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A BI-OBJECTIVE INTEGRATED TRANSPORTATION AND INVENTORY MANAGEMENT UNDER A SUPPLY CHAIN NETWORK CONSIDERING MULTIPLE DISTRIBUTION NETWORKS

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Abstract. In order to respond to the customer's needs effectively and efficiently, logistics is characterized as a part of the supply chain that executes and handles forward and reverse movement and storage of products, services, and related data. An efficient logistic network is needed for the supply chain that executes forward and reverses products' movement. This study resolves the supply chain network's logistic problem to determine the appropriate order allocation of products from multiple plants, warehouses, and distributors to minimize total transportation and inventory costs by simultaneously determining optimal locations, flows, shipment composition, and shipment cycle times. The multi-objective logistic cost minimizes through the value function approach for obtaining the optimal order allocation. An actual data-based case study has been applied to examine the effectiveness of the multi-objective supply chain network. These results are very relevant for the manufacturing sectors, particularly those facing the logistics issue in the supply chain network. The findings indicate the optimal logistic costs. The results enable managers to cope with various types of logistics risks.

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1. Introduction

Flexibility and integration in the supply chain (SC) are essential in reducing overall costs and improving overall performance. SC strategy involves a supply chain network (SCN) comprising economic, logistical, and financial decision-making concerns. Economic decisions contribute to long-term growth and supply chain management (SCM), whereas logistical choices reconnect to optimal use of different resources. With increasing competitiveness, many businesses have been engaged in purchasing, processing, and transportation activities in multiple states and cities in recent decades. Dealing with increasing competition and creating a worldwide SCN with lower costs, increased flexibility, and a higher standard of customer support are now critical business problems. The designed optimization models can help the managers place the warehouse center and transport

Keywords. Multi-level networking, multi-objective optimization, supply chain network, logistic management, value function approach.

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channels to use goods from one place to another. Traditionally, transportation cost is the primary purpose of optimization in SCN. Still, companies are increasingly concerned with inventory cost issues, and there is a growing need to consider goals, such as holding costs.

SCM defines the connection between logistics and other business functions such as acquisition, development, management of the system distribution channel, and customer service [35]. Since the early 1990s, business conditions have changed, and competition required that buyers buy the right products at the right time, at the right moment, and in a suitable situation, at the lowest cost. Operations outsourcing positions allow a company to concentrate on its core skills. It will enable companies to leverage their money better to efficiently handle operations while enabling world-class service suppliers and use their equipment and human resources infrastructure. Logistics have become part and parcel of every business today. Without logistics support, a company's distribution, manufacturing, or project management cannot survive [21]. Charles *et al.* [14] formulated a multi-objective optimization model (MOOM) of a supply chain network with order allocation problems to minimize total transportation cost and delivery time. They solved the developed model by three different goal programming approaches to obtain the optimal solution. Ali *et al.* [3] developed a new mathematical programming model of inventory management by considering conflicting linear fractional objective functions with different factors such as holding cost, purchasing price, selling price, demand, and ordering cost. The authors developed two separate inventory management models with linear and non-linear membership functions and solved them using the intuitionistic fuzzy goal programming technique.

Tuzkaya and Önüt [53] designed a new model to assess the best supply of products between multiple vendors, warehouses, and producers. The goal was to reduce net inventory, warehouse, producer, and penalty costs for vendors, distributors, and warehouses. Bashiri *et al.* [9] developed a modern multi-item mathematical model of strategic and operational production with varying times to control decisions for a multi-stage network. The primary purpose was to optimize overall net profits over periods measured by subtracting total expenses from total sales. The net fee covers capital costs for construction, the addition of facilities, running facilities, and costs related to raw materials, production, procurement, and transportation. Sadigh *et al.* [42] used the updated genetic algorithm to construct a deterministic multi-objective SCN problem of supply selection that intertwines with the output decision and distributor position. Three goals have been considered: the first one is related to minimization of the overall expense, including order cost, delivery cost, location of fulfillment centers, and cost of shipping; the second one is associated with the depreciation of the delivery time of the transport of imported goods to customers, and third on related with maximization of component efficiency. Sarrafha *et al.* [47] developed a multi-objective model for the SCN consisting of manufacturers, factories, delivery centers, and consumers. A novel multi-objective biogeography-based optimization technique is designed to solve the two goals' problem; minimize overall SCN costs and reduce average commodity tardiness to distribution centers. A simulation-based multi-objective model was developed by Tsai and Chen [52]. They specified the required configurations of the reorder point and order quantities to reduce at the same time three objective features, which are the estimated values of the overall product cost, the average production volume, and the frequency of stock-outs. Sarkar *et al.* [46] proposed economic and environmental sustainability by introducing innovative products. The production system consisted with remanufacturing unit. Mohammed and Duffuaa [36] developed an efficient tabu search algorithm to solve the multi-stage SCN problem. The model developed in this paper has three aims: to increase revenue to generate as much capital for investors in the supply chain; the second aim is to reduce risk. The third and last aim is to mitigate overall emissions from the supply chain.

The main contributions of this paper include:

- An integrated transportation and inventory model is formulated to optimize total supply chain cost. Transportation cost is the combination of costs incurred from plants to warehouses and warehouses to distributors.
- Total inventory cost includes holding costs, ordering costs, and cost of working capital blocked up in the inventory due to delays in transportation. Develop a solution approach based on the value function approach.
- A real-world case study of TV sets validates the applicability of the proposed model. The value function approach has been used to determine the proper shipment allocation.

– The robustness of the model has been assessed with other scalarization techniques, *i.e.*, goal programming and fuzzy programming. The decision is established for the model's relevance by carrying out the sensitivity analysis.

The paper's remaining part is structured as follows: Section 2 provides a detailed overview of supply chain issues in the literature, focusing on multi-optimization. In Section 3, we discuss the supply chain of ABC Company. Section 4 presents the supply chain's mathematical model formulation, using the proposed optimizing technique to solve the formulated problem. Section 5 provides a case illustration to demonstrate the application of the proposed model. Finally, concluding remarks are made in Section 11.

2. Literature review

A detailed review of recent literature on newly developed SCN has introduced different features and general patterns in various models.

2.1. Supply chain network

Xu *et al.* [56] formulated the SCN model to identify the network structure that can concurrently meet the goals of minimization of total expense. It consists of the fixed costs of plants and distribution centers, inbound and outbound transport costs, and maximization of consumer satisfaction, which can provide adequate delivery time. Guiffrida and Jaber [22] examined the consequences of enhancing distribution efficiency when the distribution period is perceived to determine delivery output in sequential supply chains. The variability of a distribution to final customers is modeled as an investment function. Bilgen [11] discussed production and distribution planning problems in an SCN that included allocating quantities for output across different production lines in factories and supplying goods to distribution centers. Moon *et al.* [37] concentrated on reliability of a smart production system that was emissions-controlled. A two-tier supply-location attribution model with accidental demand was proposed by Wang *et al.* [55] to minimize the setup, interconnections, and profit-maximizing between production and distribution. Peidro *et al.* [39] suggested a model that tackles strategic planning problems for constructing, producing, and distributing SCs in the ceramic field. They maximized the total gross profit, eliminated backorder volumes, and decreased idle time in multi-supplier multi-level distribution centers. Seidscher and Minner [48] have evaluated constructive and reactive trans-shipment approaches in a multi-locational distribution network. They believe each sector's demands can meet from a default collection of warehouses, considered constructive transfers to a warehouse outside the range. They concluded that productive management of transitions would contribute to considerable cost reductions. Bandyopadhyay and Bhattacharya [8] developed a multi-objective SCN problem concerning buyers and suppliers. The objectives were to optimize the two-tier supply chain's average cost, decrease order quantity volatility, and reduce the overall inventory of the product. Alvarez *et al.* [4] introduced side exchanges for spare parts from two warehouses to distinguish preferred consumers. If the preferred customer's requirement in one warehouse cannot be complied with by the stock available, a trans-shipment flow from the other warehouse would consider. Otherwise, the central depot uses emergency restoration, or the order is backed up. Díaz-Madroñero *et al.* [17] considered an SCN where the first-tier manufacturer represents a manufacturing client and decides the supplier's production strategy using details from the vehicle assembler, truck capacity, and stock levels. For suppliers, producers, retailers and variable demand driven by selling and advertisement prices, Mahapatra *et al.* [32] model has established co-op advertising, in which all the actual expenses are treated as fuzzy. The author optimized the revenue by considering the SC decision support system, variable periods, deliveries, pricing, and marketing costs. Taki *et al.* [15] designed the three-echelon SCN design with the model's goals: to reduce the SC's overall expense and improve the distribution efficiency, which may be equal to reducing the risk of not supplying the goods concerning an increase in demand.

In recent years, various researchers have identified multiple approaches to SCM. Among them, Gupta *et al.* [23] formulated a bi-objective SCM model to optimize the conventional facility location models to incorporate a range of logistic system elements, such as transportation costs and different inventory costs, in a multi-product, multi-site network. Sarkar *et al.* [44] developed an artificial neural network (ANN) with multithreading to solve a model having multiple items under uncertainty. Akbarpour *et al.* [2] proposed a bi-objective model for building a pharmaceutical relief network under unexpected demand conditions for perishable goods. Arasteh [6] and Bera *et al.* [10] proposed a fuzzy multi-objective linear model to maximize the product's quality in uncertain situations by considering the three-layer supply chain. They considered some limitations: lack of order, market demand, and manufacturing capacity for minimizing total cost. Zandkarimkhani *et al.* [58] used fuzzy multi-goal programming to reduce total costs in the pharmaceutical SC under uncertain situations. Formulating the model included multi-products, multi-period, multi-locations, and vehicle routing. Sometime, Delfani *et al.* [16] developed a robust fuzzy model to minimize total cost in the multi-layer pharmaceutical supply chain in uncertainty. They considered the product's reliability and the delivery time as significant constraints.

2.2. Effectiveness of multi-capacitated logistics under SCN

To support e-tailers optimally and fulfill customer orders while reducing their logistics costs in e-tail environments, Torabi *et al.* [51] built a mixed-integer programming model. The goal was to create an optimum distribution schedule for customer orders by reducing overall freight and transportation costs after satisfying the demand. In a study of merchandise distribution networks, Ahmadi *et al.* [1] incorporated constructive transshipments for a company selling seasonal and non-seasonal goods to different consumers. The fundamental goal of this paper is to optimize the overall cost and consumer satisfaction. The overall cost function includes the production output and inventory price, shipping to all destinations, and the chosen facilities' annual fixed fee. The second objective is related to the quality of service rendered by the network and evaluates consumers' satisfaction over the planning period. In light of uncertain demand for an SCN, Amin and Baki [5] introduced a MOOM with mixed-integer linear programming (MILP) that considers global factors, including several manufacturers, suppliers, factories, distribution centers, market channels, storage centers, and produced goods. This study optimizes the delivery time and total profit of the SCN. A closed-loop network for reprocessing waste products has been developed by Nurjanni *et al.* [38] as a MOOM to reduce overall transportation costs and emissions in the SCN. The developed model has been solved using an optimization process consisting of three scalarization approaches: weighted sum method, weighted Tchebycheff, and augmented weighted Tchebycheff. Bilir *et al.* [12] have proposed a new mathematical model integrating the idea of SCN modeling into competitive location considerations (*e.g.*, evolving market demand and customer care-related functions). Sabri and Beamon [40] developed a stochastic multi-objective responsive SCN model to analyze performance parameters like flexibility (volume), lead time, total cost, and customer service levels in the considered SC. This model integrates production distribution, supply, and demand complexities and establishes a multi-objective efficiency vector for the SC network.

Farrokh *et al.* [29] dealt with an SCN model design that includes recycling and disposal processes and formulated a mixed-integer programming model that optimized SCN configuration, fluctuations, and operational risks. Fattahi *et al.* [19] tackled a multi-period network modernization challenge, where consumer zones have stochastic price-dependent demand for multiple products. To build a network of the minimum cost against disruptions and provide decision-makers with the flexibility to prioritize network resilience over prices, Margolis *et al.* [34] developed a novel deterministic MOOM. Singh and Goh [49] incorporated supply chain strategy techniques into delivery plans to the hospital level, from sourcing raw materials to developing standardized medicines. The model consists of two goals with unknown parameters, including medicine demand, cost and time coefficients, and limitations at various levels related to the pharmaceutical supply chain. Gupta *et al.* [25] designed a MOOM for SCN's production-distribution process to discover how many units of the item could be delivered from the beginning to the end such that all the volume manufactured is fully utilized. All the demand levels are fully met such that no inventory will leave in the stock. Kugele *et al.* [28] developed a novel solution approach using goal programming for finding the unique solution with degree of difficulty. The application was in the smart production system. Han *et al.* [26] considered an automated production output, procurement, and outbound delivery scheduling that originated in a three-stage SC composed of a producer, a retailer, and many customers. The goal was to set down plans for processing jobs and define distribution plans from the producer to all consumers such that the total number of late jobs, manufacturing costs, and shipping costs can reduce.

