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Research Article

Solving multi-depot vehicle routing problem with incoterms: A case study for export logistics

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ABSTRACT

In today's global market, the international trade methods used in exports have great importance in terms of transportation, including pre-shipment, and post-shipment services due to their impact on buyers and senders. To carry out export operations at low costs and on time, models, that address the multi-depot, multi-product, and heterogeneous fleet vehicle routing problems, together with delivery methods and costs based on the responsibilities of the seller and buyer, are needed. In this study, a mixed integer programming model is presented for companies with production facilities and warehouses in different regions to carry out export operations using Incoterms delivery methods. The objective is to minimize total costs, including holding costs, transportation costs, and the costs associated with delivery terms (incoterms). The customer's distance from each depot, the various vehicle capacities, the number of vehicles in use, the holding costs at each depot, and the delivery terms (incoterms) are all taken into account during the modeling and solving process to find the best solutions. The results show that the model is applicable to exporting firms with a distribution network characterized by a multi-depot, multi-product, heterogeneous fleet.

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INTRODUCTION

Sociocultural, political, and technological developments in the globalizing world, as well as rapid economic development, have led to the emergence of intense competition. In particular, increasing customer expectations have forced manufacturers to prioritize logistics services and invest in establishing the necessary systems. This situation has led to the continuous development of vehicle routing for reasons such as short life cycles, the emergence of e-commerce, an increase in the number of products transported in densely populated areas, and traffic problems.

Dantzig and Ramser [1] first proposed the "truck dispatching problem" and modeled a homogeneous fleet that could serve many gas stations from a central location to minimize travel distance. Clarke and Wright [2] generalized this problem as the "linear optimization problem," which is frequently encountered in logistics. One of the most widely studied topics in this field is known as the

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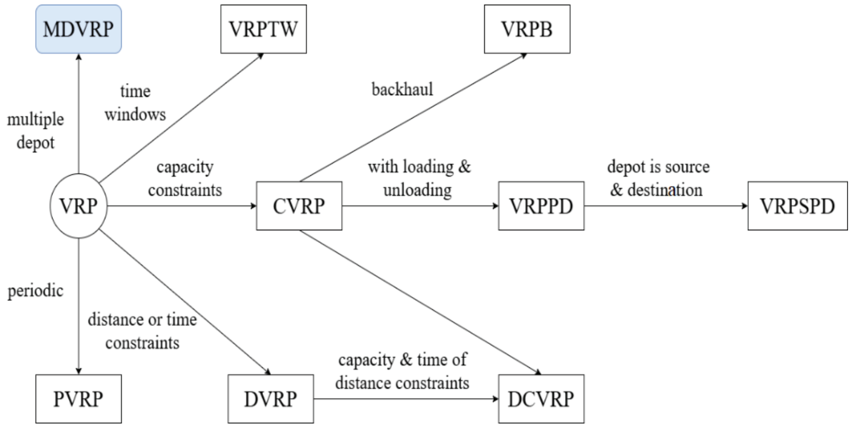

Figure 1. VRP variant hierarchy.

"vehicle routing problem (VRP)"[3]. VRP is an important topic widely researched in logistics science due to its potential cost savings and service improvement opportunities for organizations dealing with the physical distribution of products [4]. When only customers are clearly grouped around each depot, a distribution network problem can be solved as multiple individual single-depot VRPs; otherwise, when customers are to be served from any of the depots using the available fleet of vehicles, a multi-depot-based solution must be utilized [5].

The VRP variant hierarchy is illustrated in Figure 1. One of these variants considers a common, more realistic case in which goods are distributed from several depots to final customers [6,7]. The distribution network problem can be resolved as multiple distinct single-depot VRPs if customers are clearly grouped around each depot. If not, a multi-depot-based strategy must be employed, allowing customers to be served from any depot using the available vehicle fleet. In this study, we address the Multiple Depot Vehicle Routing Problem (MDVRP), a version of the vehicle routing problem involving multiple depots.

