An Internet of Things Embedded Sustainable Supply Chain Management of B2B E-Commerce

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Abstract: Adopting digital technologies in a business can help with sustainable supply chain management. These technologies can make e-commerce development faster and empower the emergence of B2B e-commerce businesses. In this study, our focus was to develop a framework for an Internet of things (IoT) embedded sustainable supply chain to deliver textile items using a B2B e-commerce business model. We formulated a mixed-integer non-linear programming (MINLP) model to minimize the total supply chain cost, including the B2B orders’ packaging, handling, and transportation, with carbon emission taxation. Furthermore, the purchasing cost of the RFID tags and IoT facilities that were provided on the transport vehicles was high. The proposed model was solved by using the global solver in the LINGO software package and finding the optimized value of the total supply chain network cost. We tested the proposed model in different case scenarios, i.e., small- to significant-sized problems. Then, a sensitivity analysis was performed to observe the variations in the overall cost of the supply chain network when there were changes in the main parameters of the proposed model. The results of the models showed that models can be helpful for efficient logistics planning and supply chain design.

Keywords: digital technologies; sustainable supply chain; Internet of things (IoT); e-commerce; logistics; textile products

1. Introduction

The textile industry is responsible for the design, production, and distribution of cloth and yarn. According to a Statista report by Ziyun Zhang, the growth of the Indian textile industry increased by 8.7% from the fiscal year 2015 to the fiscal year 2020, which is more than the last observation, which was 7% from the fiscal year 2010 to the fiscal year 2015 [1]. Traditionally, the textile industry is known as a major polluter, resulting in various environmental degradation, including water pollution, greenhouse emission, and various other hazardous health impacts. It is essential to reduce these related environmental degradation aspects. Sustainable practices can help in achieving this. Various sustainable practices include less water usage, less use of fertilizers and pesticides, and using the 3R’s, i.e., the reduce, reuse, and recycle philosophy. The key player of the fourth revolution of industry (Industry 4.0) is the IoT, which improves visibility and communication across the whole supply chain and logistics value chain [2]. Industry 4.0 has been accepted as the most critical factor and plays a significant role in the era of digitalization [3]. In the era of Industry 4.0, there are three major barriers, namely, a lack of research and development, poor infrastructure, and a non-supportive policy ecosystem [4]. In digital technologies, including IoT, blockchain, AI, and cloud computing, robust development stresses a suitable decision model for an efficient inter-organizational information systems adoption process [5]. A smart manufacturing plant prefers the practice of innovative advancements.
in digital technology, “including the IoT, cloud computing, hi-tech sensors, AI, data capture and analytics, digital fabrication, and other innovative mobile devices, models of marketing, platforms that use algorithms to direct motor vehicles (including ride-sharing apps, autonomous vehicles, and ride services), and implanting altogether in an interoperable worldwide value chain, shared by several industries from various nations” [6].

Supply chain management (SCM) is progressively becoming dynamic and complex. IoT and RFID are two main factors that play a substantial role in satisfying consumer needs in the supply chain [7]. SCM is improved by the IoT solutions’ integrated special tags, for example, QR codes, NFC, and RFID, with products to generate smart tags, in addition to storing supplementary information related to a product [8]. The supply chain management collaboration with the logistics lessens the total costs while enhancing the services to consumers in the supply chain. Growing regional influence, rapid innovation, and global progress have reached the supply chain as a crucial part [9]. When studying the VRP (vehicle routing problem), especially for arrivals on time, finding the travel time becomes critical in the optimization of logistics industries. Traffic IoT links devices and performs data collections from many channels, such as sensors, vehicle detectors, traffic cameras, and GPS, which may be applied to analyze the actual traffic status and eventually increase the logistics management efficiency for Logistics 4.0 [10].

However, there are some noticeable gaps in the IoT implementation domain in the sustainable supply chain networks used for the delivery of B2B orders in the textile-based e-commerce industry. Hence, there is a strong need for an optimization model that includes order packaging, handling, and transportation with the carbon emission concerns and the concerns related to the IoT facilities providing transport vehicles with the application of the operations research concepts.