2.3. Multi-capacitated SCN with multi-objective studies

Liang [30] formulated a fuzzy MOOM with a linear membership function to solve the integrated multi-time production and distribution scheduling problem. This work aimed to reduce production costs and overall processing time regarding inventory volumes, available machine flexibility, workforce requirement at each source, and estimated demand and usable warehouse space at each start and total expenditure. Sarkar *et al.* [45] considered a complex multi-phase manufacturing system that can control defective production rate automatically. Tapia-Ubeda *et al.* [50] researched incorporating SCN design and control for conventional spare parts operations. They introduced a generic network management method for simultaneously simulating warehouse sites and stock control decisions, thereby reducing the overall expense of the supply chain network of spare parts. Zandkarimkhani *et al.* [58] suggested considering the inventory location and transportation concerns and demand ambiguity for logistics operations and decomposable pharmaceuticals delivery. A bi-objective integer non-linear programming model was developed based on a vendor-managed inventory strategy in a three-echelon SC, including one manufacturer, one vendor, and multiple retailers, the maximum efficiency of SCN [41]. Avci and Selim [7] considered a three-echelon heterogeneous SC structure consisting of a consumer, a retailer, and many suppliers and formulated a MOOM with premium freight in convergent SC. This paper aimed to evaluate the product's demand adjustment factor, the optimum stock level, and the distributor's versatility levels for products that provide the best storage cost and premium freight performance.

A multi-objective MILP model formulated for three-level global SC, which includes manufacturer, distributor, and customer, with the primary aim to minimize total cost, lead time, and lost sales in the process industry [18, 31]. Kadziński *et al.* [27] formulated MOOM for the SC, minimizing transportation cost, transportation time, and dust emission. The SC addressed in this study focuses on the distribution of white goods in the South Eastern European market, and they used interactive algorithms to solve the formulated problem SC. Validi *et al.* [54] proposed a systematic approach that focuses on a capacitated logistics distribution model for Ireland's two-layer dairy SC market demand. This study aimed to provide customized delivery routes based on the dairy supply chain's carbon emissions and production costs for processing milk products.

Zhang *et al.* [59], in contrast to the traditional SCN, a new conceptual paradigm for modeling SCN with several delivery networks was implemented in this study. The paradigm built in this study helps the consumers by delivering direct goods and services from the facilities available rather than the traditional flow of products and services. Mahmoodi *et al.* [33] developed a MOOM focused on multi-product transportation at the five stages of SCN that consists of vendors, producers, dealers, distributors, and consumers. This study aimed to assess the output and supply in each SCN node under the competitive market's uncertain demand. The model has three key goals: reducing costs, mitigating risk, and optimizing efficiency. Table 1 gives an overview of the method and applications used in the above studies.

From the above review, one can see that most of the studies have been carried out concurrently to understand the three relevant parameters, costs, resilience, and customer service level. We have identified that none of the studies measure the supply chain cost by optimizing the transportation and inventory cost for different shipments. This paper provides a realistic multi-objective mathematical programming model for the SCN design problem to address the shortcomings. In this work, we consider the optimization of transportation and inventory costs for different shipments of a supply chain process. The parameters of the model formulation include: items, set of cycles-times, set of shipping costs, active manufacturing locations, active warehouses/stores, ordering or setup costs, shipping costs from the manufacturer to the warehouse, shipping costs from the warehouse to the dealer, storage capability of product flow, manufacturer capability of producing goods. This paper introduces a multi-nonlinear shipping model focused on decision-making, including the configuration of the shipping network, choosing transport means, and transferring individual customer shipments through a particular transport system. A decision-maker aims to minimize transportation and inventory costs of complete orders while attaining the promised responsiveness. The sector of electronics is one where logistic movement is carried out worldwide. Electronics components are produced and assembled as finished products in various locations. An electronic product case study has been chosen to investigate how the company handled its nationwide

Table 1. Shared process information of the reviewed works.

Authors	Objective function dimensions (Single/Multi-objective)	Solutions approach	Application/case study	Type of model (L/NL)	Parameter (Deterministic/ Stochastic/Fuzzy)	Dynamic
Sadigh *et al.* [42]	Single-objective	Genetic algorithm	Illustrative example	Non-linear	Deterministic	Time independent
Sarrafha *et al.* [47]	Multi-objective	Biogeography based optimization	Illustrative example	Non-linear	Fuzzy	Time dependent
Mohammed and Duffuaa [36]	Multi-objective	Tabu search algorithm	Illustrative example	Non-linear	Stochastic	Time independent
Xu *et al.* [56]	Multi-objective	Genetic algorithm	Liquor supply chain	Non-linear	Deterministic	Time independent
Bilgen [11]	Single-objective	Fuzzy programming	Consumer goods supply chain	Non-linear	Deterministic	Time dependent
Wang *et al.* [55]	Multi-objective	Genetic algorithm	Illustrative example	Non-linear	Deterministic	Time dependent
Bandyopadhyay and Bhattacharya [8]	Multi-objective	Evolutionary algorithm, Non-dominated sorting genetic algorithm-II, Strength Pareto evolutionary algorithm	Retail chain supply chain	Non-linear	Stochastic	Time independent
Akbarpour *et al.* [2]	Multi-objective	Mini-max robust optimization technique	Pharmaceutical Industry	Non-linear	Stochastic	Time dependent
Arasteh [6]	Multi-objective	Fuzzy programming	Illustrative example	Non-linear	Stochastic	Time dependent
Bera *et al.* [10]	Multi-objective	Weighted sum method	Illustrative example	Linear	Fuzzy	Time independent
Zandkarimkhani *et al.* [58]	Multi-objective	Chance constrained goal programming	Pharmaceutical Industry	Non-linear	Stochastic	Time dependent
Delfani *et al.* [16]	Multi-objective	Fuzzy programming	Illustrative example	Non-linear	Stochastic	Time dependent
Torabi *et al.* [51]	Multi-objective	Benders decomposition	Illustrative example	Linear	Fuzzy	Time independent
Ahmadi *et al.* [1]	Multi-objective	Possibilistic programming approach	Household products supply chain	Non-linear	Deterministic	Time dependent
Amin and Baki [5]	Multi-objective	Fuzzy programming	Electrical and electronic supply chain	Linear	Deterministic	Time dependent
Nurjanni *et al.* [38]	Multi-objective	Weighted sum method, Weighted Tchebycheff, Augmented weighted Tchebycheff	Illustrative example	Non-linear	Deterministic	Time independent
Margolis *et al.* [34]	Multi-objective	$\varepsilon-$constraint method	Food supply chain	Linear	Deterministic	Time dependent
Singh and Goh [49]	Multi-objective	Scalarization technique	Pharmaceutical supply chain	Linear	Fuzzy	Time dependent
Gupta *et al.* [25]	Multi-objective	Additive fuzzy programming	Illustrative example	Linear	Stochastic/ Fuzzy	Time independent
Kugele *et al.* [28]	Multi-objective	Goal programing	Smart production system	Non-linear	Stochastic	Production rate dependent
Han *et al.* [26]	Single-objective	Polynomial-time solution algorithm	Illustrative example	Non-linear	Fuzzy	Time dependent
Liang [30]	Multi-objective	Fuzzy programming	Ballscrew supply chain	Non-linear	Deterministic	Time dependent
Tapia-Ubeda *et al.* [50]	Single-objective	Generalized benders decomposition	Steel pipe products supply chain	Linear	Deterministic	Time dependent
Sadeghi *et al.* [41]	Multi-objective	Bat algorithm, Multi-objective particle swarm optimization	Illustrative example	Linear	Deterministic	Time dependent
Avci and Selim [7]	Multi-objective	Non-dominated sorting genetic algorithm-II	Automotive supply chain	Non-linear	Stochastic	Time dependent
Liu and Papageorgiou [31]	Multi-objective	$\varepsilon-$constraint method, lexicographic minimax method	Agrochemical supply chain	Linear	Deterministic	Time dependent
Ensafian and Yaghoubi [18]	Single-objective	Goal programming, Robust optimization model	Platelet supply chain	Non-linear	Stochastic	Time dependent
Kadziński *et al.* [27]	Multi-objective	Weighted sum method, ε-constraint method, evolutionary algorithms	Furniture supply chain	Non-linear	Deterministic	Time dependent
Validi *et al.* [54]	Multi-objective	Genetic algorithm	Dairy supply chain	Linear	Deterministic	Time Independent
Zhang *et al.* [59]	Multi-objective	Artificial bee colony	Illustrative example	Linear	Deterministic	Time dependent
Mahmoodi *et al.* [33]	Multi-objective	Modified NSGA-II	Illustrative example	Non-linear	Fuzzy	Time independent

manufacturing network. The simplicity of model development and implementation helps decision-makers monitor logistics regarding capability load carrying capacity and arrangement for the workforce without studying advanced programming methodologies.

3. Case study for ABC company

ABC Group is a leader in Consumer Electronics and Telecommunications in India. It manufactures color TVs, washing machines, refrigerators, microwaves, vacuum cleaners, lanterns, audio systems, video systems, telephones, and monitors. Besides, it provides services like telecom. It has a significant market share in the

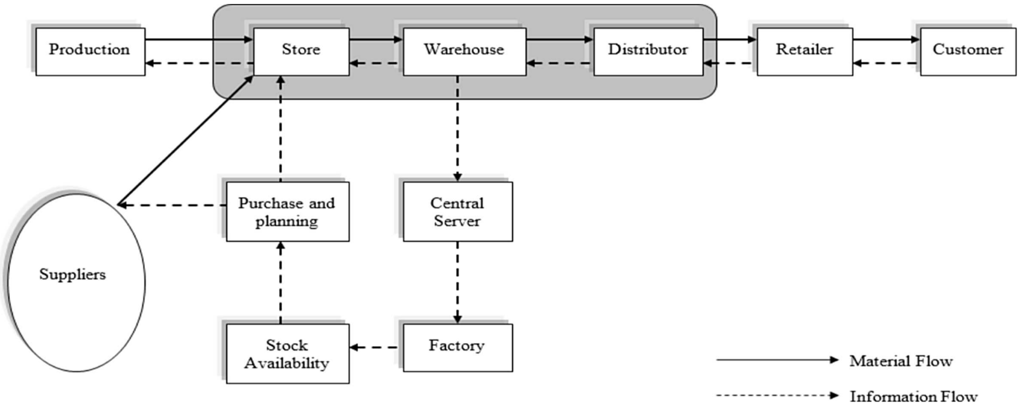

FIGURE 1. Existing multi-directed supply chain of ABC.

southern, western, and eastern parts of India and a sufficient share in India's northern part. The factory in consideration is part of the ABC group and focuses on home and kitchen appliances. It is an ISO 9000 quality system and IS 14000 environment management certified company. It has three factories in India. All its products are sold in India and partly exported to Europe and the Middle East. The production plants are in Bangalore, Noida, and Palakkad.

Color TVs comprise this business group's principal product, and it had a 20.3% market share in the country in the financial year 2000–2001. Despite a slowdown in the consumer durables business and increased taxation by local governments, ABC achieves over 1 438 212 color television sets. ABC company is the first company to sell over a million television sets in three successive financial years. While overall volumes of color television sets declined in 2000–2001 compared to the previous year, ABC retains its premier brand position across all screen sizes (as validated by ORG). ABC has its premier position in frost-free refrigerators, which comprise about 15–20% of the refrigerator market, with a market share of 22%. Many new products and concepts are launched, such as non-CFC refrigerators, four new direct cool refrigerators, and a new washing machine technology called the perfect wash system, preventing fabric damage-two new upper-end models of microwave ovens and auto-ignition for gas tables. ABC company has a 15% share in washing machines.

The ABC company's supplier base comprises 215 suppliers, including overseas suppliers, local suppliers, and group company suppliers. The logistic network includes various branches and warehouses, which operate through distributors. The SC of ABC company depicts in Figure 1. The present study's scope is limited to the CTV distribution system considering only one tier, *i.e.*, the first-level distributor. The ABC company has about 13 warehouses and 17 distributors across different locations in the country. The company has three plants for the assembly of Televisions situated at Noida, Palakkad, and Bangalore. Combined, these plants can produce 140 000 television units per month in the peak season of October and November. Planning completes Bangalore's corporate office, which sets the three units' production; it completes at the company's Noida unit. All three manufacturing plants assemble 20-inch and 21-inch general models of televisions. The turnover of the Noida plant is around Rs. 320 crores. The ABC company's supply chain includes procurement of raw materials, manufacturing operations, and transportation. The company currently has 35 international vendors and around 180 local vendors.