The solution of the multi-depot vehicle routing problem with multi-product, heterogeneous fleet, and incoterms conditions is of great importance for exporting companies. The study focuses on the Multi-Depot Vehicle Routing Problem (MDVRP) and develops a mathematical model that incorporates Incoterms delivery conditions in the context of export logistics. The model aims to minimize total costs, including transportation, storage, and delivery expenses, by optimizing the transportation of various products from different depots to customers. According to the reviewed literature, there have been no problem structures and mathematical models with the indicated conditions (incoterms delivery terms) and features (multi-depot, multi-product, heterogeneous fleet) presented in this paper. Integrating all of these features allows the solution to be more valuable and realistic for some industries. Through the use of a multi-product structure and a heterogeneous fleet of vehicles, the model offers solutions suitable for real-life scenarios. It has been tested in several conditions and shows effectiveness in route and cost optimization.

Literature Review

Studies in the literature, categorized according to objective function, fleet type, product type, and solution method, are depicted in Table 1.

Table 1. Studies in the literature according to objective function, fleet type, product type, and solution method

Authors	Fleet type	Product type	Objective function	Solution method
Liu and Lee 2003 [8]	Homogeneous	Single-product	Minimizing the sum of depot-establishing, transportation, and inventory costs.	Heuristic method
Currie et al. 2003 [9]	Heterogeneous	Multi-product	Minimizing total costs (fixed vehicle and operating costs)	Exact and heuristic methods
Kang et al. 2005 [10]	Homogeneous	Single-product	Minimizing transportation cost	Exact algorithms-MIP
Ho et al. 2008 [11]	Homogenous	Single-product	Minimizing the total delivery time	Hybrid algorithms (GA, SA,TS)

Table 1. Studies in the literature according to objective function, fleet type, product type, and solution method (continued)

Authors	Fleet type	Product type	Objective function	Solution method
Moin et al, 2011 [12]	Homogeneous	Multi-product	Minimizing inventory and transportation costs, variable travel costs, and fixed vehicle costs	MILP, hybrid genetic algorithm
Aras et al, 2011 [13]	Homogeneous	Single-product	Maximizing total profit	MILP and TS-based heuristic
Benslimane et al, 2013 [14]	Heterogeneous	Single-product	Minimizing total distribution cost	MILP, Ant Colony Algorithm
Ramos et al, 2014 [15]	Heterogeneous	Multi-product	Minimizing distance and CO^2 emissions	MILP
Zhang et al, 2014 [16]	Homogeneous	Multi-product	Minimizing delivery cost	MILP, GA
Rahmani et al. 2016 [17]	Homogeneous	Multi-product	Minimizing total travel cost, opening cost of selected processing centers, and fixed vehicle costs	MILP, Nearest Neighbor Heuristic, Best Sequential Insertion, Hybrid Clustering Algorithm
Tirkolaee et al, 2017 [18]	Heterogeneous	Single-product	Minimizing total costs, including vehicle usage costs, total traveled distance, and earliness and tardiness costs of services	MILP
Saragih, et al. 2019 [19]	Heterogeneous	Single product	Minimizing the sum of the fixed costs of locating opened depots, routing costs, expected inventory costs, and truck transportation cost of retailers, depots, and suppliers.	MINLP and SA-based Heuristic
Yao et al. 2019 [20]	Homogenous	Single-product	Minimizing the total cost of the delivery process	Ant Colony Optimization (ACO)
Wang et al. 2020 [21]	Heterogeneous	Multi-product	Minimizing the makespan and the total travel time.	MILP, Adaptive Large Neighborhood Search (ALNS)
Moonsri et al. 2022 [22]	Heterogeneous	Multi-product	Minimizing transportation, labor, and holding cost.	MILP, HSADE
Kaveh et al. 2022 [23]	Heterogeneous	Multi-product	Minimizing travel cost	Exact Method
Erdem, 2023 [24]	heterogeneous	Multi-product	Minimizing total energy costs	MILP and AGVNS heuristic
Nguyen, et al. 2022 [25]	heterogeneous	Multi-product	Minimizing the number of unserved customers, number of vehicles needed, and total travel distance	MILP, A-ALNS
Lin et al. (2023) [26]	heterogeneous	Multi-product	Minimizing the sum of the total fixed vehicle cost and the total travel distance	MILP and ALNS algorithms
Çil et al, 2023 [27]	homogeneous	Multi-product	Minimizing the total cost of the workstation and transportation cost.	CP, MILP, MILNP, SA, and MS-SA
Suarez et al., 2024 [28]	homogeneous	Multi-product	Maximizing dispatch, Minimizing wastage	MILP, DP
Arenas-Vasco et al., 2024 [29]	heterogeneous	Multi-product	Minimize the total time elapsed in the operation.	MILP
Maleki et al., 2024 [30]	heterogeneous	Multi-product	Minimize the total cost of the network consisting of transportation, establishment, and waste processing costs	Augmented ε-constraint method, LP-Metric method, Fuzzy method
Li, N., 2025 [31]	homogeneous	Multi-product	Minimize supplier's total cost	ACO and Fuzzy Adaptive GA
Li and Wang, 2025 [32]	homogeneous	Multi-product	Minimize the total transportation cost, the penalty cost violating online time windows and the split delivery cost.	ALNS

