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A Mixed-Integer Programming Model for Optimizing the Distribution Network of a Packaging Company

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Abstract Designing a distribution network for a company is critical as it determines how efficiently and cost-effectively products are transported. An optimized distribution network should minimize costs and delivery times while maximizing service levels. In this context, the location and number of facilities such as warehouses and factories, as well as the choice of transportation modes, play a significant role in the network's performance. This study examines a distribution network design problem experienced by a packaging company. Currently, the company operates a single-warehouse shipment management system for its operations in France. However, the company's sales group in France believes that replacing the single-warehouse system with a two-warehouse system could optimize transportation costs while ensuring on-time deliveries. Therefore, the company analyzes the feasibility of such a transition. To achieve this, mixed-integer linear programming (MILP) models are developed, minimizing total distribution costs between the manufacturing plants and the warehouses while determining the distribution of deliveries through three transportation modes—trucks, trains, and ships—that ensures timely delivery of demands. The results indicate that the company should maintain its current single warehouse policy but can favor reduction in transportation costs by focusing on production lead times and delivery prices of transportation modes.

Keywords Mixed Integer Linear Programming · Distribution Network Design Problem · Transportation Mode Selection · Supply Chain Network Design Problem

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A Mixed-Integer Programming Model for Optimizing the Distribution Network of a Packaging Company

Supply chain network design is a strategic process that determines the optimal configuration and operation of supply chains to ensure the efficient flow of goods from suppliers to end customers (Jahani, Abbasi, Sheu, & Klibi, 2024). It involves critical decisions regarding the location of facilities, transportation modes, inventory levels, and the relationships between supply chain components. Effective supply chain network design minimizes costs, enhances customer satisfaction, and reduces risks while adapting to dynamic market conditions (Khalili-Fard, Sabouhi, & Bozorgi-Amiri, 2024). Despite its strategic importance, designing cost-effective and efficient networks remains a challenge due to the complex interplay between transportation, warehousing, and inventory management.

This study focuses on optimizing the distribution network system of a flexible global packaging company with a significant presence in Europe. The company currently employs a single-warehouse strategy to serve its customers in France but faces challenges due to increasing transportation costs and constraints associated with delivery deadlines. To address these issues, the company is evaluating the feasibility of transitioning to a two-warehouse system to improve cost efficiency and delivery performance. For this task, in this study, a mixed integer linear programming (MILP) model that minimizes the total transportation costs between the manufacturing plants and the warehouses using three different transportation modes—trucks, trains, and ships—is developed. The developed model is applied for the current single-warehouse system and the two-warehouse system together with two different scenario analysis and the results are compared to give insights to the company.

The primary research questions guiding this study are as follows:

- How can the transition from a single-warehouse to a two-warehouse system impact transportation costs and delivery performance?
- What is the optimal transportation strategy that minimizes total transportation costs while meeting delivery deadlines under capacity and mode constraints?
- How can sensitivity analyses provide insights into the effects of varying key parameters such as production time and transportation availability on the supply chain's performance?

This study contributes to the literature by presenting a MILP model that integrates on-time delivery, transportation mode selection, and capacity utilization of the transportation modes. Unlike many studies that treat these aspects separately, this research combines them to provide a comprehensive evaluation of warehouse management strategies. The findings offer valuable insights for both researchers and practitioners by highlighting the cost implications of multi-warehouse systems, and the trade-offs involved in transportation mode selection. The remainder of this study is organized as follows. The next section presents a summary of the existing literature on the distribution network design problem. The Methods section outlines the problem definition for the packaging company of concern together with the proposed MILP approach, and the Results section evaluates the cost-efficiency of the proposed strategy using real-world data. The discussion section provides the implications of the findings, limitations, and directions for future research, and the study is concluded in the Conclusions section.

