) 16, (4) 8, (7) 12	36	1832.800

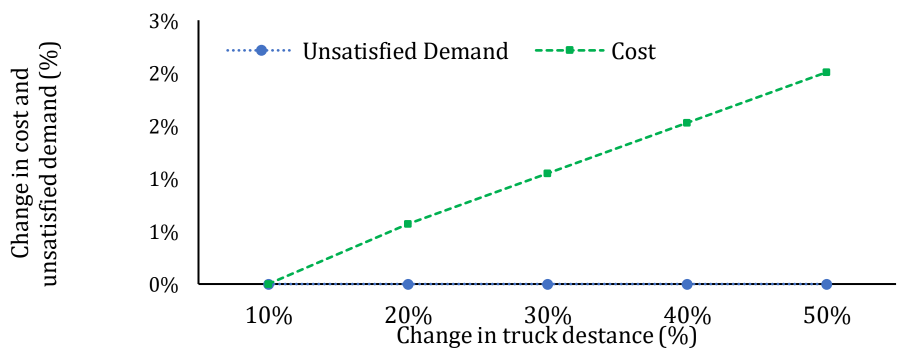

Figure 9. *Changes of unsatisfied demands and cost for the distance trucks to the transfer points.*

5.3. Effect of the Amount of Pickup Demand

Among the model's parameters, the demand for pickups can be remarked as the most influential parameter in the model. As the demands increase, the possibility of shortages in the network is fortified. So, any shortages in the network may cause customers' dissatisfaction and may negatively affect the organizations' reputation. Therefore, we design five problems based on the normal situation where the pickup demand is changed 5 percent in each step.

Table 16. The sensitivity analysis for the amount of pickup demand.

Test Problem	Pickup Demand	Active TPs	(Pickup No.) Unsatisfied Demand	Unsatisfied Demand	Objective Function
1	+5%	(1,2,5)	(1) 16, (4) 8, (7) 12	36	1832.800
2	+10%	(1,2,5)	(1) 20, (3) 54, (7) 37	111	1843.171
3	+15%	(1,2,5)	(1) 70, (3) 4, (4) 100, (14) 83	186	1851.968
4	+20%	(1,2,5)	(3) 4, (4) 100, (7) 101, (7) 87	261	1860.766
5	+25%	(1,2,4)	(1) 2, (3) 24, (4) 405, (7) 106, (10) 6, (14) 93	336	1869.563
Original		(1,2,5)	(1) 16, (4) 8, (7) 12	36	1832.800

The results are displayed in Table 14 and Figure 8. They confirm that the growth of pickup demands had a surprising impact on unsatisfied demands and a slight increase in total cost.

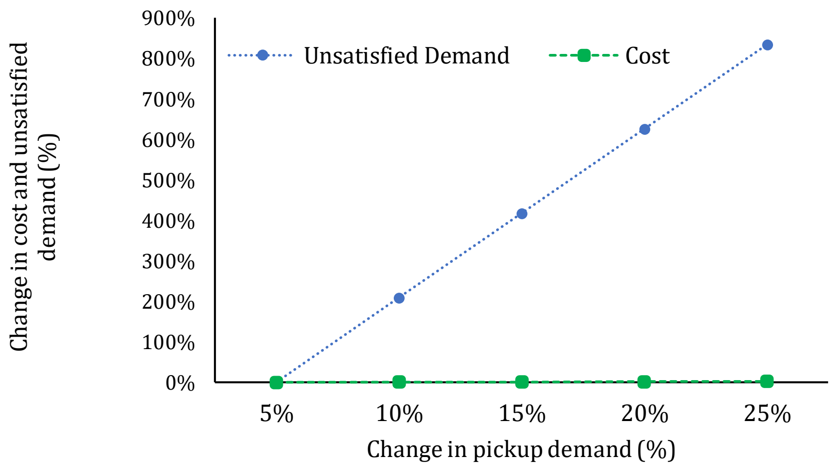

Figure 10. Changes of unsatisfied demands and cost for the amount of pickup demand.

5.4. Effect of the Penalty of Unsatisfied Demands of Pickups

As previously mentioned, the amount of penalty for unsatisfied demand of pickups varies according to the type of customers. Therefore, the company prefers to provide the services based on the prioritization of customers, which the model sets a higher penalty for high-priority customers. Here, three different scenarios are implemented to check the sensitivity of the proposed network according to the penalty of unsatisfied demand: (I) penalty of pickup No. 4 from 25 change to 30, (II) penalty of pickup No. 2 from 26 change to 23, and (III) penalty of pickup No. 2 from 26 change to 15.