MIP: Mixed integer programing; MILP: Mixed-integer linear programing; MINLP: Mixed-integer nonlinear programing; HSADE: Hybrid self-adaptive differential evolution algorithms; AGVNS: Adaptive General-Variable Neighborhood Search; A-ALNS: Applying an adaptive large neighborhood search; CP: Constraint programing; SA: Simulated annealing; MS-SA: Multi-start simulated annealing; DP: Dynamic programing; ACO: Ant colony optimization FAGA: Fuzzy adaptive genetic algorithm; ALNS: Adaptive large neighborhood search; GA: Genetic algorithm

Liu and Lee [8] designed a mathematical model for a single-product multi -depot location and routing problem with inventory control decisions. The aim is to minimize the sum of the warehouse-opening, shipping, and inventory costs. The fleet type is homogenous (vehicle capacity is the same). A two-stage heuristic method was proposed to solve this problem. The proposed heuristic method is more effective than existing methods that do not consider inventory control decisions. Ramos et al. [15] discussed the planning of recyclable wastewater systems due to economic and environmental concerns. They define service areas and vehicle routes within logistics networks with more than one warehouse where different products are collected. This problem was modeled as a multiple product, multi-depot vehicle routing problem, and the aim was to minimize distance and CO_2 emissions. The MILP method for solving this problem was developed and applied to a real case study. Six different scenarios were examined within the scope of service areas and purpose functions. As a result, economic and environmental targets were achieved by saving up to 22% and decreasing CO_2 emissions by 27%. Yao et al. [20] discussed the problem of fresh seafood delivery and aimed to find the most appropriate routes to minimize the total cost during the entire delivery process. For this reason, the fresh seafood distribution problem was modeled as a multi-depot vehicle routing problem with a homogeneous fleet. The Ant Colony Optimization (ACO) algorithm is used to solve this problem. In light of the findings, the proposed model is found to be applicable. Moonsri et al. [22] studied multi-product (different sizes of eggs), multi-depot vehicle routing for a heterogeneous fleet, inventory, and time window restrictions to solve an egg distribution problem in Thailand. To solve this problem, a Mixed Integer Linear Programming (MILP) model is designed. The aim is to minimize the total cost. Researchers suggested Hybrid Self-Adaptation Differential Evolution Algorithms (HSADE) for this study. The results demonstrate that HSADE's performance is better than the current method and that HSADE can provide an average improvement of 14.13% in total cost. Erdem [24] aimed to minimize total energy costs by studying milk collection problems with heterogeneous fleets. At the same time, sustainable transport targets were taken into consideration through an environmentally friendly approach. The mathematical model was formulated, and AGVNS was proposed to solve this problem. The findings obtained during the analysis indicate that the problem has been successfully solved in terms of solution quality and time. Lin et al. [26] focused on the post-harvest operations of fruits and vegetables. Mobile pre-processing units are relatively new agricultural applications. Mobile pre-processing services reduce total operating costs compared to traditional center pre-processing. In this context, the current problem of pre-processing operations in short food supply chains was formulated using a heterogeneous fleet and a mixed integer programming model, and an ALNS was proposed. These findings demonstrate the potential of mobile pre-processing units in small-scale agricultural applications.