This study focused on developing a framework for an IoT embedded sustainable supply chain for the textile industry. In this, we aimed to deliver the textile items from the manufacturing firm to the wholesale warehouse using the B2B e-commerce business model with a minimum optimized cost and in a smarter way. This is, we focused on a solution for sustainable supply chain problems in the adoption of IoT technology for textile businesses. A mathematical model was formulated to minimize the total cost of an IoT embedded smart supply chain network. The cost included the B2B orders packaging, handling, and transportation with a carbon emission taxation cost. We also included the purchasing cost of RFID tags and IoT facilities that were installed on packaged products and transport vehicles, respectively. To find the minimum cost, an MINLP optimization model was formulated. The proposed model captured the problems related to the order processing, handling, and transportation of textile products from manufacturers to wholesalers.

The contributions of this study include:

- A sustainable framework of the supply chain which includes the order packaging, handling, transportation problems, as well as a problem related to the implantation of IoT facilities in transport vehicles for B2B e-commerce.
- Managing the transportation cost with carbon emission tax, packaging, and handling costs, purchasing cost of RFID tags, and installation cost of IoT facilities in the transport vehicles.
- Attention to supply chain problems with IoT technology adoption in textile industries.

The rest of the paper is organized as follows. The background of the research is given in Section 2. Section 3 defines the problem description of this study, along with the mathematical model. The solution approach is proposed in Section 4. In Section 5, a case study is discussed. In Section 6, the results are presented for considered scenarios. Lastly, Section 7 concludes the whole work and also provides limitations and future research directions.
2. Literature Review

2.1. Literature Based on the Internet of Things in the Supply Chain

Hossija et al. [11] performed a deep bibliometric analysis on the security-related source of threats and challenges in the applications of IoT. Ayaz et al. [12] highlighted the wireless sensors’ potential and IoT in agricultural sectors and the expected challenges faced during the integration of this technology in conventional farming practices. Abbasi et al. [13] focused on measuring the credit risk of supply chain finance by applying the concept of the Internet of things (IoT). They also described the hierarchical structure of IoT and its main technologies and combined the business procedure of inventory pledge financial model and unique functions of the IoT technology to design the financial model of a supply chain. Liu et al. [14] proposed an innovative IoT-based technology cloud laundry e-commerce business model for mass-scale laundry services. Rejeb et al. [15] performed a bibliometric analysis on IoT research in logistics and supply chain management. They reviewed 807 research articles published in the last twenty years. Zhou et al. [9] introduced a field-programmable gate array (FPGA) and Internet of things (IoT) for the collaboration of the logistics and supply chain. Ekren et al. [16] investigated the crosswise shared-based inventory business models for a network of electronic groceries, where the online items are linked with the IoT environment. Chen et al. [10] proposed a new approach, i.e., the gradient boosting partitioned tree model, to predict the traveling time by using big data analytics, where the data used was collected from the infrastructure of industrial IoT. Anitha et al. [2] focused on enabling the connectivity and visibility of a supply chain by implementing the IoT-based technology and observed the performance of the IoT in the supply chain.

2.2. Literature Based on the Supply Chain for the Textile Industry

Muthu [17] provided several strategic approaches to achieving sustainability goals in the textile industry. The significance of green supply chain management and eco-design was emphasized. Further, the effect of using alternatives in the production and consumption of textile products was highlighted. Eda et al. [18] introduced some ways to measure the sustainability performance of the textile industry using the MCDM method. Shen et al. [19] highlighted the sustainability issues in textile supply chains. Kazancoglu et al. [20] and Oelze [21] presented a framework for the barriers involved in implementing the concepts of sustainability and circular economy in supply chain network design for the textile industry. Nunes et al. [22] provided the role of technological innovation for sustainable growth in the textile industry. Similarly, Muthu [23] highlighted building sustainable design and business models for production and consumption. Various standards and certification practices were also reported. Khan et al. [3] conducted a systematic review that mapped the extensive area of sustainable development and examined the main research domain, which encompassed the circular economy, sustainable business models, and triple-bottom lines perspectives within the framework of Industry 4.0. Sadowski et al. [24] presented the changes in the textile and apparel industry in Poland between the years 2004 and 2020. They discussed basic features, such as production value, innovation, the structure and size of the industry, and the use of communication and information technology.