Existing Studies on the Distribution Network Design Problem

The distribution network design problem is an optimization problem that involves determining warehouse and facility locations and selecting transportation modes to ensure efficient, cost-effective and timely delivery of products from production points to customers (Li, Liu, & Yang, 2024). The problem requires strategic planning of logistics processes with the goal of minimizing total costs and maximizing service levels in a supply chain (Lee, Ko, & Moon, 2024). Inventory and network design in supply chains involved in the above-mentioned problem type is a frequently studied topic in literature. You and Grossmann (2009) developed a MINLP model for inventory management and multi-level supply chain configuration in the chemical industry under stochastic demand. By reformulating the problem into a decomposable concave minimization program, they achieved near-optimal solutions with reduced computational costs. Dündar, Tekin, Peker, Şahman, & Karaoğlan (2022) addressed wheat supply chain optimization with a multi-period, multi-stage model, enhancing efficiency and resilience through real-world applications. Bacchetti, Bertazzi, and Zanardini (2020) improved supply chain distribution planning by optimizing warehouse replenishment and distribution strategies, minimizing costs in complex logistics networks. Moreover, Ayyıldız, Şahin, & Taşkın (2023) explored a supply chain network design issue through a split delivery vehicle routing problem with multi-depot, multi-commodity, and time windows characteristics.

The optimization processes involve multiple objects to be considered in most supply chain networks. Hajmirfattahtabrizi and Song (2019) proposed a mixed-integer nonlinear programming (MINLP) model with a multi-objective function for supply, production, and distribution systems. The model minimizes total costs and integrates supply chains, reducing bottlenecks by 19.73% using MATLAB computations. Similarly, Ghahremani-Nahr, Najafi, and Nozari (2022) focused on optimizing transportation and distribution in perishable product supply chains. Their model integrates multiple vehicles and analyzes demand uncertainties using the Sequential Convex Approximation and Genetic Algorithm, achieving higher efficiency with the former. Qiu et al. (2024) applied game theory to optimize oil substitution, transportation, and pipeline pricing, reducing costs and emissions in China's fuel supply chain.

The selection of transportation modes in distribution systems is also of interest to many researchers. Mogale, Dolgui, Kandhway, Kumara, & Tiwari (2017) and Mogale, Kumar, Kumara, & Tiwari (2018) tackled food grain distribution challenges in India's Public Distribution System. They developed MINLP models addressing vehicle selection, seasonal supply, silo storage, and demand constraints. Using metaheuristics like Improved Max-Min Ant System and Hybrid Particle-Chemical Reaction Optimization, they demonstrated superior efficiency and cost reduction. Zhou and Zhang (2023) focused on multimodal transportation, employing network graph theory and the Dijkstra algorithm to optimize costs and enhance logistics systems. Kravets et al. (2020) optimized grain export cargo flows via a multi-criteria nonlinear programming model, emphasizing time and cost efficiency in rail transport.

Determining the optimal location of the facilities is another major task in supply chain design. Buriticá, Escobar, and Gutiérrez (2018) optimized warehouse location selection for a Colombian soft drink company using k-means clustering and MILP. They minimize the distribution network costs while meeting the capacity constraints. Boujelben et al. (2014) designed multi-product distribution networks for the automotive industry, considering transport and capacity constraints to reduce costs. Kheirabadi et al. (2019) designed a two-tier supply chain network, selecting facility locations and transport modes to minimize costs and enhance product availability. In a similar effort, Kızılkaya, Kevser, Ofluoğlu, Ölçücüer, and Demirel formulated a Euclidean minimum model and p-median model to determine the optimal warehouse location for an electrical home appliances company.

To derive the optimal solutions for the mathematical models constructed to represent the distribution network design problems, diverse optimization techniques such as advanced algorithms and heuristics are employed. Luathep, Sumalee, Lam, Li, and Lo (2011) introduced a global optimization algorithm for mixed transportation network design problems, leveraging Wardrop's user equilibrium. Baller, Fontaine, Minner, & Lai (2022) addressed logistics optimization at the assembly level in the automotive industry using MILP, achieving significant cost reductions and improved transport efficiency. Yang and Zhou (2017) reformulated travel time reliability measures for dynamic transportation networks, demonstrating computational efficiency with MILP.

Strategic and tactical decisions in the supply chain planning horizons are also important study fields. Sadjady and Davoudpour (2012) emphasize strategic facility positioning and transportation mode selection to minimize total network costs, contributing to efficient distribution network design. Bilgen and Ozkarahan (2007) optimized wheat distribution planning for overseas shipments, minimizing costs over a three-month horizon using MILP.