In the literature, studies show that objective functions containing transportation costs based on road lengths are considered. In addition, it is observed that multi-product and heterogeneous fleet models have been discussed more recently. In this study, the problem structure of heterogeneous fleets and multiple products is considered, and, unlike in other studies, a model structure, including delivery terms and costs, is used for companies that export abroad. The multiple problem structure enabled the calculation of total inventory costs in each warehouse which varied according to product type. On the other hand, the heterogeneous fleet structure allows the use of vehicles of varying capacities on the basis of product types.

Our contributions: The structure of the problem and the mathematical model offers a novel contribution to the literature by integrating the vehicle routing problem with Incoterms (international trade delivery conditions). While there are many studies on the multi-depot vehicle routing problem in the literature, this study stands out by introducing the integration of delivery terms and costs within the context of export logistics. The study has a unique place within the fields of international trade and logistics due to the new and innovative ideas.

- A distribution model is presented for companies with production facilities and warehouses in different regions to conduct export operations using Incoterms delivery methods.
- This study focuses on the export logistics activities of the case study. The problem is formulated as a multi-depot, multi-product, heterogeneous fleet vehicle routing problem that can be used in various real-world export operations for factories. The objective is to minimize total costs, including transportation costs, holding costs, and delivery terms (incoterms).
- To solve this problem, the customer's distance from each depot, the different capacities of each vehicle, the numbers of vehicles used, the holding cost at each depot, and delivery terms (incoterms) are considered in the modeling and solving processes to obtain optimal solutions. Mixed-Integer Linear Programming (MILP) model is used to solve the indicated problem.

Export Operations in Logistics

The concept of Incoterms, which stands for "International Commercial Terms", explains the supply chain requirements for the sale and purchase of goods. These international trade methods express the practical ways in which the obligations, risks, and costs for the seller and buyer are accepted during the exchange of goods [33]. The International Chamber of Commerce developed Incoterms regulations, which are especially important for maintaining stability in international trade and preventing expressions in contracts about international trade from being interpreted incorrectly in different countries. The responsibilities of buyers and sellers are shown in Table 2.

International sales transactions carry significant risks for both buyers and sellers. These risks include the following: the possibility of the goods being delivered without problems if a product is sent from one country to another, the complete cost of the goods, the protection of the goods, transportation risks, customs issues and misunderstandings about commercial terms due to unfamiliar commercial legislation in the buyer's and seller's countries. In Table 2, some of the incoterms: delivery methods are explained, such as FAS, FOB, CFR, and CIF [34].

Free alongside ship (FAS) is the delivery term of the seller (exporter) and refers to the placement of the goods alongside the ship at the loading port. From that point onward, the buyer (importer) firm, takes over all costs for the goods and risks of damage to the goods.

Free on board (FOB) is the delivery term of the seller who delivers the goods up to the point at which they pass the ship's rail in the loading port. The seller (exporter) is obliged to load the goods on the ship. From that point onward, the buyer, importer, firm assumes all costs, losses, and damage risks related to the goods.

Cost and freight (CFR) is the delivery terms of the seller (exporter) company, which indicate the costs required for the transportation of the goods to the specified arrival (port), and freight. "The cost of goods and freight" means that the seller delivers the goods to the loading port after the goods have passed the ship's rail. Additional costs arising from various situations that result in damage from the moment of delivery are the responsibility of the buyer company.