2.3. Literature Based on B2B E-Commerce

Shen et al. [19] provided a discussion of the critical issues of sustainability in the textile industry with a focus on supply chains. Hempel and Kwong [25] examined several of the challenges faced by the B2B e-commerce marketplace in an emerging economy. The emerging economies show a meaningfully different business context, owing mostly to their less developed legal, physical, and financial infrastructures. Claycomb et al. [26] examined several models, along with the overall use of B2B e-commerce as the dependent
variable and innovation channel factors, context, characteristics, and organization structure as the predictor variables. Ma et al. [27] focused on the B2B spot markets and considered a supply chain composed of two manufacturers and one supplier. Manufactures procure raw material for the dual sources, i.e., from a supplier with a forward collaboration or from a business-to-business spot market. Prajapati et al. [28] focused on sustainable vehicle routing problems for the pickup and delivery of agro-food grains in e-commerce. They considered triple-bottom lines of sustainability, where one is the potential accidents regarding transport vehicles that capture the driver safety concerns, which is considered a social factor.

2.4. Literature Based on the Solution Approaches

Zhang et al. [29] developed an e-commerce forward and reverse logistics service trading system and found the solution of a VRP with simultaneous pickup and delivery in an e-commerce logistics organization. They formulated an MINLP model and solved it by using two approaches, namely, an exact approach in CPLEX and metaheuristic algorithms (i.e., a parallel differential evolutionary algorithm (Par-DE) and block-based genetic algorithm (BBGA)). Garg et al. [30] implemented the concepts of deep neural language processing to offer a new approach for implications about the engagement of employees in the logistics industry. Kushwaha et al. [31] also used natural language processing summarization approaches to observe the emerging new management domains after the bibliometric analysis of published research articles in the reputed management journals. A comparative review based on the previous studies is given in Table 1.

Table 1. Comparative literature review.

| Authors Name         | IoT | Supply Chain | Logistics | Model | Textile | Sustainability | E-Commerce |
|----------------------|-----|--------------|-----------|-------|---------|----------------|------------|
| Abbasi et al. [13]   |     | √            | √         |       |         |                |            |
| Liu et al. [14]      |     | √            |           |       |         |                | √          |
| Rejeb et al. [15]    |     | √            |           |       |         |                |            |
| Ekren et al. [16]    |     | √            |           |       |         |                |            |
| Zhou et al. [9]      |     | √            |           |       |         |                | √          |
| Anitha et al. [2]    |     | √            |           |       |         |                |            |
| Konstantakopoulos et al. [32] |     | √            |           |       |         |                |            |
| Khan et al. [3]      |     |              |           |       |         |                | √          |
| Kazancoglu et al. [20] | √   |              |           |       |         |                |            |
| Ma et al. [27]       |     | √            |           |       |         |                |            |
| Oelze [21]           |     | √            |           |       |         |                |            |
| Nunes et al. [22]    |     | √            |           |       |         |                |            |
| Current study        |     | √            |           |       |         |                | √          |

From the previous literature (as summarized in Table 1), we found that very few researchers focused on developing a sustainable framework for the textile products supply chain that includes the B2B order packaging, handling, transportation, and IoT facilities on the transport-vehicle-related concerns. Moreover, implementing IoT facilities in the supply chain network becomes challenging and crucial to make it smarter and more efficient. Most of the previous studies focused on the bibliometric and empirical-based analysis of IoT in the supply chain. These things motivate us to consider the IoT-facility-related factors (which may be parameters and/or decision variables) for the formulation
of a mathematical model. In this study, we considered purchasing the RFID tags for tracking and the cost associated with installing IoT facilities in all transport vehicles and other major keywords, which are given in bolded part of the Table 1.

3. Problem Description

This study focused on an IoT embedded sustainable framework of a supply chain in B2B e-commerce that included order packaging, handling, and transportation problems, along with the IoT facilities provided on the transport vehicles and RFID tag purchasing. A proposed framework is shown in Figure 1 in which there were four major entities, i.e., the e-commerce platform, third party logistics, manufacturer, and wholesaler. This work mainly focused on sustainable virtual supply chain problems in textile industries working with the B2B e-commerce business model. This can be helpful for companies such as myRaymond (Uttar Pradesh, India), Loyal Textile Miles Ltd. (Chennai, India), ZoomTail Apparel Wholesale (Bengaluru, India), Regal Fashion Fabrics (Maharashtra, India), and Suratfabrics (Surat, India), which are working in several cities of India. In this study, the main focus was on the B2B order packaging; transportation, while keeping in mind the environmental concern; and the implementation of IoT facilities in the transport vehicles to make the supply chain smarter, faster, and flexible. We formulated an optimization model that captured the costs, such as order packaging and handling costs; transportation cost, along with a carbon emission taxation cost; the purchasing cost of RFID tags; and IoT facilities. The formulated optimization model helped to find the optimized routes for the order pickup and delivery by selecting the best possible pickup point. Moreover, the best allocation of transport vehicles played a significant role in minimizing the total cost of the supply chain network.