Table 1

Summary of the examined studies

Study	Objective	Key Constraints	Decision Type
Bilgen and Ozkarahan (2007)	Minimize the total transportation, inventory, blending, and loading costs	Blending capacity, loading capacity, vessel capacity, blended product capacity, demand satisfaction.	Tactical
You &Grossmann (2009)	Minimizing the total supply chain design cost	Distribution center selection and assignment, customer demand zone assignment, and linking constraint	Tactical
Luathep, et al. (2011)	Minimizing the total travel time	Budget constraint, capacity expansion, travel time constraints	Tactical
Sadjady and Davoudpour (2012)	Minimizing the product lead time cost, transportation costs, inventory holding costs, opening and operating costs of facilities and warehouses.	Capacity levels for warehouses and plants, capacity on transportation modes, demand satisfaction, and binary nature of decision variables.	Strategic
Boujelben, et al. (2014)	Minimize the total distribution costs	Volume constraints on transport, covering distance constraints, and volume and capacity constraints on distribution centers	Strategic
Mogale, et al. (2017)	Minimize the overall cost	Vehicle capacity, demand satisfaction, silo storage constraints, and seasonal procurement constraints	Tactical
Yang and Zhou (2017)	Minimizing the total travel time	Travel time constraints, transportation network	Tactical
Buriticá, et al. (2018)	Minimize the total cost of the distribution network	Storage capacity, transport capacity, compliance of the demand	Strategic
Mogale, et al. (2018)	Minimize transportation, inventory holding, and operational costs	Demand satisfaction, silo capacity, seasonal procurement constraints, vehicle capacity	Tactical
Hajmirfattahtabrizi and Song (2019)	Minimizing the total cost in the procurement, production, and distribution processes	Supply constraint, demand constraint, inventory level, decision variable bounds, production and distribution	Tactical

Study	**Objective**	**Key Constraints**	**Decision Type**
Kheirabadi, et al. (2019)	Minimize the overall cost	Capacity limitations (demand and raw material), fixed and variable costs of transportation modes, and purchasing costs of raw materials	Strategic
Bacchetti, et al. (2020)	Minimizing the total transportation cost	Inventory level constraints at the production plants and regional warehouses, one-step direct shipping and two-step direct shipping constraints, vehicle capacity constraints, and demand satisfaction.	Strategic
Kravets, et al. (2020)	Maximizing transportation time in the plan	Number of routes and loading stations	Tactical
Dündar, et al. (2022)	Minimize the transportation cost	Capacity limitations and demand satisfaction	Tactical
Ghahremani-Nahr, et al. (2022)	Minimizing the transfer time of perishable fruits and vegetables from cultivation centers to customers	Inventory levels, specific deterioration times, demand constraints, capacity use	Tactical
Zhou and Zhang (2023)	Minimization of the total cost	Transportation cost and time constraints	Tactical
Qiu, et al. (2024)	Maximizing the overall system efficiency	Oil supply and demand capacity, transportation capacity, batch requirements, loading and unloading capacity, oil depot capacity	Strategic
The current study	Minimize the total transportation cost between warehouses and production plants	Demand satisfaction, transportation mode constraints, delivery risk reduction constraints	Strategic

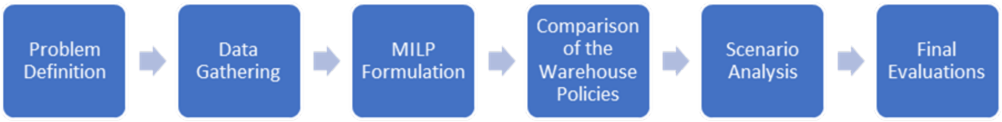
The used methodologies and the key indicators that are considered in the above-mentioned studies are summarized in Table 1. Overall, the existing studies highlight advancements in supply chain optimization through various mathematical models and solution techniques. Common themes include minimizing costs, addressing uncertainties, and enhancing efficiency across supply chain networks. Techniques such as MINLP, MILP, and advanced heuristics are widely applied, while strategic decisions like facility location and multi-modal transportation further enrich the field. Future research could focus on integrating sustainability and resilience into supply chain design to address global challenges. In addition to the existing studies, this study focuses on strategic decision-making with the objective of minimizing the total transportation costs between warehouses and the production plants by considering demand satisfaction, transportation mode selection, and delivery risk reduction constraints.

METHODS

The steps of the proposed method are displayed in Figure 1 and are detailed in the following subsections.

Figure 1

Flowchart of the proposed method



Problem Definition

This study focuses on the design and optimization of a distribution network for a packaging company. The company operates with a centralized structure, comprising a single plant and a warehouse. Customer demands are fulfilled from the warehouse at specific times, with the demand volumes and delivery schedules being predetermined. To transport products from the plant to the warehouse, the company employs three transportation modes: train, ship, and truck.