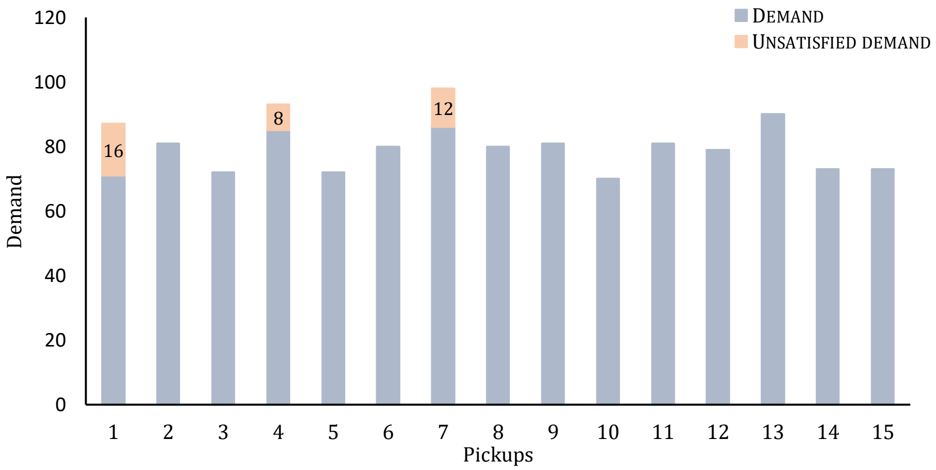

Figure 11. Changes of unsatisfied demands under scenario (I).

In scenario (I), the penalty of pickup No. 4 is altered from 25 change to 30 and Figure 11. shows the behavior of the network, in which pickup No. 4 is faced with a shortage of 8 units. In the next scenario, Figure 12. shows that by increasing the value of the penalty of pickup No. 2 from 26 change to 23 (make it a high-value customer), this amount of shortage is assigned to pickup No. 3.

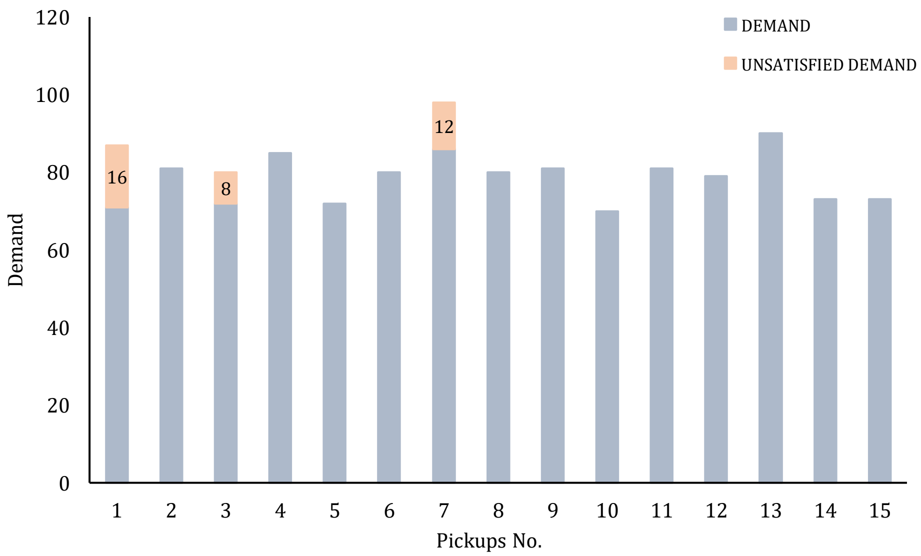

Figure 12. Changes of unsatisfied demands and cost for the penalty of unsatisfied demands of pickups.

In the last scenario, we alter the penalty of pickup No. 2 from 26 change to 15, which in real-world we may interpret as the company deciding to reduce a customer's priority (for instance, due to heavy debt). Figure 13. shows that by reducing the penalty amount for pickup No. 2 from 26 to 15, the unsatisfied demand for pickup No. 2 has increased from 0 to 36, and this amount has been allocated to the rest of the customers.