The planning process for CTV manufacturing units conducts at Noida, Bangalore, and Palakkad. The corporate office of ABC company in Bangalore prepares a rolling plan (called sales and operations plan) every month. This plan gives projected sales for the current month and the following three months. A production plan for each manufacturing unit is made based on the projected sales for the next three months and current

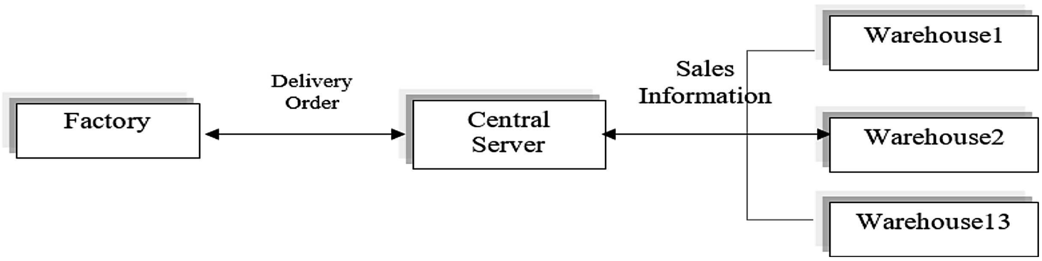

Figure 2. Distribution information process at ABC company.

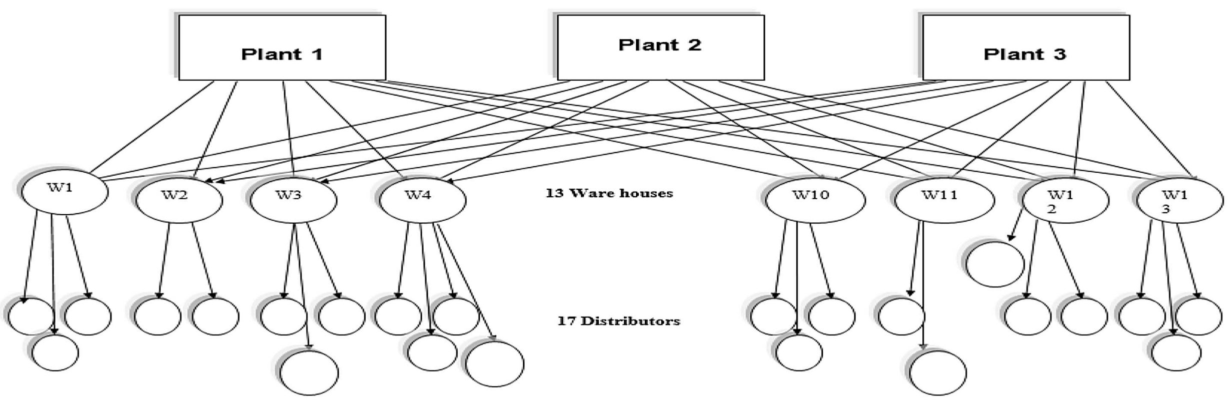

Figure 3. Multi-capacitated networking of ABC company.

stock levels. This production plan is the basis for the entire materials management system for the plant. It holds special significance for imported items because they are essential items.

3.1. Distribution process at ABC company

The distribution of color TVs from ABC manufacturing units to distributors/dealers is represented in Figures 2 and 3.

Periodically, orders are electronically sent to the factory. The respective warehouses and distributors send their electronic/manual format requirements to the head office in Bangalore, where the data is recorded/entered into the central server, which contains the database of requirements compiled for the entire country. Then, the factory's planning process starts compiling this information with the monthly plan, and the entire production schedule is generated at the factory. Completed orders are dispatched in the form of a First-In-First-Out (FIFO) basis for a particular warehouse. Care is taken in designing the transportation route (either to cover full truckload or, in the event of the non-existence of full truckload, to club neighboring warehouse requirements accordingly truck size is decided). Distributors place an order on warehouses depending upon requirements received from retailers. Distributors dispatch the material in small trucks or tempos and ensure that the material is delivered on time with minimum cost. The existing distribution network is represented in Figure 3.

3.2. Cause and effect diagram of multi-capacitated networking of ABC company

Figure 4 depicts the reasons for shortcomings in the existing supply chain of ABC company.

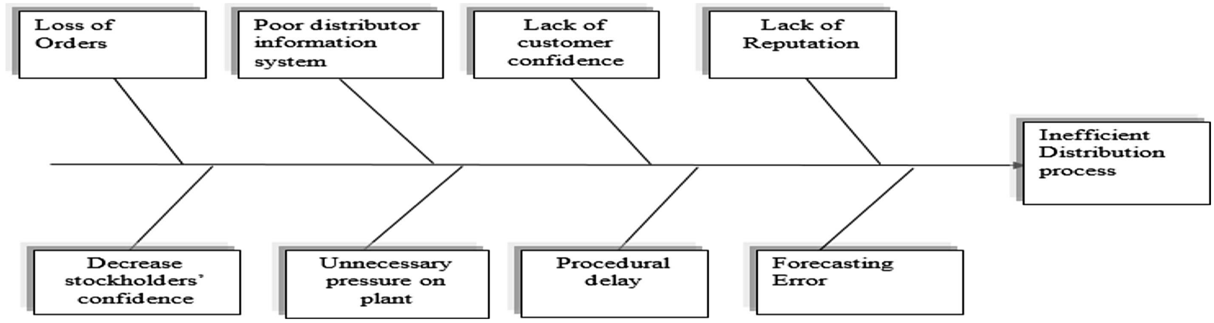

Figure 4. Causes and effect for ABC company.

– **Loss of orders**
The existing distribution channel is shown in Figure 3. Each plant supplies to specific warehouses, and in turn, each warehouse supplies to three or four distributors, depending on the distributor's location. The following problems are faced if any shortage occurs at any warehouse:
(a) Owing to no contact between warehouses, a request is sent to the factory every time a shortage occurs at any warehouse, even though the stock may be available at another warehouse.
(b) There is no coordination between dealers/distributors; similarly, requisitions are always sent to the plant.
Both of these result in the loss of customers to the organization.
– **Lack of customer confidence**
If the retailer does not have an item in the distribution down-line, the customer will not wait. Instead, s/he will buy an item from another company. This results in a decrease in customer confidence.
– **Lack of reputation**
If any customer returns without a product, s/he is likely to tell other persons, resulting in reputation loss. These situations reduce customer confidence and, in turn, market share.
– **Decrease stakeholders' confidence**
If the company starts losing orders and, in turn, customer confidence, market share will reduce slowly. If company performance is not good, stakeholders' confidence decreases.
– **Unnecessary pressure on plant**
If there is a shortage at any warehouse, the warehouse only contacts the plant. If the plant cannot supply, the warehouse does not contact another nearest warehouse. This increases unnecessary pressure on the plant, though it is not necessary.
– **Procedural delay**
All this ends in lengthy procedures to transfer data and compilation.

The supply chain manager of an ABC company faces multiple issues related to transshipment, loss of orders during shipment, lack of customer confidence due to delay in delivery time, lack of reputation, decreased stakeholder confidence, unnecessary pressure on plants, and procedural delay. We have designed a multi-objective supply chain model that optimizes transportation and inventory costs with the optimal distribution policy to overcome this issue. The developed framework is illustrated below in the next section.

4. Complex supply chain networking

A MILP model can be developed for the problem of identifying an ideal two-tier delivery network (Fig. 5). This has been attained as follows:

– The goal is to optimize the network's overall expense by minimizing the transportation and inventory cost. These costs include shipping, material processing, work capital blocked in the warehouse due to transport

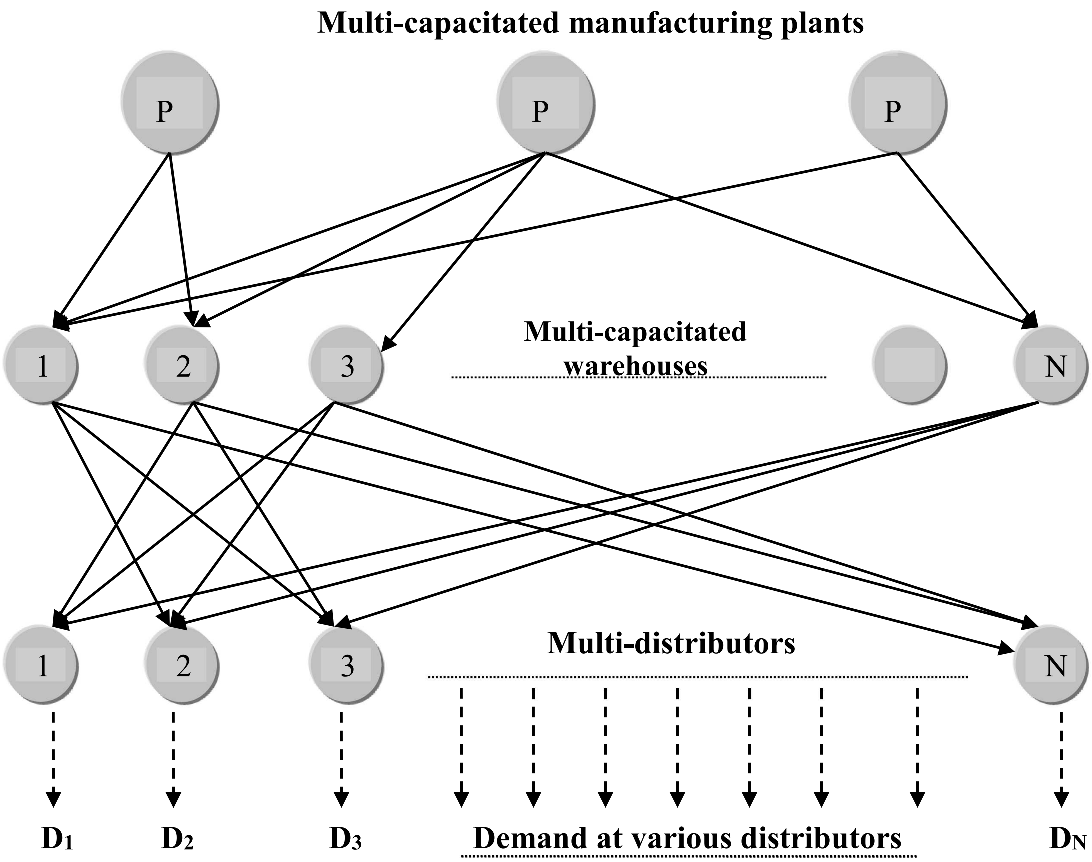

FIGURE 5. Multi-capacitated tree diagram.

time or shipping time, the total cost of maintaining inventory, setup cost, and inventory storage costs incurred due to the risk condition.

- Goods movement decisions can be calculated by a vector ($Y_{\alpha\gamma\beta\vartheta\omega}$) determination (integer variable describing the flow of product (α) from the warehouse (ϑ) to distributors (N) with cycle times (β), shipment size (γ), and $\vartheta = \omega$ implies that products flow in-out at the same place).
- All the demand nodes are represented by distributors (N). This means that we will have N number of distributors in the design along with 30 nodes of demand. Goods move from production plants into different territories, as describe by the decision variable ($X_{\alpha\gamma\beta\lambda\vartheta}$), where $X_{\alpha\gamma\beta\lambda\vartheta}$ is an integer variable.

4.1. Assumptions of the model

We considered the following basic assumptions of SC before designing the proposed mathematical model:

(1) Each distributor purchases goods either from warehouses only. They cannot give the order to the plant directly. The plant will send the product to the warehouse first.
(2) The overall monthly average demand at separate nodes has been considered independent of one another. The demand for all markets is independent. There are no relations between markets. It is assumed that the production still has the item ready as the order comes. That means the company is using a push strategy for

its market. There is no shortage at the plant level. The large stock is held at the factories for direct selling, and retailers replenish it by the manufacturer at frequent intervals. The model is not considering operating costs at the warehouse. The warehouse is used as a cross-docking strategy.

(3) The company manufactures large types of TV. Nevertheless, the model is on two types of TV: 20″ CTV and 21″ CTV. Therefore, we assume various 20″ CTV models as a single model and 21″ CTV models as a single model.