![Figure 1](image_url). A framework of an IoT embedded sustainable supply chain in a B2B E-commerce textile industry.
Assumptions

- Availability of transport vehicles at 3PLs and products at manufacture are known and satisfy the demands of the wholesalers.
- IoT facilities only for transport vehicles are taken into consideration, assuming that 3PLs, manufacturers, and wholesalers have already installed the IoT system.
- E-commerce platforms work as a mediator for manufacturers and wholesalers.
- The manufacturer and wholesaler have well-established IoT facilities. Given this, we considered the IoT facilities on transport-vehicle- and RFID-tag-related factors in our proposed model.

Mathematical Formulation

A mathematical model was formulated to determine the minimum cost of delivery, along with the order tracking using the IoT devices, and is presented in this section. Graph G \((M, W)\) is shown in Figure 1, where \(MF_m\) is used for the set of manufacturing plants indexed by \(m \ (m = 1, 2, \ldots, M)\), \(WS_w\) for the set of wholesalers with index \(w \ (w = 1, 2, \ldots, W)\), and set of orders are represented by \(O_r\) with index \(r \ (r = 1, 2, \ldots, R)\). \(X_{mwr}\) is a binary decision variable that decides whether the order quantity is moving in the network and the value of this variable is either 1 or 0.

Sets

\(MF_m\) — Set of manufacturers \((m = 1, 2, \ldots, M)\).
\(WS_w\) — Set of wholesalers \((w = 1, 2, \ldots, W)\).
\(O_r\) — Set of orders \((r = 1, 2, \ldots, R)\).

Parameters

\(D_{mwr}\) — Traveling distance (in kilometers) between MF \(m\) and WS \(w\).
\(A_{rm}\) — Availability of order \(r\) at MF \(m\).
\(Dem_{rw}\) — The order \(r\) demanded by the WS \(w\).
\(C^{tc}\) — Transportation cost (INR/vehicle/kilometer).
\(C^{tax}\) — Carbon taxation cost (INR/vehicle/kilometer).
\(C^{hand}\) — Handling cost (INR/quantity).
\(C^{pack}\) — Packaging cost (INR/quantity).
\(C^{RFID}\) — Purchasing cost of RFID tags (INR/tag).
\(C^{IoT}\) — Purchasing cost of IoT facilities (INR/facility).
\([C^{RFID,LL} - C^{RFID,UL}]\) — Range of purchasing cost of RFID tags (INR/tag).
\([C^{IoT,LL} - C^{IoT,UL}]\) — Range of cost of IoT devices for installation in transport vehicles (INR/vehicle).
\(M^{alloc\_IoT}\) — Allocated amount for the IoT systems.
\(V^{cap}\) — Vehicle weight carrying capacity.

Decision variables

\(Q_{mwr}\) — Quantity of order \(r\) moving from MF \(m\) to WS \(w\).
\(N_{mwr}\) — Number of vehicles required to transport an order \(r\) from MF \(m\) to WS \(w\).

Binary decision variables

\(C^{RFID}\) — Purchasing cost of RFID tags (INR/tag).
\(C^{IoT}\) — Purchasing cost of IoT facilities (INR/facility).
\[ X_{m wr} = \begin{cases} 1, & \text{if quantity of an order } r \text{ moving from MF } m \text{ to WS } w \\ 0, & \text{otherwise} \end{cases} \]

**Mathematical model**

The mathematical model contained an objective function and was subjected to constraints.

**Objective function**

\[
Z_{\text{tot}} = \sum_{m \in M} \sum_{w \in W} \sum_{r \in R} \left\{ \left( C^{\text{packg}} + 2 \cdot C^{\text{hand}} + C^{\text{install}} \right) Q_{m wr} + \left( C^{\text{c}} + C^{\text{tax}} \right) D_{m w} + C^{\text{IoT}} \right\} X_{m wr}
\]

Equation (1) is the objective function equation in which the first part calculates the total packaging cost, handling cost, and purchasing cost of the RFID tags, while the second part gives the total transportation cost with carbon emission tax and installation cost of IoT facilities in the transport vehicles.