Cost insurance and freight (CIF) means that the seller delivered the goods to a loading port where the goods crossed the ship's rail. The seller (exporter) is obligated to pay the costs of transporting the goods to the specified destination and the price of the freight. However, the additional expenses caused by damage that occurs after the goods pass the handrail are the responsibility of the seller [35].

Multi- Depot Vehicle Routing Problem for Export Logistics

The MDVRP for export logistics was designed for companies that produce tile ceramics and export them to other countries. The shipping transactions of the company can be carried out from either the production factory or the distribution warehouses throughout the country. The products exported by the company are shipped on standard size palettes. The product types differ. In other words, although the products have different colors and features, the standard packaging dimensions are the same. In this study, the warehouses and customers discussed are shown on a map of Türkiye (Fig. 2).

The nodes shown in Figure 2 indicate Çanakkale Çan Depot, Yozgat Depot, İzmir Depot, Gemlik-Borusan Port, Haydarpaşa Port, İskenderun Port, İstanbul Ambarlı Port, İzmir Port, İzmit- Derince Port, Mersin Port, Halkalı Train Station, and Ankara, respectively.

The solution aims to develop a distribution plan that minimizes the total cost of the company according to different scenarios. In each scenario, the delivery method used for customers' orders exported by the company was changed,

Table 2. Buyer (B) / seller (S) cost distribution according to the incoterms chosen.

Operations	Incoterms			
	FAS	FOB	CFR	CIF
Packing	S	S	S	S
Loading containerization	S	S	S	S
Pre_carriage	S	S	S	S
Customs export formalities	S	S	S	S
Consolidation platform-departure	B	S/B	S	S
Principal transportation	B	B	S	S
Transportation insurance	B	B	B	S
Consolidation platform-arrival	B	B	B	B
Customs export formalities duties and taxes	B	B	B	B
Post carriage	B	B	B	B
Unloading	B	B	B	B

Figure 2. Depots and customer locations in Türkiye.

and the mathematical model was solved. For example, in the first scenario, products are distributed to the 5th node according to the FOB or FAS delivery method, (incoterms), whereas the second scenario is realized according to CIF delivery to the 5th node. In different scenarios, the company's delivery and road costs results were obtained by changing the methods of delivery to customers.

Proposed Mathematical Model

In this study, a mixed integer programming model was proposed to solve multi-depot, multi-product and heterogeneous fleet vehicle routing problem. The following assumptions were considered in this model.

- ✓ Each customer can be assigned to a single route (vehicle).
- ✓ The sum of customer demands on a route cannot exceed the capacity of the vehicle on that route.
- ✓ Sub tour elimination: All routes must include customer service to be considered complete.
- ✓ A vehicle can leave from a certain point.
- ✓ Each customer can receive services from a single route.
- ✓ Transportation costs are calculated according to the travelled distance. Each distance unit is also equal to a unit of cost.
- ✓ The sum of customer demands assigned to a warehouse should be less than the warehouse's capacity for each product.
- ✓ The location and number of warehouses are predetermined.
- ✓ A customer can be assigned to a warehouse only if there is a route from that warehouse to that customer.

Notations

Sets

j: customers
i: depots
k: vehicles
g: products
y: delivery terms

Parameters

c_{ij}: transportation cost from *i* to *j*,
m_{ig}: capacity for depot *i* and product *g*,
h_{ig}: holding cost for depot *i* and product *g*
q_{jg}: demand of customer *j* for product *g*,
v_k: vehicle capacity of *k*
s_y: incoterms cost for delivery terms *y*

Decision Variables

$$x_{ijk} = \begin{cases} 1, \text{if } i \text{ immediately precedes } j \text{ on route } k \\ 0, \text{otherwise} \end{cases}$$

$$z_{ij} = \begin{cases} 1, \text{if customer } j \text{ is alloted to the depot } i \\ 0, \text{otherwise} \end{cases}$$

U_{lk}: auxiliary variable for the sub-tour elimination constraint along route *k*

$$e_{yj} = \begin{cases} 1, \text{if customer } j \text{ is delivered by delivery terms y} \\ 0, \text{otherwise} \end{cases}$$