4.2. Notation

A deterministic logistics model describes using the following parameters and variables. Here α symbolize the number of items, β symbolize cycle-time, γ symbolize shipping category, λ symbolize the number of available manufacturing plants, ϑ symbolize the number of available warehouses, and ω symbolize the number of shipments from the distribution center, O symbolize the setup cost of an item. The notation is grouped into three categories, as follows:

Input parameters

T_β	Cycle time of each shipment
$C_{\gamma\lambda\vartheta}$	Shipping cost from multiple plant j to multiple warehouses
$G_{\gamma\vartheta\omega}$	Shipping costs from multiple warehouses to multiple distributors
E_γ	Capacity of the shipment
U_λ	Capacity of the flow of product within the network
$D_{\alpha\omega}$	Product demand fulfills by the distributor
$\mathrm{SIG}_{\alpha\omega}$	Variation of demand at each distributor during the lead time for each item
$\mathrm{LTW}_{\lambda\vartheta}$	Shipment time period from multiple plants to multiple warehouses
$\mathrm{LTD}_{\vartheta\omega}$	Shipment time period from multiple warehouses to distribution centers

Integer decision variables

$X_{\alpha\gamma\beta\lambda\vartheta}$	Represents shipment of each product from multiple plants to multiple warehouses with cycle time-period β, shipment category γ
$Y_{\alpha\gamma\beta\vartheta\omega}$	Represents shipment of each product from multiple warehouses to multiple distribution centers with cycle time-period β, shipment category γ
$U_{\gamma\beta\lambda\vartheta}$	Represents the number of trucks required for the shipment of each product from multiple plant to multiple warehouses with cycle time-period β and shipment category γ
$V_{\gamma\beta\vartheta\omega}$	Represents the number of trucks required to transport the product from multiple warehouses to multiple distribution centers with cycle time-period β and shipment category γ

Binary variables

$A_{\alpha\beta\lambda\vartheta}$	Binary variable, equal to 1 if the item α is ordered on cycle time-period β from plant to warehouse, otherwise 0
$B_{\alpha\beta\vartheta\omega}$	Binary variable, equal to 1 if the item α is ordered on cycle time-period β from warehouse to distributor, otherwise 0

4.3. SC model structure

In the SC, transportation and inventory costs are considered the most critical factors for determining the network's efficiency. Transportation is vital in business logistics; approximately one-third to two-thirds of companies' logistics costs affect shipping. Logistics could not put its benefits into maximum play without well-developed distribution networks. Efficient transportation in logistics operations will provide more outstanding performance, optimize operational costs, and improve the standard of service. On the other hand, the cost of inventory can do a business or break it. However, in many companies, the possibilities of minimizing inventory costs are still not discussed at all or not implemented entirely. The primary function of the resulting mathematical model contains the following components:

Transportation costs

Transportation is a significant factor in the industry's SC. It links the company directly with its SCs associates, such as vendors and consumers, and significantly impacts its satisfaction. Transportation costs can be an essential part of the total logistics expenditure of a business. The shipping proportion can be more than 50% with higher fuel prices. Complete transportation costs shall be the amount of the shipping costs incurred within the SC network, which mathematically can be formulated as follows:

$$\sum_{\beta}\sum_{\gamma}\sum_{\lambda}\sum_{\theta} C_{\gamma\lambda\vartheta}\, U_{\gamma\beta\lambda\vartheta}/T_{\beta} + \sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega} G_{\gamma\vartheta\omega}\, V_{\gamma\beta\vartheta\omega}/T_{\beta}.$$

Average inventory holding cost

The carrying costs are related to the total expenditures associated with storing or transporting product items from a logistical viewpoint. Essentially, this paragliding concept covers costs incurred for storing and maintaining products over different periods (warehouse rents, facilities, machinery, employment, utilities), insurance rates, inflation, price volatility, damage, stealing, shrinkage, and deterioration. For 99.87% customer service, the standard total inventory can be calculated as $3\sigma + X_{\alpha\gamma\beta\lambda\vartheta}/2$ (decided by the company). The total cost of holding inventory mathematically can be formulated as:

$$\sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\lambda}\sum_{\vartheta} \frac{1}{2} T_{\beta} X_{\alpha\gamma\beta\lambda\vartheta} + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega} \frac{1}{2} T_{\beta} Y_{\alpha\gamma\beta\vartheta\omega} + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega} \left(\mathrm{SIG}^2_{\alpha\omega}(A_{\alpha\beta\lambda\vartheta}\mathrm{LTW}_{\lambda\vartheta} + B_{\alpha\beta\vartheta\omega}\mathrm{LTD}_{\vartheta\omega})\right)^{0.5}.$$

Ordering costs

Ordering costs are the expense reflecting the manufacturer's costs to produce and implement the order. The ordering costs can be assessed by calculating the sum of an economic order for a logistics item. The overall shipping costs would therefore increase along with the sum of orders placed. Full setup costs are the amount of the cost of placing the order within the SC network, mathematically can be formulated as:

$$\sum_{\alpha}\sum_{\beta}\sum_{\lambda}\sum_{\vartheta} \frac{O}{T_{\beta}} A_{\alpha\beta\lambda\vartheta} + \sum_{\alpha}\sum_{\beta}\sum_{\vartheta}\sum_{\omega} \frac{O}{T_{\beta}} B_{\alpha\beta\vartheta\omega}.$$

Cost of working capital blocked up in the inventory due to delay in transportation

In other terms, this cost is the interest on loans. This is taken to be 1.2% of the monthly unit sales price. Inventory costs for products shipped to the distributor due to the delay in transport time are measured in two parts, the transportation of products from the production plant (λ) *via* warehouses (ϑ) to the distributor (ω), ($\vartheta, \omega = 1$ to ϑ), and inventory cost due to delay in transport time between plant (λ) and warehouses (ϑ), mathematically can be formulated as:

$$\sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\lambda}\sum_{\vartheta} \mathrm{LTW}_{\lambda\omega} X_{\alpha\gamma\beta\lambda\vartheta} + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega} \mathrm{LTD}_{\vartheta\omega} Y_{\alpha\gamma\beta\vartheta\omega}.$$

In the above-formulated model, we have considered 11 constraints that have the following function:

> Constraint (1) ensures that each item's demand at each destination is met; constraint (2) is a capacity limitation at each facility (3) is the warehouse balance constraint. Constraints (4)–(7) are freight rates on shipment according to weight; constraints (8) and (9) ensure that only one cycle time applies to an item. Constraints (10) and (11) restrict the number of open plants and warehouses.

The equations described in Section 4.2 have established different linear and non-linear cost and constraint functions. The logistics model has been compiled with all the linear and non-linear functions defined above.

Minimize $\mathbf{Z_1}$

$$\sum_{\beta}\sum_{\gamma}\sum_{\lambda}\sum_{\theta} C_{\gamma\lambda\vartheta}U_{\gamma\beta\lambda\vartheta}/T_{\beta} + \sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega} G_{\gamma\vartheta\omega}V_{\gamma\beta\vartheta\omega}/T_{\beta}$$

Minimize $\mathbf{Z_2}$

$$\begin{aligned}&\sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\lambda}\sum_{\vartheta}\frac{1}{2}T_{\beta}X_{\alpha\gamma\beta\lambda\vartheta} + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega}\frac{1}{2}T_{\beta}Y_{\alpha\gamma\beta\vartheta\omega}\\ &\quad + \sum_{\alpha}\sum_{\beta}\sum_{\lambda}\sum_{\vartheta}\frac{O}{T_{\beta}}A_{\alpha\beta\lambda\vartheta} + \sum_{\alpha}\sum_{\beta}\sum_{\vartheta}\sum_{\omega}\frac{O}{T_{\beta}}B_{\alpha\beta\vartheta\omega}\\ &\quad + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\lambda}\sum_{\vartheta}\mathrm{LTW}_{\lambda\omega}X_{\alpha\gamma\beta\lambda\vartheta} + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega}\mathrm{LTD}_{\vartheta\omega}Y_{\alpha\gamma\beta\vartheta\omega}\\ &\quad + \sum_{\alpha}\sum_{\beta}\sum_{\gamma}\sum_{\vartheta}\sum_{\omega}\big(\mathrm{SIG}^2_{\alpha\omega}(A_{\alpha\beta\lambda\vartheta}\mathrm{LTW}_{\lambda\vartheta} + B_{\alpha\beta\vartheta\omega}\mathrm{LTD}_{\vartheta\omega})\big)^{0.5}\end{aligned}$$

Subject to

$$\sum_{\beta}\sum_{\gamma}\sum_{\vartheta} Y_{\alpha\gamma\beta\vartheta\omega} = D_{\alpha\omega}, \quad \forall\alpha,\omega \tag{1}$$

$$\sum_{\beta}\sum_{\gamma}\sum_{\vartheta} X_{\alpha\gamma\beta\lambda\vartheta} \le U_{\alpha\lambda}, \quad \forall\alpha,\lambda \tag{2}$$

$$\sum_{\beta}\sum_{\gamma}\sum_{\omega} Y_{\alpha\gamma\beta\vartheta\omega} = \sum_{\beta}\sum_{\gamma}\sum_{\lambda} X_{\alpha\gamma\beta\lambda\vartheta}, \quad \forall\vartheta,\alpha \tag{3}$$

$$\sum_{\alpha} T_{\beta}X_{\alpha\gamma\beta\lambda\vartheta} \le E_{(\gamma+1)}U_{\gamma\beta\lambda\vartheta}, \quad \forall\gamma,\beta,\lambda,\omega \tag{4}$$

$$\sum_{\alpha} T_{\beta}Y_{\alpha\gamma\beta\vartheta\omega} \le E_{(\gamma+1)}V_{\gamma\beta\vartheta\omega}, \quad \forall\gamma,\beta,\vartheta,\omega \tag{5}$$

$$\sum_{\alpha} T_{\alpha}X_{\alpha\gamma\beta\lambda\vartheta} \ge E_{\gamma}U_{\gamma\beta\lambda\vartheta}, \quad \forall\gamma,\beta,\lambda,\vartheta \tag{6}$$

$$\sum_{\alpha} T_{\beta}Y_{\alpha\gamma\beta\vartheta\omega} \ge E_{\gamma}V_{\gamma\beta\vartheta\omega}, \quad \forall\gamma,\beta,\vartheta,\omega \tag{7}$$

$$\sum_{\beta} A_{\alpha\beta\lambda\vartheta} \le 1, \quad \forall\alpha,\lambda,\vartheta \tag{8}$$

$$\sum_{\beta} B_{\alpha\beta\vartheta\omega} \le 1, \quad \forall\alpha,\vartheta,\omega \tag{9}$$

$$\sum_{\gamma}\sum_{\beta} X_{\alpha\gamma\beta\lambda\vartheta} \le \sum_{\beta} A_{\alpha\beta\lambda\vartheta}U_{\lambda}, \quad \forall\alpha,\lambda,\vartheta \tag{10}$$

$$\sum_{\gamma}\sum_{\beta} Y_{\alpha\gamma\beta\vartheta\omega} \le \sum_{\beta} B_{\alpha\beta\vartheta\omega}U_{\lambda}, \quad \forall\alpha,\vartheta,\omega. \tag{11}$$

4.4. Solution approach

In the above-formulated model, Z_1 deals with optimizing total transportation cost, and Z_2 deals with optimizing total inventory cost. The solution obtained from the above-formulated model will be the optimum quantity to be transported from different sources to different destinations to minimize an ABC company's transportation and inventory costs. Since many efficient algorithms are available to solve a MOOM, firstly, the problem must be converted into a single objective problem by using some compromise criterion. The above-formulated model can be expressed as a value function approach model, which is given below: a function that reflects the decision-maker's preferences among the objective vectors is called a value function. The value function approach is one of the most common methods for solving multi-objective optimization problems. The value function of an optimization problem gives the value attained by the objective function at a solution while only depending on the problem's parameters. The main advantage of using the value function approach is that it provides a complete ordering of the objective functions according to the decision-maker's preferences [24].

$$\text{Minimize } \phi\left(\sum_{t=1}^{2} \tilde{Z}_t\right)$$

Subject to

$$\begin{aligned}
&\sum_{\beta}\sum_{\gamma}\sum_{\vartheta} Y_{\alpha\gamma\beta\vartheta\omega} = D_{\alpha\omega}, && \forall \alpha, \omega\\
&\sum_{\beta}\sum_{\gamma}\sum_{\vartheta} X_{\alpha\gamma\beta\lambda\vartheta} \le U_{\alpha\lambda}, && \forall \alpha, \lambda\\
&\sum_{\beta}\sum_{\gamma}\sum_{\omega} Y_{\alpha\gamma\beta\vartheta\omega} = \sum_{\beta}\sum_{\gamma}\sum_{\lambda} X_{\alpha\gamma\beta\lambda\vartheta}, && \forall \vartheta, \alpha\\
&\sum_{\alpha} T_\beta X_{\alpha\gamma\beta\lambda\vartheta} \le E_{(\gamma+1)} U_{\gamma\beta\lambda\vartheta}, && \forall \gamma, \beta, \lambda, \omega\\
&\sum_{\alpha} T_\beta Y_{\alpha\gamma\beta\vartheta\omega} \le E_{(\gamma+1)} V_{\gamma\beta\vartheta\omega}, && \forall \gamma, \beta, \vartheta, \omega\\
&\sum_{\alpha} T_\alpha X_{\alpha\gamma\beta\lambda\vartheta} \ge E_\gamma U_{\gamma\beta\lambda\vartheta}, && \forall \gamma, \beta, \lambda, \vartheta\\
&\sum_{\alpha} T_\beta Y_{\alpha\gamma\beta\vartheta\omega} \ge E_\gamma V_{\gamma\beta\vartheta\omega}, && \forall \gamma, \beta, \vartheta, \omega\\
&\sum_{\beta} A_{\alpha\beta\lambda\vartheta} \le 1, && \forall \alpha, \lambda, \vartheta\\
&\sum_{\beta} B_{\alpha\beta\vartheta\omega} \le 1, && \forall \alpha, \vartheta, \omega\\
&\sum_{\gamma}\sum_{\beta} X_{\alpha\gamma\beta\lambda\vartheta} \le \sum_{\beta} A_{\alpha\beta\lambda\vartheta} U_\lambda, && \forall \alpha, \lambda, \vartheta\\
&\sum_{\gamma}\sum_{\beta} Y_{\alpha\gamma\beta\vartheta\omega} \le \sum_{\beta} B_{\alpha\beta\vartheta\omega} U_\lambda, && \forall \alpha, \vartheta, \omega
\end{aligned}$$