**Subject to constraints**

\[
\sum_{m \in M} Q_{m wr} X_{m wr} \leq A_{m r}, \forall m \in M, r \in R
\]

(2)

\[
\sum_{m \in M} Q_{m wr} X_{m wr} = D_{m wr}, \forall w \in W, r \in R
\]

(3)

\[
N_{m wr} = \frac{Q_{m wr} X_{m wr}}{V_{\text{cap}}}, \forall m \in M, w \in W, r \in R
\]

(4)

\[
\sum_{m \in M} X_{m wr} = 1, \forall w \in W, r \in R
\]

(5)

\[
\sum_{m \in M} \sum_{w \in W} \sum_{r \in R} \left( C^{\text{RFID}} Q_{m wr} + C^{\text{IoT}} N_{m wr} \right) X_{m wr} = M^{\text{allocat, IoT}}
\]

(6)

\[
C^{\text{RFID, LL}} \leq C^{\text{RFID}} \leq C^{\text{RFID, UL}}
\]

(7)

\[
C^{\text{IoT, LL}} \leq C^{\text{IoT}} \leq C^{\text{IoT, UL}}
\]

(8)

\[
X_{m wr} = \{0, 1\}, \forall m \in M, w \in W, r \in R
\]

(9)

\[
Q_{m wr} \geq 0, \forall Q_{m wr} \in Z^+, m \in M, w \in W, r \in R
\]

(10)

\[
N_{m wr} \geq 0, \forall N_{m wr} \in Z^+, m \in M, w \in W, r \in R
\]

(11)

Constraint (2) makes sure that the total availability should be greater than or is equal to the sum of the quantity to be shipped at the wholesalers. Equation (3) makes sure that the order quantity moving from the manufacturers to the wholesaler should be equal to the demand. Equation (4) calculates the number of vehicles needed to deliver the order. Equation (5) makes sure that the order should be picked up only once. Equation (6) restricts the total cost related to IoT. Constraints (7) and (8) provide the range of purchasing costs of RFID tags and IoT facilities, respectively. Equations (9)–(11) are binary and non-negativity constraints.
4. Solution Approach

The proposed model considered the transportation cost with carbon emission tax, packaging, and handling costs. The problems related to the closed-loop supply chain with price-sensitive demand [33], forward and reverse logistics problems with customer relationship [34], sustainable furniture supply chain in B2B e-commerce [35], minimization of B2B orders delivery time with transport vehicles maintenance due to damage [36], and sustainable food grain supply chain network design [37] were formulated using an optimization model and solved using the LINGO optimization tool. These were the main motivations to choose the LINGO optimization tool to solve our proposed MINLP model. The LINGO optimization tool works in the LINDO programming language and can solve all types of programming, such as linear, nonlinear, integer, mixed-integer, mixed-integer nonlinear, and quadratic.

5. Case Study

To find the solution to this proposed MINLP model, we used a GLOBAL solver in the LINGO 19 software package. For the computational work, we used a machine with the following configuration system type: 64-bit operating system, x64-based processor, Intel (R) Core (TM) processor, RAM–32 GB installed, and an i7 CPU @ 2.30 GHz.

5.1. Input Data for the First Instance

In this case study, there were three manufacturers, five wholesalers, and five orders from each wholesaler. The main focus was to minimize the total cost of an IoT embedded sustainable supply chain network used for the delivery of B2B orders. The values of the input parameters were as follows: the packaging cost (in INR/quantity) was 20, handling cost (in INR/quantity) was 10, transportation cost (in INR/vehicle/kilometer) was 60, and carbon emission taxation cost (in INR/vehicle/kilometer) was 10. Purchasing of RFID tags (in INR/tag) was [753.68–1130.02]. The cost of the IoT devices for installation in transport vehicles (INR/vehicle) was [100,000–500,000] and the total allocated amount for the IoT was 5,000,000 INR. Other parameter values are given in Tables 2–4.