Mathematical Formulation

$$min \sum_{i\in I\cup J}\sum_{j\in I\cup J}\sum_{k\in K} c_{ij}\, x_{ijk} + \sum_{i\in I\cup J}\sum_{j\in J}\sum_{g\in G} h_{ig}\, q_{jg} z_{ij} + \sum_{g\in G}\sum_{y\in Y}\sum_{j\in J} q_{jg}\, e_{yj} s_y \quad (1)$$

$$\sum_{k\in K}\sum_{i\in I\cup J} x_{ijk} = 1 \qquad j \in J \quad (2)$$

$$\sum_{y\in Y} e_{yj} = 1 \qquad j \in J \quad (3)$$

$$\sum_{j\in I\cup J}\sum_{g\in G} q_{jg}\, x_{ijk} \le v_k \qquad k \in K \quad (4)$$

$$U_{lk} - U_{jk} + N x_{ijk} \le N - 1 \qquad l, j \in J, k \in K \quad (5)$$

$$\sum_{j\in I\cup J} x_{ijk} - \sum_{j\in I\cup J} x_{jik} = 0 \qquad k \in K, i \in I \cup J \quad (6)$$

$$\sum_{i\in I}\sum_{j\in J} x_{ijk} \le 1 \qquad k \in K \quad (7)$$

$$\sum_{j\in J} q_{jg} z_{ij} \le m_{ig} \qquad i \in I, g \in G \quad (8)$$

$$-z_{ij} + \sum (x_{ilk} + x_{ljk}) \leq 1 \qquad i \in I, j \in J, k \in K \tag{9}$$

$$x_{ijk} \in \{0,1\} \qquad i \in I, j \in J, k \in K \tag{10}$$

$$z_{ij} \in \{0,1\} \qquad i \in I, j \in J \tag{11}$$

$$e_{yj} \in \{0,1\} \qquad y \in Y, j \in J \tag{12}$$

$$U_{lk} \geq 0 \qquad l \in J, k \in K \tag{13}$$

The objective function is to minimize total costs, including transportation, holding and delivery terms (incoterms) costs (1). The transportation cost is obtained by multiplying the travel distance by the unit travel cost. The holding cost is obtained by multiplying the holding cost for each depot i, for product g, by the demand of customer j for product g to be sent. The Incoterms costs are calculated by multiplying the costs associated with the delivery terms by the number of deliveries to which these terms are applied, if chosen.

The cost of delivery terms is proportional to incoterms. For example, if an FOB is selected, the incoterms cost of the FOB includes packing, loading, containerizing, pre-carriage, and customs-export formalities. If CIF is selected, the incoterms cost for CIF includes packing, loading, containerization, pre-carriage, customs-export formalities, consolidation platform departure, and principal transportation.

Table 3. Incoterms for customers in case 1

2 depot- max 10 customers	Node label	Delivery method
node 1 and node 2	depot	
node 3	customer	internal
node 4	customer	export (FOB/ CFR)
node 5	customer	export (FAS/ FOB)
node 6	customer	export (CIF)
node 7	customer	export (FAS/ FOB/ CFR)
node 8	customer	export (FOB)
node 9	customer	export (FOB/ CFR)
node 10	customer	export (FAS)
node 11	customer	export (CFR/ CIF)
node 12	customer	internal
3 depot- max 9 customers		
node 1 and node 2 node 3	depot	
node 4	customer	export (FOB/ CFR)
node 5	customer	export (FAS/ FOB)
node 6	customer	export (CIF)
node 7	customer	export (FAS/ FOB/ CFR)
node 8	customer	export (FOB)
node 9	customer	export (FOB/ CFR)
node 10	customer	export (FAS)
node 11	customer	export (CFR/ CIF)
node 12	customer	internal
4 depot- max 8 customers		
node 1 and node 2 node 3 node 4	depot	
node 5	customer	export (FOB/ CFR)
node 6	customer	export (CIF)
node 7	customer	export (FAS/ FOB/ CFR)
node 8	customer	export (FOB)
node 9	customer	export (FOB/ CFR)
node 10	customer	export (FAS)
node 11	customer	export (CFR/ CIF)
node 12	customer	internal