Each transportation mode has its own cost structure. Specifically, containers can be transported using trains or ships, while trucks are used for smaller volumes that cannot fully use the container capacity. Containers can only be dispatched if they are fully loaded, meaning that the volume of products being transported matches the container's capacity. Otherwise, such unutilized volumes must be transported via trucks, which are less cost-effective than trains and ships. Consequently, the company minimizes the use of trucks to optimize overall transportation costs.

Production at the plant takes approximately two weeks, with an additional two weeks allocated for transportation to the warehouse. However, the production time is variable, averaging around two weeks. This temporal structure necessitates careful planning to align production schedules with delivery deadlines to ensure timely fulfillment of customer demands.

The dataset used for this study includes detailed information about a one-month planning horizon, such as: demand volumes and their corresponding delivery dates to the warehouse, required completion dates for production to meet delivery deadlines, the capacity of containers, transportation costs per unit product via trucks, transportation costs per container for trains and ships, and so on. The problem includes key operational challenges, including demand scheduling, mode selection for transportation, and cost minimization. This study develops mathematical models to address these challenges, aiming to optimize the company's distribution network by minimizing costs while ensuring timely delivery.

Assumptions for Choosing the Transportation Modes

The packaging company meticulously plans its order and delivery processes to ensure operational efficiency and cost minimization. Orders are processed through sales representatives and production planning, where raw material procurement and production schedules are coordinated. Completed products are dispatched from İstanbul warehouse to warehouses in France using the most suitable transportation method (road, rail, or sea). As mentioned previously, the company currently operates a single warehouse in Paris, France. However, the new system proposes two warehouses, located in Marseille and Strasbourg. This transition involves evaluating the most efficient transportation modes and routes for deliveries from İstanbul to these locations, considering transportation times and costs.

Road transport using trucks provides a fast and flexible delivery option, with shipments to Paris, Marseille, and Strasbourg. In contrast, rail transport using trains is an economical and environmentally friendly option for long distances. Transportation by sea using ships is more economical than other modes of transportation. However, the transportation times may be longer than the other methods. Containers are used in ships and trains, while products are sent without containers via trucks.

The selection of transportation modes in the packaging company's delivery processes is guided by specific rules to ensure cost efficiency, operational reliability, and customer satisfaction. It is assumed that deliveries must reach the warehouse by the specified deadline, and no backlogging is allowed. In addition, train and ship departures occur once a week on designated days, while road transport operates three times a week. Here, transportation mode selection must prioritize minimum cost while meeting deadlines. Moreover, train and ship containers must be fully loaded, while this restriction does not apply to trucks. Furthermore, for security reasons, no more than 80% of a delivery can be transported by train or ship. This regulation is assumed to be necessary by the company as it provides risk reduction to prevent delays in deliveries due to interruptions in sea or rail transportation. It is also assumed that separate routes and ports/stations are used for the eastern and western regions of France in the two-warehouse system, while loads from different warehouses cannot be combined. Last but not least, orders assigned to a specific warehouse must be delivered there, with no transfers between the warehouses.

A MILP model was developed to optimize the distribution network system and minimize the total transportation cost. The reason why this model is preferred is that the adopted decision variables consist of integers and real numbers. The assumptions that will enable the adoption of the model are as follows: Production time is β days for each order, and there are no delays due to production capacity. The deadline time of the deliveries is γ days for each order, and deliveries are made only on specified days a week for each transportation mode. Even if there is an emergency, express shipping is not possible and transportation times are deterministically known. The locations of the warehouses will be opened at the points determined by the sales group, and the customers are assigned to a single warehouse closest to them. In addition, there is no capacity limit in the warehouses and all products in the container occupy the same volume of space. That is, the only capacity issues in the model are related to the capacities of the transportation modes.

Mathematical Model

Based on the problem definition and the assumptions, the MILP model is constructed to find the optimal distribution network design as follows:

Sets and Indices:

T Set of days $t \in T = \{1,2,\ldots,H\}$

tr Truck

sh Ship

turn Train

Parameters:

D_t Demand volume at time t

C_{tr} Transportation cost per unit product for using a truck

C_{sh} Transportation cost per container using a ship

C_{trn} Transportation cost per container using a train

Cap_{sh} Capacity of a container for a ship

Cap_{trn} Capacity of a container for a train

atr_t 1 if it is possible to use a truck for starting the shipment from the plant to the warehouse at time t; 0 otherwise

ash_t 1 if it is possible to use ship for starting the shipment from the plant to the warehouse at time t; 0 otherwise