where $\phi(\cdot)$ is a scalar function, which summarizes each objective function's significance. The value function $\phi(\cdot)$ takes an appropriate value according to the nature of the optimization problem for each problem. In this study, $\phi(\cdot)$ be the weighted sum of squares of both functions. The above-formulated model under this conjecture becomes:

$$\text{Minimize } \sum_{t=1}^{T} \zeta_t \tilde{Z}_t$$

Subject to

$$\sum_{\beta}\sum_{\gamma}\sum_{\vartheta} Y_{\alpha\gamma\beta\vartheta\omega} = D_{\alpha\omega}, \qquad \forall \alpha, \omega$$

$$\sum_{\beta}\sum_{\gamma}\sum_{\vartheta} X_{\alpha\gamma\beta\lambda\vartheta} \leq U_{\alpha\lambda}, \qquad \forall\alpha,\lambda$$

$$\sum_{\beta}\sum_{\gamma}\sum_{\omega} Y_{\alpha\gamma\beta\vartheta\omega} = \sum_{\beta}\sum_{\gamma}\sum_{\lambda} X_{\alpha\gamma\beta\lambda\vartheta}, \qquad \forall\vartheta,\alpha$$

$$\sum_{\alpha} T_{\beta} X_{\alpha\gamma\beta\lambda\vartheta} \leq E_{(\gamma+1)} U_{\gamma\beta\lambda\vartheta}, \qquad \forall\gamma,\beta,\lambda,\omega$$

$$\sum_{\alpha} T_{\beta} Y_{\alpha\gamma\beta\vartheta\omega} \leq E_{(\gamma+1)} V_{\gamma\beta\vartheta\omega}, \qquad \forall\gamma,\beta,\vartheta,\omega$$

$$\sum_{\alpha} T_{\alpha} x_{\alpha\gamma\beta\lambda\vartheta} \geq E_{\gamma} U_{\gamma\beta\lambda\vartheta}, \qquad \forall\gamma,\beta,\lambda,\vartheta$$

$$\sum_{\alpha} T_{\beta} Y_{\alpha\gamma\beta\vartheta\omega} \geq E_{\gamma} V_{\gamma\beta\vartheta\omega}, \qquad \forall\gamma,\beta,\vartheta,\omega$$

$$\sum_{\beta} A_{\alpha\beta\lambda\vartheta} \leq 1, \qquad \forall\alpha,\lambda,\vartheta$$

$$\sum_{\beta} B_{\alpha\beta\vartheta\omega} \leq 1, \qquad \forall\alpha,\vartheta,\omega$$

$$\sum_{\gamma}\sum_{\beta} X_{\alpha\gamma\beta\lambda\vartheta} \leq \sum_{\beta} A_{\alpha\beta\lambda\vartheta} U_{\lambda}, \qquad \forall\ \alpha,\lambda,\vartheta$$

$$\sum_{\gamma}\sum_{\beta} Y_{\alpha\gamma\beta\vartheta\omega} \leq \sum_{\beta} B_{\alpha\beta\vartheta\omega} U_{\lambda}, \qquad \forall\alpha,\vartheta,\omega$$

where $\sum_{t=1}^{2} \xi_t = 1, \forall\ t = 1, 2, \ldots, T$ are weights according to the relative importance of the objective functions. For each objective function, the weights are frequently seen as broad measurements of relative importance. However, choosing a set of weights indicates a preference for one goal or another is challenging, and a reference is often ambiguous. It is undoubtedly conceivable to arrange or classify, by relative significance, a set of discrete choices since it generally includes some degree of uncertainty in measuring preference. In addition, the solution may not necessarily represent the desired preferences that are purportedly integrated into the weights, even with a complete understanding of the objectives and a good choice of weights. Transportation costs may be one of the most significant logistics expenses for companies with high inventories. However, the efficient management of logistics minimizes transportation costs, increasing companies' profit margins. With decreased transportation costs, companies may cut consumer retail prices and invest resources in more demanding transactions, for instance, manufacturing and inventory management. In this study, the higher weight is given to optimizing transportation cost with the weightage of 0.60, and 0.40 weightage for the optimization of inventory cost, which is decided by the company.

5. Real data from multi-capacitated ABC company

To explain the proposed work, we emphasize an actual case study of a distribution network of ABC company in India. In this section, we first present the data set of the ABC supply chain, then use the above-defined proposed approach to measure the overall cost of transportation and inventory cost simultaneously. The supply chain manager of a company decides to implement a new inventory management program. The supply chain manager tries to identify shipping policies that simultaneously optimize inventory and transportation costs. The supply chain manager understands that the management planning tool is a gateway to cost savings to implement this task successfully. He developes a mathematical model to optimize inventory and transportation costs together. To show the efficacy of the developed model of ABC-SCN, a numerical instance is with multiple products, warehouses, distributors, plants, shipment size, number of trucks, and the number of or-

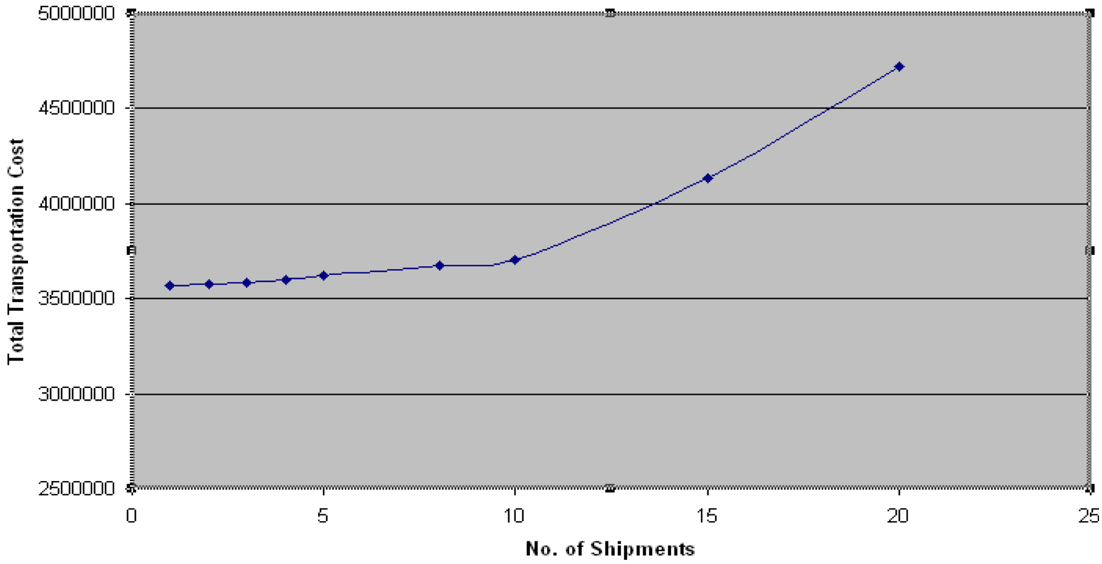

Figure 6. Total transportation cost variations with number of shipments.

ders, respectively. The associated information for each possible route for the multiple stages is presented in Tables A.1, A.2, A.3, A.4, A.5, A.6, A.7, A.8 and A.9, respectively.

6. Results and discussions

The model runs with different combinations to get insights into various costs on the optimal distribution network. The LINGO software solves the formulated problem, a comprehensive tool designed to build and solve linear and non-linear programming problems. The model is forced on the transportation and various inventory-related costs during lead time with a 99.97% service level decided by the company to achieve customer satisfaction. The current transportation cost of the company is very high (around 30% of product) in both products, which has to min. by this model. Sametime, the model, forces inventory to relate to cost under uncertainty. The model finds bottlenecks of its supply chain in its outbound logistics, *i.e.*, the parts from the finished goods inventory to the customer. The obtained results are interpreted below:

(a) Considering transportation cost

The following optimal distribution network is in Figure 6. The optimal transportation cost for different numbers of shipments is in Tables A.10 and A.11. Variation of total Transportation cost with the number of shipments is shown in Figure 7. At first, the total transportation cost does not vary much because as the shipment size reduces, it transports the CTV by a small truck. Nevertheless, as the number of shipments increases, shipment size reduces below small truck capacity; here, the total transportation cost is used instead of unit transportation cost.

(b) Considering total inventory cost

Working capital expenses are blocked up during the shipment of CTV because of transport time, the overall cost of maintaining inventories, and the cost of storing supplies. The optimal inventory cost for a different number of shipments/orders is in Table A.12. The variation of total inventory cost with the number of shipments/orders is in Figure 8. From the graph, one can see that the minimum optimal inventory cost comes at eight shipments, and when the number of shipments is six and ten, the optimal total logistics cost is minimum. As shown in

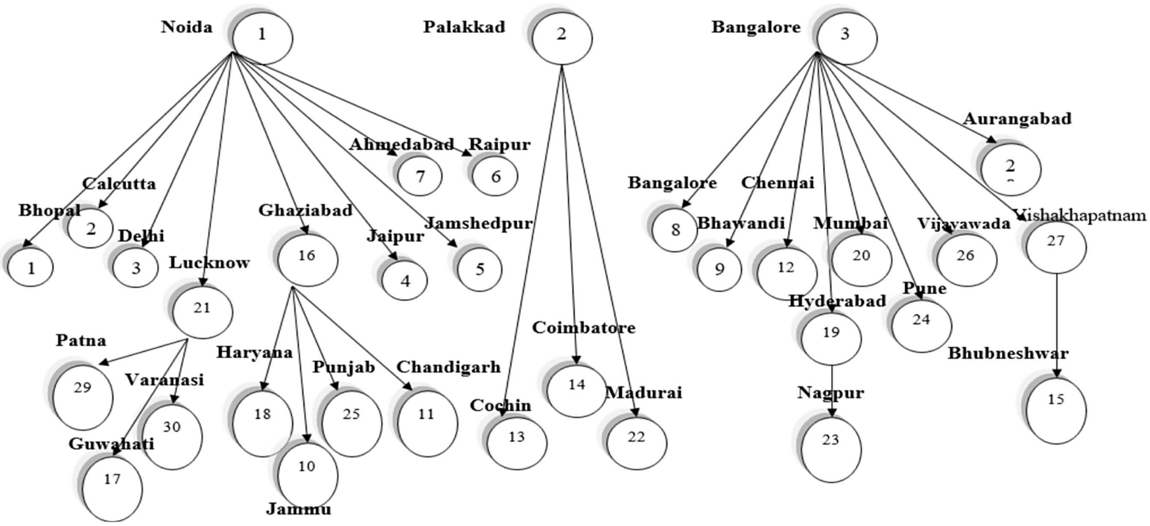

FIGURE 7. Optimal complex distribution network.

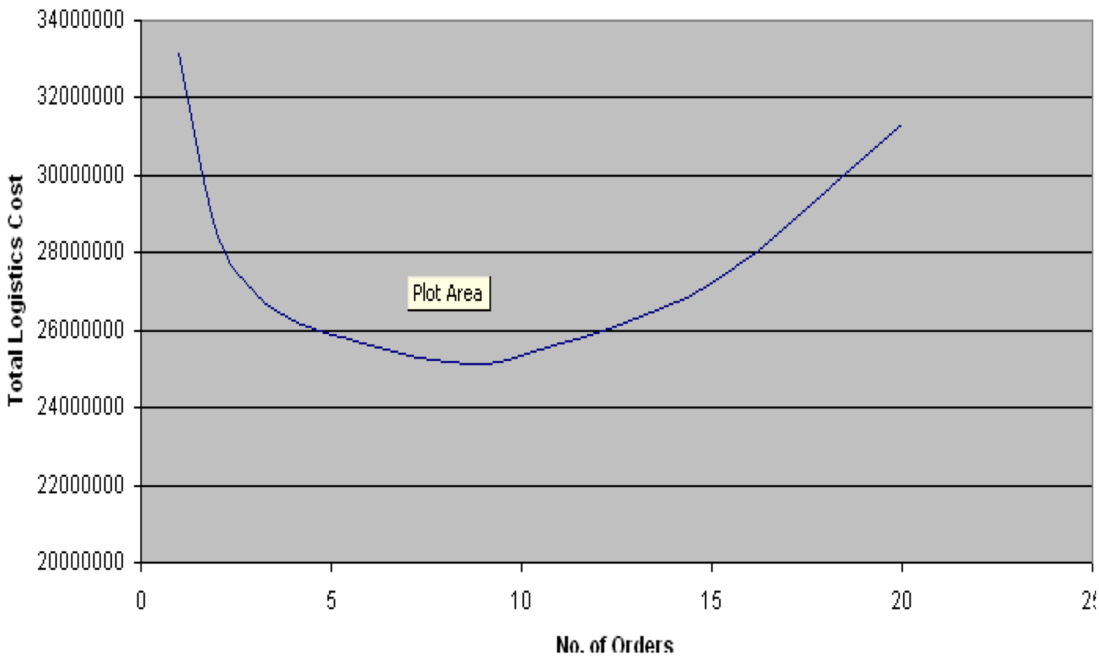

FIGURE 8. Total inventory cost variation with number of orders.