Table 2. Distance between node m and node w.

| d_mw | w1   | w2   | w3   | w4   | w5   |
|------|------|------|------|------|------|
| m1   | 758  | 985  | 986  | 789  | 796  |
| m2   | 896  | 875  | 658  | 964  | 785  |
| m3   | 689  | 785  | 589  | 968  |      |

Table 3. Availability of products.

| A_mr | r1   | r2   | r3   | r4   | r5   |
|------|------|------|------|------|------|
| m1   | 50,000| 10,000| 40,000| 70,000| 15,000|
| m2   | 90,000| 80,000| 90,000| 78,000| 84,600|
| m3   | 98,700| 68,900| 10,000| 79,990| 60,000|

Table 4. Demand of products.

| dem_wr | r1   | r2   | r3   | r4   | r5   |
|--------|------|------|------|------|------|
| w1     | 100  | 150  | 24   | 310  | 42   |
| w2     | 50   | 140  | 150  | 30   | 41   |
| w3     | 200  | 160  | 160  | 180  | 160  |
| w4     | 30   | 260  | 170  | 190  | 32   |
| w5     | 35   | 28   | 180  | 210  | 39   |
5.2. Output Values

For the given data sets, the optimized routes for order pickup and delivery in the supply chain network are shown in Figure 2. In this, there was a total of 304 variables, of which, 302 were non-linear and 75 were integral in nature. Furthermore, there were 553 constraints; out of these, 376 were nonlinear. The optimized value of the total cost of the network was 6,649,813 INR and was found within 379.35 s of computation time. The optimized values of the decision variables, i.e., the purchasing of RFID tags and the cost of IoT facilities for installation in transport vehicles, were 753.69 INR and 100,000 INR, respectively. These values chosen by the global solver in the LINGO 19 software package were very close or equal to the lower limits provided in the range. The optimized value of the total cost needed for purchasing RFID tags and IoT facilities was 4,574,762 INR. At the same time, the total carbon emission taxation cost was 97,050 INR. Moreover, the total cost associated with the order packaging, handling, and transportation was 1,978,001 INR. Similarly, we used the same process for all the case scenarios used to validate the proposed MINLP model.

![Figure 2. Optimized transport quantity and routes for order pickup and delivery.](image)

6. Results and Discussion

Here, we provide the values of input data for the first case scenario, which are given in Section 5.1, where computational experiments are given in Section 6.1, and a discussion on the findings is given in Section 6.3.

6.1. Computational Experiments

We tested the proposed MINLP model in ten different case scenarios in small-to-large-sized problems. The computational experiments are given in Table 5. As shown in Table 4, in the first case scenario, i.e., the small-sized problem, there was a total of 304 variables, of which, 302 were nonlinear, while 75 were integral in nature, and there was a total of 553 constraints, with 376 being nonlinear. The optimized value of the total network cost was 6,649,819 INR, which was found within 379.35 s of total elapsed time. However, in the last case scenario, i.e., a large-sized problem, there were 18 manufacturers, 35 wholesalers, and 45 orders. We found only local optima after the program stopped at an elapsed time of 76:40:36 (HH:MM:SS). Meanwhile, in the ninth case scenario, there were 12 manufacturers, 25 wholesalers, and 30 orders. In total, there were 36,004 variables, of which, 36,000 were nonlinear, while 9000 were integral in nature, and there was a total 54,753 number of constraints with 36,001 being nonlinear. We found the global optimal value of the total cost of the sustainable supply chain network, which was 51,912,420 INR, which was found within 15,417.71 s of total elapsed time.
Table 5. Computational experiments in five different cases.

| Sr. No. | Instances m-w-r | Number of Variables | Number of Constraints | Total Cost, INR | Elapsed Time, s |
|---------|-----------------|---------------------|----------------------|----------------|-----------------|
|         |                 | Total   | Nonlinear | Integer | Total   | Nonlinear |               |               |                |
| 1       | 3-5-5           | 304     | 302       | 75      | 553     | 376       | 6,649,813      | 379.35         |
| 2       | 4-7-7           | 788     | 784       | 196     | 1228    | 785       | 8,827,601      | 489.57         |
| 3       | 5-8-8           | 1284    | 1282      | 320     | 2307    | 1601      | 11,092,980     | 755.11         |
| 4       | 6-10-10         | 2400    | 2400      | 600     | 3703    | 2401      | 17,014,650     | 985.32         |
| 5       | 7-15-15         | 6304    | 6302      | 1575    | 11,253  | 7876      | 38,013,270     | 1254.74        |
| 6       | 7-15-17         | 7144    | 7140      | 1785    | 10,968  | 7141      | 32,123,440     | 1298.56        |
| 7       | 7-17-20         | 9524    | 9520      | 2380    | 14,623  | 9521      | 43,930,680     | 1693.25        |
| 8       | 9-20-25         | 18,004  | 18,000    | 4500    | 27,503  | 18,001    | 70,081,120     | 3145.56        |
| 9       | 12-25-30        | 36,004  | 36,000    | 9000    | 54,753  | 36,001    | 51,912,420     | 15,417.71      |
| 10      | 18-35-45        | 113,404 | 113,400   | 28,350  | 176,678 | 113,401   | 56,587,000     | -------         |