$atrn_t$ 1 if it is possible to use a train for starting the shipment from the plant to the warehouse at time t; 0 otherwise

β Days necessary to complete the production processes after receiving the order

γ Deadline time for an order

θ Risk reduction scalar for transportation by train or ship

months	maximum number of containers that can be loaded on a ship for the company
contr	maximum number of containers that can be loaded on a train for the company

Decision variables:

z	Objective function
xtr_t	Number of products started to be transported from the plant to the warehouse by trucks at time *t*
xsh_t	Number of containers started to be transported from the plant to the warehouse by ships at time *t*
$xtrn_t$	Number of containers started to be transported from the plant to the warehouse by trains at time *t*

Objective Function:

$$z = \sum_{t=1}^{H} c_{tr} * xtr_t + \sum_{t=1}^{H} c_{sh} * xsh_t + \sum_{t=1}^{H} c_{trn} * xtrn_t \tag{1}$$

Constraints:

$$atr_{t+\beta} * xtr_{t+\beta} + ash_{t+\beta} * Capsh * xsh_{t+\beta} + atrn_{t+\beta} * Captrn * xtrn_{t+\beta} = D_t, \forall t \in \{\gamma+1, \gamma+2, ..., H\} \tag{2}$$

$$Capsh * xsh_{t+\beta} \leq \theta * D_t, \forall t \in \{\gamma+1, \gamma+2, ..., H\} \tag{3}$$

$$Captrn * xtrn_{t+\beta} \leq \theta * D_t, \forall t \in \{\gamma+1, \gamma+2, ..., H\} \tag{4}$$

$$xsh_t \leq contsh, \forall t \in \{1, 2, .., H\} \tag{5}$$

$$xtrn_t \leq conttr, \forall t \in \{1, 2, .., H\} \tag{6}$$

$$xtr_t, xsh_t, xtrn_t \geq 0 \tag{7}$$

$$xsh_t, xtrn_t \; Integer \tag{8}$$

The objective function in Equ. (1) minimizes the total transportation cost. Equ. (2) ensures demand satisfaction on time for each order using three different transportation modes. Equ. (3) and Equ. (4) stand for risk reduction constraints, which provide an upper limit on the proportion of products transported via trains or ships for each order considering safety issues. These risk reduction constraints ensure the company's regulation that not all of the products are delivered through using only trains or only ships. Equ. (5) and Equ. (6) limit the number of containers loaded on each train and ship to be less than the company's allowed space for these transportation modes per travel. Equ. (7) and Equ. (8) are nonnegativity and integer constraints.

Here, as can be seen in Equ. (5) and Equ. (6), capacity restrictions only exist for ship and train modes. In addition, the parameters atr_t, ash_t, and $atrn_t$ take the value of 1 if it is possible to start shipments using these transportation modes on day *t*, considering the order day, production time (β), and delivery day.

RESULTS

Because of our negotiations with the company, order numbers, order dates, order quantities, warehouse location, delivery dates, delivery methods, and delivery costs were obtained. Apart from the current Paris location, two separate warehouse locations planned to be used were determined. Then, the MILP model is solved using the CPLEX solver in GAMS Studio 47 software.

About the Input Data

The company performs sea shipment and rail shipment deliveries by the container leasing method, and one container has a capacity of 24000 kg in both delivery methods. According to the data received from the company, in the current delivery method used for sea shipment, the order arrives at the port of Paris in 13 days and €3120 is paid for each container. Delivery occurs once a week on Tuesdays. Rail shipment takes 11 days to reach the Paris warehouse and €3840 is paid for each container. Delivery occurs once a week on Thursdays. Road shipment delivery to the warehouse takes 6 days. Payment is made at € 0.24/kg. All of these monetary values are provided by the company and they are scaled from the real values into these amounts based on a scalar whose exact value is unknown to the authors for confidentiality. Delivery occurs three times a week on Tuesdays, Thursdays, and Sundays. For the implementation, it is decided to choose a four-week period from the 2023 October actual order data. The reason for this selection is that this period is closest to the 2023 whole year average values and it is the period with the least divergence from seasonal factors such as agriculture, inflation, etc. Demand levels in kg are given in Table 2 for the single-warehouse case for the 2023 October period. Likewise, Table 3 displays the demand levels for the same period for the two-warehouse case: one warehouse for the eastern regions and one warehouse for the Western Regions.