Figure 9, the optimal distribution network and shipment size, freight category, number of orders, and number of frights are required to transport the CTV.

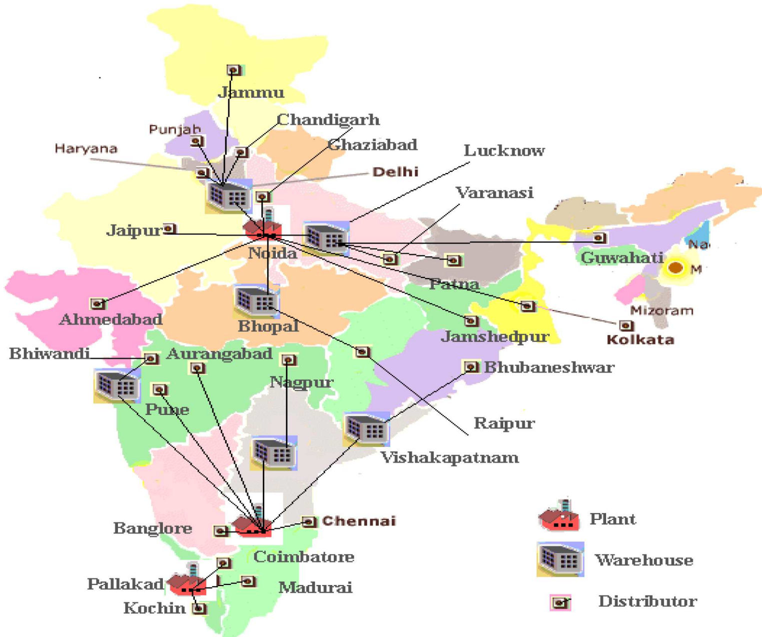

FIGURE 9. Optimal distribution network.

7. Comparative analysis with closely related models and techniques

In this section, the comparison considers the result with the previous studies of SCN models. The considered model for comparison is with certain assumptions. We employed the dataset used in this paper by making some adjustments in the considered models, and the dataset values have been changed or modified accordingly. A comparison of the result shows below.

7.1. Comparison with Charles *et al.* [14]

Charles *et al.* [14] proposed a fuzzy goal programming approach to solve the formulated multi-objective SCN problem. Three different goal programming approaches have been used to obtain the proposed approach's optimal solution. The proposed model leads to the development of a new SCN mathematical model generally aimed at reducing shipping costs and distribution times. The formulated model includes the quantity supplied from the vendor to the manufacturing plant and the quantity in the manufacturing plant that cannot surpass the capacity and quantity delivered *via* the warehouse. Its model covers the customer's demand, amounts of raw material that cannot exceed the volume had to customers from the warehouse, and the amount of the raw material purchased from the supplier. Following the approach suggested, the transportation and delivery time costs are more than by employing the same dataset on the model developed by Charles *et al.* [14]. The transportation and inventory cost of the considered SCN problem is Rs. 4 132 966 and Rs. 26 261 126. The reason for getting the different results is that the new details on non-preference relations have been used in the model. It shows that the present manuscript's approach is advantageous compared to Charles *et al.* [14].

7.2. Comparison with Gupta *et al.* [25]

Gupta *et al.* [25] developed an efficient model based on the fuzzy goal programming technique for solving the multi-objective SCN by simultaneously minimizing the total shipping costs and time, including inventory volumes, available initial stock at each source and consumer demand, and availability of storage capacity at each destination, including the overall shipping budget. In the proposed work, after determining the problem's fuzzy goals, a satisfactory solution has been efficiently derived by updating the minimal satisfactory levels with considerations of the overall satisfactory solution. In the existing situation defined by Gupta *et al.* [25], the Company has only two products for transportation and inventory management. Here, we are discussing transportation and inventory management of 20″ and 21″ CTV. In the current study, the author tried to minimize the sum of positive deviations of the SCN with a limited number of constraints. By making only minor changes in the datasets, we have fit them to the model proposed by Gupta *et al.* [25]. The preferred compromise solution with a deviation of 0.0963 and 0.0557 from the set goal is Rs. 4022.351 and Rs. 26 432 610. The obtained solution satisfies all the termination conditions, and it is a satisfactory solution.

7.3. Comparison with techniques

Furthermore, we have compared our proposed technique with the other scalarization techniques, *i.e.*, goal programming and fuzzy programming. After solving the formulated model with the goal programming technique, the total transportation and inventory cost are found to be Rs. 4 161 281 and Rs. 28 328 860, respectively, with a positive deviation of 0.33 and 0.67 from the set goal. The fuzzy programming technique is a straightforward method. This technique gives us the set of non-dominated (efficient) solutions and an optimal compromise solution. After applying it to the formulated model, the total transportation and inventory costs are found to be Rs. 3 861 783 and Rs. 27 254 255, respectively, with the maximum degree of overall satisfaction of 0.72 for the solution.

8. Sensitivity analysis

In this section, we have conducted a sensitivity analysis (Tab. A.14), through which managers will be able to identify areas for improvement that can boost the system's profitability or customer experience. To demonstrate the sensitivity of the numerical solution on the quantity shipped from one place to another destination, we have performed ten further sensitivity tests with increasing or decreasing demand and capacity limitation at each facility for the various 20″ CTV and 21″ CTV models for multi-distributors available in Bhopal, Calcutta, Delhi, Jaipur, Jamshedpur, Raipur, Ahmedabad, Bangalore, Bhiwandi, Calicut, Chandigarh, Chennai, Cochin, Coimbatore, Bhubaneswar, Ghaziabad, Guwahati, Haryana, Hyderabad, Mumbai, Lucknow, Madurai, Nagpur, Pune, Punjab, Vijayawada, Vishakhapatnam, Aurangabad, Patna, and Varanasi. In all ten cases, all the parameters of the formulated model except demand and capacity limitation are kept constant except for change in demand and capacity units.

Following the same pattern of the original problem, ten new compromise solutions using the value function approach have been generated and presented in Table A.13. They show that the increase or decrease in demand and capacity units of the firms affects both the transportation cost and inventory cost because of the change in the allocation of units from one source to another destination. With this sensitivity analysis, it is evident that uncertainty in demand and supply directly impacts transportation and inventory costs because it directly impacts the total logistics expenses and costs in other functional areas of the organization. Since transportation and inventory costs are currently a key problem for the logistics sector as well as other businesses, accounting for around 40–50% of overall logistics expenses and 4–10% of final product selling prices.

9. Limitations and scope for future work

This research seeks to identify the best logistics network by taking into account varying logistical costs. This study is limited to the supply chain network design of Fast-Moving Durable Goods (FMDG), Fast Moving Consumer Goods (FMCG), and Medicine. The model is semi-static because it involves inventory cost, ordering cost, the plant's capacity & warehouse, lead time, and buffer stock parameters in multi-periods and multi-products. Various other costs (shortage cost, cost of setting up the warehouse, and manufacturing cost of goods) and risk parameters have been proposed in various studies [15,28,29,36,43] can be incorporated in the present model. Some exciting research areas for the future are:

- One of the critical problems of the organization is the minimization of the obsolescence of finished items in stock. The model built aims to simulate shipping costs and enforce a strategy to minimize this obsolescence.
- This model can be incorporated into production facilities' output preparation and planning ().
- The company's primary concern is to minimize the overall costs of logistics. Just two tiers of destinations are in the present model. The research could be expanded to the retailers' stage.
- Analysis can consider that we will transport a full truckload and find the optimal network and logistics cost in a shipment.
- If freight costs are charged per unit rather than shipping, total logistics costs can be charged by growing demand. The model can then be generalized by realizing that by choosing the correct route, we can transfer the products to a variety of distributors.
- The developed model of logistics can be combined with the geographical information system.

Based on some famous case studies, we will try to modify our model that including [13] analyzing efficiency and customer perceptions of corporate social responsibility towards luxurious fashion products using multi-methodological optimization techniques in the fashion supply chain industries. Garai and Sarkar [20] designed a multi-objective environmentally conscious closed-loop SCM that was customer-centric. Yadav *et al.* [57] introduced a flexible production system that involves strategic and operational decision-making by controlling by-products.

10. Managerial insight

Following are the managerial insight of the study:

- The proposed model customizes (in terms of product & lead time) to solve the supply chain network problem in an uncertain environment, identify bottlenecks in the distribution network and develop a suitable model that eliminates the bottlenecks.
- Our model includes two objectives. The first one is based on minimizing the total cost of a supply chain, including inventory, transportation & warehousing costs under risk, which leads to profitability; the second objective is to see the impact of lead time on product cost & delivery. The proposed model research is helpful to chain managers, purchasing managers, logistic managers, and operations managers for decision-making in SC network design, multi-product & multi-period product distribution problems, and warehouse management under a risk environment.
- The traditional SC model for multi-product, multi-period problems considered the cost uncertain, but various unpredicted factors influence the cost. Therefore, this study considers the risk and the forecasted change by non-learning programming at an uncertain cost and time. This planning makes this model more robust, which managers may use in different sectors.
- Our model gives the manager a clear vision to decide on the opening of plant, distribution centers, and warehouses to be more receptive to supply chain interruptions.

11. Conclusions

The present study's objective was to investigate a company's supply chain, identify bottlenecks in the distribution network, and develop a suitable model that eliminates the bottlenecks. The following activities were carried out: A literature review conducted on relevant topics such as supply chain, distribution network design model, and transportation model, which gave us an overview of the supply chain management system. A case company of ABC identified that the company has one of the country's largest distribution networks. Problems related to the ABC company were analyzed. It found that the main bottlenecks of its supply chain were in its outbound logistics, *i.e.*, parts from the finished goods inventory to the customer. The distribution setup of the ABC company consists of 13 warehouses and 17 distributors. The warehouse receives goods from the three manufacturing facilities, one in north India and two in south India. Besides catering to local demand, the warehouses supply to the distributors under them.

Thus, the ABC company consists of a total of 30 demand nodes. The primary goal was to optimize the considered delivery network by considering the varying costs associated with the distribution system. Transportation cost, inventory holding cost, ordering cost, inventory cost due to transportation time, and material handling cost have taken. The distribution system of ABC company was represented as a non-linear integer programming model. With various cost combinations and several orders, the model was run to gain insight into the effect of each cost type. An optimal network was obtained by running the model by taking the total logistics cost and three cycle times (three sets of several orders). Finally, this model is developed for a company but can quickly adapt to its problem by making only minor changes in the constraints and goals.

Appendix A.

Table A.1. Transportation time from multi-capacitated warehouse to multi-distributor.