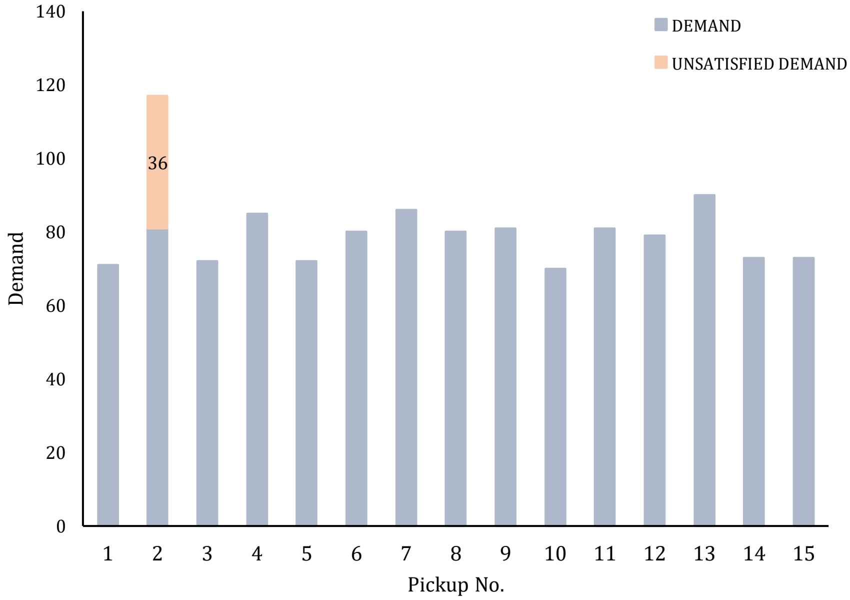

Figure 13. Changes of unsatisfied demands and cost for the penalty of unsatisfied demands of pickups.

6. Discussion

Nowadays, the industrial atmosphere seeks competitive advantages in light of many volatile components that intensively impact the excellence of structures. On the other side, businesses follow a series of guidelines and strategies declared by the top managers and main policy-makers to reap customers' profitability and satisfaction more than their counterparts in the same activity area. Distribution networks are key components of organizational processes that can be monitored and managed to reach a lower total, increase satisfaction, and stay away from unsatisfied demand.

In recent decades, the expansion of urban regions and traffic load have been listed as two elements of rising shipping costs and reducing on-time deliveries, which directly have impacted customer satisfaction. Also, establishing fixed warehouses in these areas may not be cost-effective or gain added value for the industries. On the other hand, as an outstanding tool, the advent of new technologies strengthens organizations to dominate their challenging difficulties.

We proposed a flexible distribution network to devise a mobile warehouse strategy to tackle the disputes initiated by the stated factors. In a specific manner, the trucks act as mobile warehouses, and the pickups are the mobile distribution units in the distribution region with predefined customers. Also, wireless sensors, as information technology units, are the main devices that are positioned in each vehicle, both trucks, and pickups, to flexibly communicate and monitor the conditions. All sensors convey the communications to the processing center located in the organization's building. The processing center exploits the proposed model to recognize the optimal points in the distribution region for reloading mobile warehouses and distribution units while the total cost and unsatisfied demands are at their lowest amount.

The proposed distribution network combined with digital technology is founded in real data, but the mathematical modeling and the wireless sensor network can be used for all industries where the distribution networks are the main part of their processes. Due to the product-specific traits, some industries, like agri-food or pharmaceuticals, have to consider the possibility of disruption or perishing of the products. This intrigues the logistics or distribution manager of the related businesses to customize the distribution network based on the characteristics of the products by collecting and analyzing the data on the disruption or perishability of products.

7. Conclusions

Our findings show that adding penalties to the model can assist managers in easily prioritizing their high-importance customers. To be clearer, sensitivity analysis demonstrates that more penalty for the selected customer enforces the model to set them at the highest level and satisfy the demand related to that customer. On the other, the manager can reduce the penalty of a customer in cases like lack of credits record, heavy debt, or defaulters. Logistics managers normally aim to control the inventories or warehouses to create the reliable movement of products in the network. On the other side, the managers need to handle the inventories at the lowest costs. Therefore, the managers can use the capabilities of the proposed model and wireless sensor network to provide mobile warehousing and real-time distribution. In the case that the industry manufactures different products, they also might extend the model or even equip the retailers with the sensors and connect them to the processing unit to have temporal warehouses for a short time.

In addition to managerial insights, the current study contains different limitations: (I) The authors could not find a valid or accurate value for the model's parameters; however, they used estimation methods to obtain the required data approximately. (II) Unquestionably, uncertainty exists in the real world, and this study functioned as the primary attempt in this field. So, to meticulously implement the combination of mathematical modeling and wireless sensor network, the uncertainty was not added to the mathematical formulation, but it is suggested to be considered for future works. (III) The performance and accuracy of wireless sensor networks have not been evaluated during the study.

Finally, managerial insights and limitations of this study bring about the following direction for future research: (I) The demand parameters of the distribution network can be simulated using artificial intelligent approaches or manipulated more accurately using machine learning techniques added to the wireless sensor network. (II) The uncertainty of the model can be addressed by stochastic programming methods such as the chance constraint method or robust programming models. (III) The recent COVID-19 pandemic has affected all industries' supply chains and distribution networks. For future works, disruptions caused by pandemic phenomena may be considered in the model to help the manager cope with the existing challenging conditions. (IV) Sustainability concepts such as CO2 emission or social considerations like employment opportunities or routing congestion may be developed based on the nature of business. (V) Evaluation indicators for the performance or accuracy of wireless sensor networks can be contrived in the model to improve itself for reaching better results.

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