Table 2

Demand levels for October 2023 for the single-warehouse case

Day	Demand	Day	Demand	Day	Demand	Day	Demand
1	0	8	0	15	0	22	0
2	45988	9	63889	16	33513	23	45237
3	0	10	0	17	0	24	0
4	97354	11	15715	18	43034	25	171013
5	0	12	0	19	0	26	0
6	0	13	0	20	0	27	0
7	34432	14	77611	21	97672	28	69330

Table 3

Demand levels for October 2023 for the two-warehouse case

Demands for the Eastern Region Warehouse				Demands for the Western Region Warehouse			
Day	**Demand**	**Day**	**Demand**	**Day**	**Demand**	**Day**	**Demand**
1	0	15	0	1	0	15	0
2	24789	16	193674	2	21199	16	160161
3	0	17	0	3	0	17	0
4	49573	18	25693	4	47781	18	17341
5	0	19	0	5	0	19	0
6	0	20	0	6	0	20	0
7	13948	21	52569	7	20484	21	45103
8	0	22	0	8	0	22	0
9	38598	23	21946	9	25391	23	23291
10	0	24	0	10	0	24	0
11	5636	25	73251	11	10079	25	97762
12	0	26	0	12	0	26	0
13	0	27	0	13	0	27	0
14	41743	28	34748	14	35868	28	34582

Production time β is 14 days and the deadline γ is 28 days for each order. The risk reduction scalar θ for transportation through train or ship is taken as 0.8 as required by the company. This scalar is embedded in Equation. 3 and Equ. (4) ensures that at most 80% of the demand on a day at the warehouse can be satisfied via trains or ships. As discussed previously, such kind of a scalar is considered necessary by the company to prevent risks due to security and delay concerns. Moreover, the maximum number of containers that can be loaded on a ship and train for the company, *months* and *contr*, are set as 3 and 5, with, respectively.

Numerical Findings

Two separate MILP models are developed considering the single-warehouse case and the two-warehouse case based on the mathematical model defined in the Methods section. The mathematical models generated for both cases are solved optimally in less than 0.01 s in CPLEX time. For the company's current single warehouse system, the total transportation cost is found to be 160293.120 €/month. The delivery times and delivery quantities are provided in Table 4.

Table 4

Deliveries with a single warehouse case

Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships
16	21988		1
18	25354	3	
21	34432		
23	15989		2
25	15715		
28	77611		
30	9513		1
32	19034	1	
35	97672		
37	21237		1
39	51013	5	

For the two-warehouse system, the total transportation costs of the warehouses dedicated to the Eastern and Western regions of France are found to be 121960.320 €/month and 113770.080 €/month, with, respectively. Therefore, the amount paid by the company for monthly transportation with the two-warehouse system is calculated as 235730.4 €/month, which is by far greater than the total transportation costs obtained for the current single-warehouse system. The delivery times and delivery quantity information for the two-warehouse case are displayed in Table 5.

Table 5

Deliveries with a two-warehouse case

Eastern Regions				Western Regions			
Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships	Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships
16	24789			16	21119		
18	25573	1		18	23781	1	
21	13948			21	20484		

Eastern Regions				Western Regions			
Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships	Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships
23	14598		1	23	25391		
25	5636			25	10079		
28	41743			28	35868		
30	121674		3	30	88161		3
32	25693			32	17341		
35	52569			35	45103		
37	21946			37	23291		
39	25251	2		39	25762	3	
42	34748			42	34582		

Scenario Analysis

Based on the numerical findings, it is obvious that the two-warehouse system that the company plans to adapt results in greater transportation costs when compared to the current single warehouse system. Thus, the optimal solution among these two can be determined as the current single warehouse system in terms of transportation costs. To see the impacts of changes in several parameter values on the total monthly transportation costs for the company if they continue with the current system, five different scenarios are generated. Different combinations of the effects of changes in the production time and changes in the transportation price parameters are examined in these scenarios, as displayed in Table 6.