From the computational experiment results in Table 4 and Figure 3, we can observe an increase in the complexity of the supply chain network with an increase in the number of variables and constraints, along with nonlinearity.

6.2. Sensitivity Analysis

In this section, we provide the results of the sensitivity analysis to check the variations in the total cost of a network when varying the values of the main parameters (i.e., the demand and cost-related) of the model. First, we varied the demand by ±25% and ±50% increments and then made the same adjustments to the cost-related parameters; we then observed the variations in total cost value. From Table 6, we can observe the percentage variations in the total cost values with a change in the main parameters of the model.

Figure 3. Represents the complexity of the model as increases the data sets.

6.2. Sensitivity Analysis

In this section, we provide the results of the sensitivity analysis to check the variations in the total cost of a network when varying the values of the main parameters (i.e., the demand and cost-related) of the model. First, we varied the demand by ±25% and ±50% increments and then made the same adjustments to the cost-related parameters; we then observed the variations in total cost value. From Table 6, we can observe the percentage variations in the total cost values with a change in the main parameters of the model.
Table 6. Sensitivity analysis for small-to-medium data sets.

| Cases                  | Parameters and Percentage Changes | Decreased by 25% | Decreased by 50% | Increased by 25% | Increased by 50% |
|------------------------|-----------------------------------|------------------|------------------|------------------|------------------|
| First case scenario    | Demand                            | 5,181,534        | 3,465,217        | 8,071,543        | 9,940,140        |
|                        | % Change                          | 22.08 ↓          | 47.89 ↓          | 21.38 ↑          | 49.48 ↑          |
|                        | Cost-related parameters            | 5,244,707        | 3,396,059        | 7,945,861        | 9,859,677        |
|                        | % Change                          | 21.13 ↓          | 48.93 ↓          | 19.49 ↑          | 48.27 ↑          |
|                        | Purchasing costs related to IoT facilities and RFID tags | 5,371,053 | 3,624,813 | 7,869,388 | 9,733,996 |
|                        | % Change                          | 19.23 ↓          | 45.49 ↓          | 18.34 ↑          | 46.38 ↑          |
| Fifth case scenario    | Demand                            | 31,041,636       | 21,158,186       | 48,033,567       | 57,544,488       |
|                        | % Change                          | 18.34 ↓          | 44.34 ↓          | 26.36 ↑          | 51.78 ↑          |
|                        | Cost-related parameters            | 30,604,483       | 19,622,450       | 47,284,706       | 56,966,686       |
|                        | % Change                          | 19.49 ↓          | 48.38 ↓          | 24.39 ↑          | 49.86 ↑          |
|                        | Purchasing costs related to IoT facilities and RFID tags | 30,277,569 | 20,272,476 | 47,094,640 | 57,913,216 |
|                        | % Change                          | 20.35 ↓          | 46.67 ↓          | 23.89 ↑          | 52.35 ↑          |

Note: In the Table 6, ↓ and ↑ are representing the decreasing and increasing symbols, respectively.

From Table 6, we can observe that the variation in objective function value, i.e., the total network cost was varied −22.08%, −47.89%, +21.38%, and +49.48% when we varied the demand value by −25%, −50%, +25%, and +50%, respectively; this was similar for the other parameters also. Figures 4 and 5 show the data points and trend in the percentage of total cost value for with uncertain variations in demand and cost related parameters for small and medium-sized problems respectively.