City name	Bhopal	Calcutta	Delhi	Jaipur	Jamshedpur	Raipur	Ahmedabad	Bangalore	Bhiwandi	Jammu	Chandigarh	Chennai	Cochin	Coimbatore	Bhubaneswar	Ghaziabad	Guwahati	Haryana	Hyderabad	Mumbai	Lucknow	Madurai	Nagpur	Pune	Punjab	Vijayawada	Vishakhapatnam	Aurangabad	Patna	Varanasi
Bhopal	0	5	2	2	4	2	2	5	3	3	3	5	7	6	4	2	6	3	3	3	2	6	1	3	3	3	4	2	3	2
Calcutta	5	0	5	5	1	2	7	7	7	6	6	6	8	7	2	5	3	6	5	6	3	7	4	7	6	4	3	6	2	2
Delhi	2	5	0	1	4	4	3	6	4	2	1	7	8	7	5	1	8	1	4	4	2	8	3	4	1	5	6	4	3	3
Jaipur	2	5	1	0	4	4	2	7	4	2	2	7	8	8	6	1	7	2	2	4	2	8	3	4	2	5	6	4	4	4
Jamshedpur	4	1	4	4	0	2	6	6	6	5	5	6	8	7	1	4	4	5	5	6	3	7	3	6	5	4	3	5	2	2
Raipur	2	2	4	4	2	0	4	5	3	5	5	5	6	6	2	4	6	5	3	4	3	6	1	4	5	3	2	3	3	3
Ahmedabad	2	7	3	2	6	4	0	5	2	4	4	6	6	6	2	3	8	4	4	2	4	6	3	2	4	5	6	2	5	4
Bangalore	5	7	6	7	6	5	5	0	3	7	6	1	2	1	5	6	10	6	2	3	7	2	4	3	6	2	3	3	7	6
Bhiwandi	3	7	4	4	6	3	2	3	0	5	5	4	4	4	5	4	9	5	2	1	4	5	3	1	5	3	4	4	5	5
Jammu	3	6	2	2	5	5	4	7	5	0	2	8	9	8	6	2	9	2	5	5	3	9	4	5	2	6	7	5	4	4
Chandigarh	3	6	1	2	5	5	4	6	5	2	0	8	8	8	6	1	7	1	5	5	3	9	4	5	1	6	7	5	4	4
Chennai	5	6	7	7	6	5	6	1	4	8	8	0	2	2	4	7	9	8	2	4	7	2	3	4	8	1	3	4	7	6
Cochin	7	8	8	8	8	6	6	2	4	9	8	2	0	1	6	8	11	8	3	4	8	1	5	4	8	4	5	4	8	8
Coimbatore	6	7	7	8	7	6	6	1	4	8	8	2	1	0	6	7	11	8	3	4	7	1	4	4	8	3	4	5	8	7
Bhubaneswar	4	2	5	6	1	2	2	5	5	6	6	4	6	6	0	5	5	6	4	5	4	5	3	4	6	3	2	4	3	3
Ghaziabad	2	5	1	1	4	4	3	6	4	2	1	7	8	7	5	0	8	1	4	4	2	8	3	4	1	5	6	4	3	3
Guwahati	6	3	8	7	4	6	8	10	9	9	7	9	11	11	5	8	0	7	8	9	5	10	6	6	7	7	6	8	9	4
Haryana	3	6	1	2	5	5	4	6	5	2	1	8	8	8	6	1	7	0	5	5	3	9	4	5	1	6	7	5	4	4
Hyderabad	3	5	4	2	5	3	4	2	2	5	5	2	3	3	4	4	8	5	0	2	4	3	2	2	5	1	2	2	5	4
Kurla-Mumbai	3	6	4	4	6	4	2	3	1	5	5	4	4	4	5	4	9	5	2	0	4	5	1	1	5	3	4	2	6	5
Lucknow	2	3	2	2	3	3	4	7	4	3	3	7	8	7	4	2	5	3	4	4	0	8	3	4	3	5	5	4	2	1
Madurai	6	7	8	8	7	6	6	2	5	9	9	2	1	1	5	8	10	9	3	5	8	0	5	4	9	3	4	5	8	7
Nagpur	1	4	3	3	3	1	3	4	3	4	4	3	5	4	3	3	6	4	2	1	3	5	0	3	4	2	3	2	3	3
Pune	3	7	4	4	6	4	2	3	1	5	5	4	4	4	4	4	6	5	2	1	4	4	3	0	5	3	4	1	6	5
Punjab	3	6	1	2	5	5	4	6	5	2	1	8	8	8	6	1	7	1	5	5	3	9	4	5	0	6	7	5	4	4
Vijayawada	3	4	5	5	4	3	5	2	3	6	6	1	4	3	3	5	7	6	1	3	5	3	2	3	6	0	1	3	5	5
Vishakhapatnam	4	3	6	6	3	2	6	3	4	7	7	3	5	4	2	6	6	7	2	4	5	4	3	4	7	1	0	4	4	5
Aurangabad	2	6	4	4	5	3	2	3	4	5	5	4	4	5	4	4	8	5	2	2	4	5	2	1	5	3	4	0	5	4
Patna	3	2	3	4	2	3	5	7	5	4	4	7	8	8	3	3	9	4	5	6	2	8	3	6	4	5	4	5	0	1
Varanasi	2	2	3	4	2	3	4	6	5	4	4	6	8	7	3	3	4	4	4	5	1	7	3	5	4	5	5	4	1	0

TABLE A.2. Transportation time from the multi-capacitated plant to multi-capacitated warehouse.

City name	Bhopal	Calcutta	Delhi	Jaipur	Jamshedpur	Raipur	Ahmedabad	Bangalore	Bhiwandi	Jammu	Chandigarh	Chennai	Cochin	Coimbatore	Bhubaneswar	Ghaziabad	Guwahati	Haryana	Hyderabad	Mumbai	Lucknow	Madurai	Nagpur	Pune	Punjab	Vijayawada	Vishakhapatnam	Aurangabad	Patna	Varanasi
Noida	2	5	1	1	4	4	3	6	4	2	1	7	8	7	5	1	8	1	4	4	2	8	3	4	1	5	6	4	3	3
Palakkad	6	7	7	8	7	6	6	1	4	8	8	2	1	1	6	7	11	8	3	4	7	1	4	4	8	3	4	5	8	7
Bangalore	5	7	6	7	6	5	5	1	3	7	6	1	2	1	5	6	10	6	2	3	7	2	4	3	6	2	3	3	7	6

TABLE A.3. Transportation cost from multi-capacitated warehouse to multi-distributor by high capacitated trucks.

City name	Bhopal	Calcutta	Delhi	Jaipur	Jamshedpur	Raipur	Ahmedabad
Bhopal	0	13 560	7440	5840	12 170	6300	5980
Calcutta	13 560	0	14 700	14 620	3450	8460	19 240
Delhi	7440	14 910	0	5800	14 100	14 750	9150
Jaipur	5840	14 620	5800	0	13 500	13 700	6570
Jamshedpur	12 170	3450	14 100	13 900	0	6200	17 850
Raipur	6300	8460	14 750	13 700	6200	0	12 480
Ahmedabad	5980	19 240	9150	6570	17 850	12 480	0
Bangalore	14 300	18 800	20 610	19 850	18 340	13 270	14 950
Bhiwandi	7360	19 400	11 200	12 500	19 900	10 250	5780
Jammu	11 440	18 910	5600	9800	18 100	18 750	13 150
Chandigarh	9810	16 460	3380	5360	15 500	14 130	11 530
Chennai	14 350	16 900	21 000	20 200	16 300	13 700	18 260
Cochin	19 800	23 600	26 120	25 500	26 700	19 250	18 810
Coimbatore	17 410	21 670	24 000	23 100	21 200	16 670	17 620
Bhubaneswar	11 920	5410	17 450	17 900	4340	5920	18 100
Ghaziabad	7360	13 890	1900	3570	12 500	11 680	9340
Guwahati	18 550	10 800	24 590	19 610	12 030	18 630	24 230
Haryana	8260	14 870	4700	6500	17 200	17 200	12 760
Hyderabad	8390	15 160	15 600	7200	16 900	10 100	12 080
Mumbai	7790	19 870	12 000	13 200	20 200	13 250	5750
Lucknow	6780	9800	6000	6700	10 200	9850	11 240
Madurai	18 470	21 200	22 500	26 700	23 000	21 000	19 380
Nagpur	4520	11 240	10 500	10 200	9800	3950	9700
Pune	8200	20 400	12 200	13 700	20 200	13 750	6900
Punjab	8780	18 720	4500	6650	16 680	16 750	12 347
Vijayawada	10 400	12 480	17 200	16 700	13 200	10 200	14 750
Vishakhapatnam	13 120	8660	21 000	19 800	10 340	6750	18 580
Aurangabad	5880	16 280	12 000	10 500	14 600	7900	5860
Patna	9500	6160	11 900	12 900	6850	10 250	14 790
Varanasi	6760	6800	9800	12 870	7100	9500	12 440

	Bangalore	Bhiwandi	Jammu	Chandigarh	Chennai	Cochin	Coimbatore	Bhubaneswar
Bhopal	14 300	7360	11 440	9810	14 350	19 800	17 410	11 920
Calcutta	18 800	19 400	18 910	16 460	16 900	23 600	21 670	5410
Delhi	20 610	11 200	5600	3380	21 000	26 120	24 000	17 450
Jaipur	19 850	12 500	9800	5360	20 200	25 500	23 100	17 900
Jamshedpur	18 340	19 900	18 100	15 500	16 300	26 700	21 200	4340
Raipur	13 270	10 250	18 750	14 130	13 700	19 250	16 670	5920
Ahmedabad	14 950	5780	13 150	11 530	18 260	18 810	17 620	18 100
Bangalore	0	9770	24 610	22 980	3910	5639	3900	14 400
Bhiwandi	9770	0	15 200	15 940	13 150	13 240	12 440	14 640
Jammu	24 610	15 200	0	7380	25 000	30 120	28 000	21 450
Chandigarh	22 980	15 940	7380	0	24 350	28 310	26 680	19 820
Chennai	3910	13 150	25 000	24 350	0	6840	4950	12 350
Cochin	5639	13 240	30 120	28 310	6840	0	2430	19 190

Table A.3. Continued.

City name	Bhopal	Calcutta	Delhi	Jaipur	Jamshedpur	Raipur	Ahmedabad	
Coimbatore	3900	12 440	28 000	26 680	4950	2230	0	17 260
Bhubaneswar	14 400	14 640	21 450	19 820	12 350	19 190	17 260	0
Ghaziabad	20 530	11 375	5800	2570	21 150	26 120	24 190	17 370
Guwahati	29 320	27 030	28 590	21 450	27 180	34 000	32 090	14 830
Haryana	21 340	16 750	8700	1950	24 500	27 500	26 200	18 350
Hyderabad	5620	7100	19 600	17 360	6880	9820	9020	10 750
Mumbai	9980	3850	16 000	16 370	13 300	14 130	12 650	15 070
Lucknow	19 280	13 450	10 000	7380	19 620	27 250	22 680	12 650
Madurai	4460	13 250	26 500	22 500	4450	3400	2170	16 790
Nagpur	10 490	10 230	14 500	12 490	10 900	16 400	13 890	8400
Pune	8350	3450	16 200	16 540	11 700	13 250	11 020	13 500
Punjab	21 560	17 100	8500	2100	24 700	27 350	26 500	18 200
Vijayawada	6830	10 250	21 200	20 030	3960	13 450	9190	8070
Vishakhapatnam	10 150	13 450	25 000	21 170	8100	17 200	13 010	4250
Aurangabad	9130	3600	16 000	14 450	12 350	14 000	12 700	11 040
Patna	19 880	16 775	15 900	12 010	20 300	24 750	23 280	4250
Varanasi	17 790	16 850	13 800	11 250	18 150	23 950	21 190	9650

Table A.4. Transportation cost from multi-capacitated warehouse to multi-distributor by container type truck.

City name	Bhopal	Calcutta	Delhi	Jaipur	Jamshedpur	Raipur	Ahmedabad
Bhopal	0	23 655	13 440	10 270	22 340	10 600	9800
Calcutta	23 655	0	26 144	26 560	5900	13 880	35 440
Delhi	12 384	26 144	0	8500	24 252	25 370	14 600
Jaipur	10 270	26 560	8500	0	25 244	24 100	10 270
Jamshedpur	22 340	5900	24 252	25 244	0	11 000	30 444
Raipur	10 600	13 880	25 370	24 100	11 000	0	21 000
Ahmedabad	9800	35 440	14 600	10 270	30 444	21 000	0
Bangalore	24 440	35 090	32 960	35 970	31 420	23 000	25 670
Bhiwandi	12 360	35 444	20 360	22 220	34 120	17 860	9850
Jammu	17 384	31 144	7800	13 500	29 252	30 370	19 600
Chandigarh	17 600	29 248	6100	8200	26 544	24 250	19 765
Chennai	24 340	29 544	38 000	37 560	27 832	22 950	31 830
Cochin	36 040	41 284	45 570	43 420	43 870	32 820	30 500
Coimbatore	32 400	38 780	39 500	42 360	36 220	28 832	30 000
Bhubaneswar	21 890	9124	31 445	33 564	7300	9500	31 000
Ghaziabad	12 440	25 420	3100	6890	21 188	19 864	16 700
Guwahati	33 250	18 760	43 000	36 220	20 784	31 260	42 000
Haryana	13 450	27 344	7600	11 200	29 344	29 444	22 000
Hyderabad	14 350	27 556	26 832	13 000	28 232	17 460	21 000
Mumbai	13 240	36 780	20 924	22 788	34 424	22 230	9540
Lucknow	12 000	16 600	10 500	12 500	17 840	17 560	19 400
Madurai	33 240	39 890	38 700	45 160	38 884	36 120	32 820
Nagpur	7400	20 210	18 060	17 890	17 000	7 200	16 800
Pune	15 000	37 560	20 684	23 188	34 120	23 370	12 000
Punjab	15 400	35 455	7500	11 900	28 616	28 450	21 200
Vijayawada	17 560	22 280	29 584	27 832	22 788	18 060	25 370
Vishakhapatnam	23 445	15 220	36 120	32 820	17 860	11 080	31 820
Aurangabad	10 120	29 880	20 264	18 060	24 750	12 984	10 000
Patna	18 700	9880	22 188	22 188	12 400	18 000	25 400
Varanasi	12 340	10 560	17 500	22 000	12 300	16 500	21 100

	Bangalore	Bhiwandi	Jammu	Chandigarh	Chennai	Cochin	Coimbatore	Bhubaneswar
Bhopal	24 440	12 360	17 384	17 600	24 340	36 040	32 400	21 890
Calcutta	35 090	35 444	31 144	29 248	29 544	41 284	38 780	9124
Delhi	32 960	20 360	7800	6100	38 000	45 570	39 500	31 445
Jaipur	35 970	22 220	13 500	8200	37 560	43 420	42 360	33 564
Jamshedpur	31 420	34 120	29 252	26 544	27 832	43 870	36 220	7300

Table A.4. Continued.