The scenarios are generated in the following way: The current production period, which is set to be 14 days, is assumed to be reduced to 12 days by improvements in areas such as raw material supply, production planning and reducing quality problems in Scenario 3, Scenario 4, and Scenario 5; while it is kept as 14 days in Scenario 1 and Scenario 2. In addition, to provide a two-way sensitivity analysis, the impact of a 10% decrease or increase in delivery prices for the three transportation modes on total transportation costs is analyzed within these scenarios. The delivery prices for all three transportation modes are assumed to increase by 10% in Scenarios 1 and 3, while a 10% reduction in delivery prices is considered in Scenario 4. In Scenario 5, it is assumed that there is no change in the delivery prices. Here, it is thought that a reduction in delivery prices may be possible by negotiations with the current logistics company or finding alternative suppliers, whereas an increase in delivery prices may be due to some economic crisis or supply chain disruptions. In all scenarios, all the other parameters are kept constant. The optimal solution of the current single warehouse system when the production period is set as 14 days and current delivery prices are used is also provided in the table as the base scenario for comparison purposes.

Table 6

Comparison of the optimal solution with the solutions of the scenarios

Scenario	Production Time (days)	Delivery Price Change	Orders Shipped by Trucks (kg)	Number of Containers Sent by Ships	Number of Containers Sent by Trucks	Total Transportation Costs
Base Scenario	14	-	458888	5	9	€160293.12
Scenario-1	14	+10%	458888	5	9	€174488.88
Scenario-2	14	–10%	458888	5	9	€146099.36

Scenario	Production Time (days)	Delivery Price Change	Orders Shipped by Trucks (kg)	Number of Containers Sent by Ships	Number of Containers Sent by Trucks	Total Transportation Costs
Scenario-3	12	+10%	338888	9	10	€161238.88
Scenario-4	12	−10%	338888	9	10	€134387.36
Scenario-5	12	-	338888	9	10	€147813.12

The total transportation costs because of each scenario are displayed in the last column of Table 6. Orders shipped by trucks (kg), number of containers sent by ships, and number of containers sent by trucks for each scenario are also given in Table 6. The models generated in each scenario are solved optimally in less than 0.01 s in CPLEX time. Considering the outputs displayed in Table 6, it can be seen that when the production time is reduced to 12 days, the number of containers sent via ships increases from 5 to 9, while the number of containers sent via train increases from 9 to 10. Furthermore, the products sent via trucks decreased from 458,888 kg to 328,888 kg. here, it was found that the change in delivery prices for the transportation modes had no impact on the amount of orders sent through the transportation modes. Furthermore, the total transportation costs are increasing as delivery prices increase and vice versa. The minimum transportation costs are achieved in Scenario 4 when the production time is reduced to 12 days, and the delivery prices for the transportation modes decrease by 10%. Overall, the results show that the total transportation cost could be reduced with possible changes in the values of diverse parameters in the mathematical model.

Discussion

Based on the numerical findings and the results of the scenario analysis, it is suggested that the company should keep its current single warehouse system for its operations in France, instead of introducing a two-warehouse system. However, this decision is based only on the transportation cost analysis, which omits other issues such as service quality improvements or new customer opportunities that the company may favor with a decentralized warehouse system. To incorporate these issues, a new mathematical model that combines multiple objectives and several other constraints must be generated. The proposed model also ignores customer-warehouse allocations for the two-warehouse system, which means that the transportation costs are related only to the deliveries of the products from the manufacturing plants to the warehouses, assuming a fixed delivery network between the warehouses and customers. This network is known to the company but is not shared with the authors. In fact, the transportation costs regarding the deliveries between the warehouses and customers are neglected here because the locations of the warehouses and customer-warehouse allocations have already been determined by the company.

The main reason why the company wants a comparison of single- and two-warehouse systems can be said to be to decrease transportation costs. Using a single warehouse for all deliveries can lead to high transportation costs, especially for distant regions. By utilizing two warehouses, deliveries can be made from closer locations, optimizing overall transportation costs. In the current system, shipments from a single warehouse in Paris result in longer delivery times, particularly for the southern and eastern regions. Establishing warehouses in Marseille and Strasbourg would enable faster deliveries to these areas. Additionally, demand intensity varies across regions, and a two-warehouse system allows for more flexible inventory management, improving responsiveness to fluctuations. Managing large stock volumes in a single warehouse may also create capacity constraints, whereas distributing inventory across two locations enhances storage efficiency. Moreover, relying on a single warehouse poses risks in cases of disruptions such as natural disasters, strikes, or logistical issues. An additional warehouse increases resilience and ensures a more flexible supply chain. However, it is worth mentioning that most of the above-mentioned issues are not analyzed in this study as the company only focuses on transportation costs because of deliveries between the production plants and warehouses. Nevertheless, this study helps the company in evaluating cost-efficient distribution strategies and enhancing delivery performance from a managerial point of view. Methodologically, it establishes a systematic optimization framework to analyze and compare single with two-warehouse systems, facilitating informed decision-making. Furthermore, it strengthens supply chain resilience by considering risk reductions and improving transportation mode selection processes.