![Figure 4. Variations in total cost value with changes in parameters in the small-sized problem.](image-url)
6.3. Discussion

Most of the previous articles related to the IoT in the supply chain are based on bibliometrics, survey, and empirical analysis [2,7,15,38]. This study was based on the mathematical model, where we formulated an MINLP model that captured the costs associated with the B2B order packaging, handling and transportation, carbon emission taxation cost, purchasing cost of RFID tags, and establishment cost of IoT facilities in the transport vehicles. The formulated model was validated in ten different case scenarios (small to large problems) using an exact optimization approach, i.e., a global solver in LINGO 19 software package.

The detailed information about the case scenarios was given in a case study, which was the first case scenario of our computational experiments. For this case scenario, the optimized transport quantity, transport vehicles, and routes for the B2B order pickup and delivery are shown in Figure 2. With this, the optimized value of the total cost associated with the B2B order packaging, handling, and transportation was 29.75%, the total carbon emission taxation cost was 1.46%, and the total cost related to purchasing RFID tags and implementing IoT facilities in transport vehicles was 68.79% of the total cost of the supply chain network. Here, we can say the central part of the optimized value of the total cost of the IoT embedded sustainable supply chain was constituted by the purchasing cost of RFID tags and the IoT facilities establishment in the transport vehicles. Similarly, this type of analysis can be performed for all the case scenarios considered to perform the computational experiments.

6.4. Managerial Implications

Implementation of the Internet of things (IoT) based on new technologies in the logistics and supply chain will become a vital concern for any industry. The implementation of these types of new technologies in their logistics and supply chain is not only for the better management information but also improves the system efficiency. A virtual supply chain (VSC) provides support to enhance the quality by monitoring the logistics and supply chain processes and should take real-time corrective actions. The virtual logistics and
supply chain services become more flexible, faster, smarter, and easier by implementing the IoT in the system. Virtualization might become a vital aspect for e-commerce businesses to be sustainable in this competitive world globally.

The e-commerce decision makers and government administrators can use the obtained results and perform a sensitivity analysis of this study to create policies that favor environmental, social, and economic aspects of sustainability with the adoption of the IoT system. Specifically, the obtained optimized transport quantity, routes for the order pickup and delivery, and the number of required transport vehicles for all the case scenarios (e.g., the first case scenario is shown in Figure 2 in the case study section) can be used by the third-party logistics service provider to offer better transportation and delivery services to B2B e-commerce textile-based industries. From the observation of obtained results of this study, the IoT facilities, along with the RFID tags, constituted a significant part of the total cost of the supply chain network. With this, we can suggest that e-commerce, supply chain, and logistics industries implement IoT facilities in their traditional system while keeping in mind their budget. The implementation of IoT facilities in every transport vehicle is costly. However, it could be implemented to be sustainable in the current competitive business world globally for smarter, traceable, and more efficient.

7. Conclusions and Future Work

In this study, we focused on IoT embedded sustainable supply chain problems for the textile businesses, i.e., the manufacturing plants and wholesalers. We developed a framework for the considered problem and formulated an MINLP optimization model that helped to minimize the total cost of the virtual supply chain network. The proposed model captured the problems related to the order packaging, handling, and transportation of textile products from manufacturers to wholesalers. Furthermore, the implementation of the IoT facilities in the transport vehicles and purchasing the RFID tags were also considered. The proposed MINLP model was solved by using a GLOBAL solver in the LINGO 19 software package and the optimized value of total cost was found for all the case scenarios.

It was observed that the complexity of the supply chain network increased with an increase in the number of nodes (corresponding increase in the number of variables and constraints and the total elapsed (computation) run time of CPU when increasing the size of the data set). The optimized value of the total cost of the proposed sustainable supply chain network was found for each of ten different data sets. We performed one case study in which we provided more information about what types of input data were used and what we obtained from the experiments. From this, we also concluded that the purchasing cost of RFID tags and IoT facilities establishment in transport vehicles constituted a significant part (approximately 69%) of the optimized value of the total cost. A sensitivity analysis was performed to observe the variations in the total cost of the network when changing in the main model parameters, i.e., the demand parameter, cost-related parameters, and purchasing prices of the IoT facilities and RFID tags.

This study’s limitation was the use of simulated data to create ten different case scenarios to validate the formulated optimization model. With this, the current study provided only a theoretical overview of the analysis. However, this study can be extended by using real-life data sets to validate the proposed model in practice. Furthermore, we can extend this work by changing the solution approaches (such as using any artificial intelligence techniques) and by converting this supply chain network from a single echelon to a multi-echelon one.

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