City name	Bhopal	Calcutta	Delhi	Jaipur	Jamshedpur	Raipur	Ahmedabad	
Raipur	23 000	17 860	30 370	24 250	22 950	32 820	28 832	9500
Ahmedabad	25 670	9850	19 600	19 765	31 830	30 500	30 000	31 000
Bangalore	0	16 870	37 960	42 240	7250	10 200	7120	24 560
Bhiwandi	16 870	0	25 360	27 000	22 000	22 850	21 700	25 250
Jammu	37 960	25 360	0	11 100	42 500	49 570	44 500	36 445
Chandigarh	42 240	27 000	11 100	0	41 650	48 230	47 250	32 860
Chennai	7250	22 000	42 500	41 650	0	11 800	8000	21 120
Cochin	10 200	22 850	49 570	48 230	11 800	0	3200	32 420
Coimbatore	7 120	21 700	44 500	47 250	8000	3200	0	29580
Bhubaneswar	24 560	25 250	36 445	32 860	21 120	32 420	29 580	0
Ghaziabad	34 120	19 500	8100	3500	36 800	47 050	41 670	30 000
Guwahati	48 670	47 260	47 000	36 800	48 000	60 000	55 560	25 670
Haryana	36 780	27 240	12 600	3 000	43 000	47 500	44 500	31 520
Hyderabad	9240	13 000	30 832	29 560	12 200	17 000	15 000	18 500
Mumbai	17 200	6800	24 924	27 500	23 000	24 350	21 200	26 000
Lucknow	32 450	23 250	15 500	13 000	32 900	47 500	38 700	21 200
Madurai	7600	22 780	42 700	38 700	7600	5100	3200	27 100
Nagpur	18 100	18 000	22 560	21 000	19 000	27 000	24 000	14 000
Pune	15600	6 400	24 684	27 500	20 000	23 240	19 100	23 750
Punjab	37 100	29 500	12 500	3200	42 570	47 500	44 570	31 220
Vijayawada	11 380	17 690	33 584	35 000	7 200	23 100	15 790	14 000
Vishakhapatnam	17 450	23 450	40 120	36 000	14 500	29 700	22 460	7500
Aurangabad	15 600	6800	24 264	24 800	21 240	24 000	21 300	19 000
Patna	33 820	27 560	26 188	20 700	33 400	42 570	40 700	7550
Varanasi	30 600	27 540	22 500	19 400	30 700	41 200	36 500	16 700

TABLE A.5. Transportation cost from multi-capacitated plant to multi-capacitated warehouse by high capacity truck.

Warehouse	Noida (in Rs.)	Palakkad (in Rs.)	Bangalore (in Rs.)
Bhopal	7440	18 310	14 300
Calcutta	14 910	29 670	18 800
Delhi	1900	24 900	20 610
Jaipur	5800	23 970	19 850
Jamshedpur	14 100	22 200	18 340
Raipur	14 750	17 670	13 270
Ahmedabad	9150	18 520	14 950
Bangalore	20 610	4430	1850
Bhiwandi	11200	13 140	9770
Jammu	5900	29 800	24 610
Chandigarh	3380	27 480	22 980
Chennai	21 000	5650	3910
Cochin	26 120	2100	5639
Coimbatore	24 000	1900	3900
Bhubaneswar	17 450	18 060	14 400
Ghaziabad	1900	25 090	20 530
Guwahati	24 590	32 890	29 320
Haryana	4700	27 100	21 340
Hyderabad	15 600	9820	5620
Mumbai	12 000	13 750	9980
Lucknow	6000	23 680	19 280
Madurai	22 500	2570	4 460
Nagpur	10 500	14 390	10 490
Pune	12 200	11 720	8350
Punjab	4500	27 200	21 560
Vijayawada	17 200	9890	6830
Vishakhapatnam	21 000	13 810	10 150
Aurangabad	12 000	13 420	9130
Patna	11 900	24 180	19 880
Varanasi	9800	29 190	17 790

Table A.6. Transportation cost from multi-capacitated plant to multi-capacitated warehouse by container type truck.

Warehouse	Noida (in Rs.)	Palakkad (in Rs.)	Bangalore (in Rs.)
Bhopal	12 384	32 400	24 440
Calcutta	26 144	38 780	35 090
Delhi	3100	39 500	32 960
Jaipur	8500	42 360	35 970
Jamshedpur	24 252	36 220	31 420
Raipur	25 370	28 832	23 000
Ahmedabad	14 600	30 000	25 670
Bangalore	32 960	7120	2800
Bhiwandi	20 360	21 700	16 870
Jammu	7800	43 500	39 960
Chandigarh	6100	47 250	42 240
Chennai	38 000	8000	7250
Cochin	45 570	3200	10 200
Coimbatore	39 500	3800	7120
Bhubaneswar	31 445	29 580	24 560
Ghaziabad	3100	41 670	34 120
Guwahati	43 000	55 560	48 670
Haryana	7600	44 500	36 780
Hyderabad	26 832	15 000	9240
Mumbai	20 924	21 200	17 200
Lucknow	10 500	38 700	32 450
Madurai	38 700	3200	7600
Nagpur	18 060	24 000	18 100
Pune	20 684	19 100	15 600
Punjab	7500	44 570	37 100
Vijayawada	29 584	15 790	11 380
Vishakhapatnam	36 120	22 460	17 450
Aurangabad	20 264	21 300	15 600
Patna	22 188	40 700	33 820
Varanasi	17 500	36 500	30 600

Table A.7. Total forecasted demand of various 20″ CTV model for multi-distributors.

City name	Year						Average demand	Standard deviation
	1	2	3	4	5	6		
Bhopal	1452	1594	1769	1992	2048	1608	1744	237
Calcutta	1924	1764	1947	1515	1846	1880	1813	160
Delhi	5421	4565	5401	6123	5899	5212	5437	548
Jaipur	2958	3375	3696	3188	3803	3074	3349	342
Jamshedpur	830	828	959	786	729	1041	863	116
Raipur	759	788	705	777	642	881	759	81
Ahmedabad	1278	1581	1864	1697	1982	1194	1600	315
Bangalore	3229	2795	3112	3008	2909	2997	3009	152
Bhiwandi	635	828	776	672	685	621	703	82
Calicut	204	231	249	227	304	195	235	39
Chandigarh	664	614	716	824	601	816	706	98
Chennai	2067	1313	1710	1311	1312	1539	1542	305
Cochin	1735	1198	1460	1605	1879	1335	1536	254
Coimbatore	1081	1063	1116	1158	847	947	1036	117
Bhubaneswar	856	911	985	1028	775	722	880	119
Ghaziabad	2323	2443	2036	2475	2939	2122	2390	321
Guwahati	1018	834	834	734	642	754	803	128
Haryana	1205	926	956	1159	1389	1475	1185	222
Hyderabad	1930	1954	2053	1397	1136	1564	1673	365
Mumbai	3378	312	3282	3123	2650	3958	2784	1283
Lucknow	547	731	822	584	837	615	690	125
Madurai	628	624	772	822	867	627	724	111
Nagpur	374	369	388	393	253	180	327	89
Pune	1821	2286	2333	1917	2607	2225	2199	289
Punjab	1160	629	876	981	1020	692	893	203
Vijayawada	893	771	824	806	881	737	819	61
Vishakhapatnam	1188	1173	995	1295	1112	1172	1156	99
Aurangabad	779	784	933	827	747	594	778	111
Patna	815	997	759	872	609	749	801	131
Varanasi	1789	1875	2132	2000	1929	1790	1920	133

Table A.8. Total forecasted demand of various 21″ CTV model for multi-distributor.

City name	Year						Average demand	Standard deviation
	1	2	3	4	5	6		
Bhopal	1903	2075	2240	2564	2509	2083	2229	262
Calcutta	2048	2415	2430	1988	2330	2366	2263	194
Delhi	6036	5855	6023	6754	6529	5832	6172	381
Jaipur	3482	4082	4233	3716	4341	3602	3910	357
Jamshedpur	1168	1166	1301	1120	1056	1392	1201	124
Raipur	1044	1134	1036	1116	941	1208	1080	93
Ahmedabad	1703	2012	2299	2130	2420	1617	2031	321
Bangalore	3779	3339	3662	3561	3761	3544	3608	164
Bhiwandi	955	1156	1122	984	1006	940	1028	91
Calicut	461	493	507	485	568	455	495	41
Chandigarh	1126	972	1077	1188	961	1186	1085	101
Chennai	2464	1697	2108	1694	1756	1926	1941	303
Cochin	2109	1567	1832	1977	2253	1705	1908	256
Coimbatore	1463	1440	1495	1542	1217	1317	1413	122
Bhubaneswar	1199	1267	1344	1390	1122	1070	1232	126
Ghaziabad	2836	2959	2547	2992	3457	2634	2905	323
Guwahati	1331	1144	1151	1046	951	1068	1116	129
Haryana	1598	1315	1346	1551	1784	1865	1577	224
Hyderabad	2356	2380	2486	1813	1545	1985	2095	374
Mumbai	3898	3839	3802	3642	3167	4481	3805	425
Lucknow	840	1034	1130	884	1141	910	990	130
Madurai	952	940	1096	1147	1189	950	1046	112
Nagpur	636	633	650	656	514	441	589	90
Pune	2182	2647	2694	2268	2969	2856	2603	316
Punjab	1517	976	1227	1330	1372	1037	1244	207
Vijayawada	1208	1086	1140	1223	1195	989	1141	90
Vishakhapatnam	1532	1517	1333	1641	1454	1516	1499	102
Aurangabad	1077	1082	1240	1126	1049	888	1077	115
Patna	1160	1338	1101	1224	944	1093	1144	134
Varanasi	2156	2248	2508	2368	2303	2157	2290	136

Table A.9. Shipment size, number of trucks and number of orders from multi-capacitated plant to capacitated warehouse.

Sl. No	Warehouse	Shipment size		Number of trucks		Number of orders
		20″ CTV	21″ CTV	HCV	Container	
1	Bhopal	320	415	1	2	8
2	Lucknow	420	554	1	3	10
3	Delhi	822	1030	2	5	10
4	Hyderabad	250	350	x	2	8
5	Vishakhapatnam	205	273	3	x	10
6	Mumbai	350	484	x	3	10

TABLE A.10. Shipment size, number of trucks and number of orders from multi-capacitated warehouse to multi-capacitated distributor.

Sl. No	Warehouse	Shipment size		Number of trucks		Number of orders
		20″ CTV	21″ CTV	HCV	Container	
1	Varanasi	192	230	1	1	10
2	Patna	71	107	1	x	10
3	Guwahati	72	108	1	x	10
4	Haryana	118	157	x	1	10
5	Punjab	120	127	x	1	10
6	Chandigarh	72	110	1	x	10
7	Raipur	97	110	x	1	8
8	Bhubaneswar	110	152	x	1	8
9	Bhiwandi	71	103	1	x	10
10	Nagpur	53	100	1	x	6
11	Jammu	40	87	1	x	6

TABLE A.11. Shipment size, number of trucks, and number of orders from multi-capacitated plant to multi-capacitated distributor.

Sl. No	Distributors	Shipment size		Number of trucks		Number of orders
		20″ CTV	21″ CTV	HCV	Container	
1	Jamshedpur	110	150	x	1	8
2	Jaipur	335	391	1	2	10
3	Ghaziabad	240	291	x	2	10
4	Ahmadabad	160	205	2	x	10
5	Vijayawada	82	115	x	1	8
6	Pune	220	261	x	3	10
7	Calcutta	182	227	2	x	10
8	Cochin	155	190	2	x	10
9	Coimbatore	122	160	x	1	8
10	Madurai	72	105	1	x	10
11	Bangalore	300	360	4	x	10
12	Aurangabad	78	105	1	x	10
13	Chennai	154	195	2	x	10

TABLE A.12. Cost of shipments.

Number of shipments	Total transportation cost (Rs.)	Total inventory cost (Rs.)
1	3 566 590	33 141 700
2	3 575 940	28 532 400
3	3 581 240	26 935 400
4	3 598 800	26 248 500
5	3 618 410	25 878 300
8	3 673 740	25 156 500
10	3 708 480	25 360 400
15	4 134 520	27 235 100
20	4 722 900	31 334 900

Table A.13. Comparison with other techniques for 8 shipments.

Techniques	Total transportation cost (Rs.)	Total inventory cost (Rs.)
Proposed technique	3 673 740	25 156 500
Goal programming	4 161 281	28 328 860
Fuzzy prograaming	3 861 783	27 254 255

Table A.14. Sensitivity analysis of demand.

Cases	Percentage of increase in demand	Total transportation cost (Rs.)	Total inventory cost (Rs.)
1	−25	2 842 669.981	19 465 620.15
2	−20	2 992 284.191	20 490 126.48
3	−15	3 149 772.833	2 568 554.19
4	−10	3 315 550.35	22 703 741.25
5	−5	3 490 053	23 898 675
6	0	3 673 740	25 156 500
7	5	3 857 427	26 414 325
8	10	4 050 298.35	27 735 041.25
9	15	4 252 813.268	29 121 793.31
10	20	4 465 453.931	30 577 882.98
11	25	4 688 726.627	32 106 777.13

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