The present study, which uses a MILP model to analyze production and shipment processes in manufacturing firms, is subject to certain constraints and limitations inherent in its methodology. First, the model's reliance on deterministic assumptions regarding production and shipment durations constrains its ability to accurately represent the dynamic and stochastic nature of these processes in real-world settings. In reality, production and shipment durations are subject to variability and uncertainty due to factors such as machine breakdowns, unexpected delays, and fluctuations in demand, which are not fully captured in the deterministic framework.

Second, the assumption of fixed-order quantities for incoming orders overlooks the inherent variability and uncertainty associated with demand patterns. In practice, incoming orders often exhibit stochastic behavior, characterized by fluctuations and deviations from the anticipated quantities. By assuming fixed-order quantities, the model may fail to account for the volatility and unpredictability inherent in the demand forecasting and order fulfillment processes.

Furthermore, while MILP offers computational advantages and facilitates the development of tractable optimization models, its deterministic nature limits its ability to explicitly incorporate uncertainty into the decision-making process. As a result, the model may not adequately reflect the probabilistic nature of real-world uncertainties, potentially leading to suboptimal solutions.

the decision to adopt a deterministic approach was influenced by practical considerations, including time constraints and the complexity associated with developing and solving the stochastic programming models. While the current model serves as a valuable starting point for analyzing production and shipment processes, future research efforts should aim to refine and enhance the model by incorporating stochastic elements to better reflect the inherent uncertainties in manufacturing operations.

In conclusion, while the findings of this study offer valuable insights into production and shipment processes, it is essential to recognize the limitations of the deterministic approach adopted in the modeling framework. Addressing these limitations through further research and model refinement is crucial for advancing our understanding of complex manufacturing systems and improving decision-making processes in practice.

Conclusion

To conclude, optimizing transportation processes and reducing costs play a critical role in increasing operational efficiency for companies by ensuring a more effective use of resources. In order to maintain their market share in competitive markets with changing conditions, the companies must conduct their business at a minimum cost while providing quality service. At the same time, they should keep the costs in production and post-production applications at an optimum level for minimum cost while providing quality service. When all costs are considered, transportation costs have the largest share.

This study was conducted with a flexible packaging manufacturer. The company's existing structure in France plays an important role in its European expansion strategy. In the current system, all orders going to France are sent to a single warehouse; however, the France sales group of the company is examining the feasibility of converting the current system into a two-warehouse system, one for the Eastern and one for the Western regions of France in terms of transportation costs. Therefore, this study aims to optimize the distribution network system and propose a scenario that minimizes the total transportation cost between the manufacturing plants and the warehouses. The proposed delivery system is based on three different transportation modes: trucks, ships, and trains. In line with these objectives and predictions, information such as necessary parameters and constraints were determined and necessary data were obtained from the company for the October 2023 period. A MILP model is developed and solved separately for the single-warehouse case and the two-warehouse case through the CPLEX solver of GAMS Studio 47 software. The total transportation cost for the one-warehouse system was found to be 160293.120 €/month, while for the two-warehouse system this value was calculated as 235730.4 €/month. As a result, an increase in the transportation costs of 75437.28 €/month was observed; indicating that the transition to a two-storage system has a negative impact on the total transportation costs between the manufacturing plants and the warehouses. The negative impact was observed to be because the ship and train containers were not at full capacity and therefore the more expensive truck had to be used.

In summary, it was found that the intended cost reduction could not be achieved by switching from the current one-warehouse system to a two-warehouse system. As a result of this study, it is recommended that the company remain with the current single warehouse system. At this point, scenario analyses conducted to achieve the targeted cost reduction showed that shortening the production time and decreasing the shipment prices provided a partial cost reduction. After this research, it is recommended that the company should optimize the parameters of the system to improve its warehouse management strategy in France.

Future research efforts should improve and refine the mathematical model to better reflect the uncertainties inherent in manufacturing operations. Although the findings of this study provide valuable insights into the manufacturing and shipping processes, it is important to recognize the limitations of the deterministic approach adopted in the model's methodology. Addressing these limitations through future research and model development is important to advance the understanding of complex production systems and improve decision making in practice.

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