Thus, unit incoterms costs must exceed for CFR compared to FOB. Constraint set (2) guarantees that each customer is assigned a single route. Constraint set (3) ensures that one delivery term must be selected for each customer. For example, for node 4 (customer), there are two options, FOB and CFR, while for node 5 (customer), there are also two options, FAS and FOB. For this constraint set, FAS, FOB, CFR, CIF, and internal customers are numbered 1, 2, 3, 4, 5 for the set of delivery terms "y", respectively. The capacity constraint for a set of vehicles is given by Constraint set (4). Sub-tour elimination constraint (5). The constraint set (6) shows the flow conservation. Constraint set (7) ensures that each route is served at most once. The capacity constraints for the depots are given in Constraint set (8). Constraint set (9) ensures that a customer can be assigned to a depot only if a route from that depot passes through that customer. The binary requirement on the decision variables is indicated in the constraint sets (10-12). Positive values of auxiliary variables are indicated in the constraint set (13).

COMPUTATIONAL EXPERIMENTS

Test Instances

Two different cases were presented for the derived test problems. These cases are handled as 2 depots, 3 depots, and 4 depots. The location and number of warehouses are predetermined. The number of warehouses and customers

Table 4. Incoterms for customers in case 2

2 depot- max 10 customers	Node label	Delivery method
node 1 and node 2	depot	
node 3	customer	internal
node 4	customer	export (CFR/ CIF)
node 5	customer	export (CIF)
node 6	customer	export (FAS/ FOB/ CFR)
node 7	customer	export (FOB/ CFR)
node 8	customer	export (CFR/ CIF)
node 9	customer	export (CFR)
node 10	customer	export (FOB/ CFR)
node 11	customer	export (CFR/ CIF)
node 12	customer	internal
3 depot- max 9 customers		
node 1 and node 2 node 3	depot	
node 4	customer	export (CFR/ CIF)
node 5	customer	export (CIF)
node 6	customer	export (FAS/ FOB/ CFR)
node 7	customer	export (FOB/ CFR)
node 8	customer	export (CFR/ CIF)
node 9	customer	export (CFR)
node 10	customer	export (FOB/ CFR)
node 11	customer	export (CFR/ CIF)
node 12	customer	internal
4 depot- max 8 customers		
node 1 and node 2 node 3 node 4	depot	
node 5	customer	export (CFR/ CIF)
node 6	customer	export (FAS/ FOB/ CFR)
node 7	customer	export (FOB/ CFR)
node 8	customer	export (CFR/ CIF)
node 9	customer	export (CFR)
node 10	customer	export (FOB/ CFR)
node 11	customer	export (CFR/ CIF)
node 12	customer	internal

may change according to different cases. In the first case, the delivery terms (incoterms) to be applied to the customer nodes and the related information about the internal and external customers are given in Table 3.

In the second case, the delivery terms (incoterms) to be applied to the customer nodes and the related information about the internal and external customers are given in Table 4.

In Tables 3 and 4, various delivery methods (Incoterms) were used according to the number of different warehouses and customers for testing. Generally, external customers are obtained from the 4th node (customer), and export delivery methods are defined for each of these customers. The internal customers are defined after the 11th node and before the 4th node. External customers can choose delivery methods that are preferred for each customer in cases 1 and 2. For example, when node 4 is defined as an external customer in Table 4, only FOB or CFR delivery methods can be used for this customer. In Table 5, when node 8 is defined as an external customer, only CFR or CIF delivery methods can be used with this customer. The case studies are handled using hypothetical data of parameters (such as demands, depot and vehicle capacities) and real road distances related transportation costs (https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi%3A10.7910%2FDVN%2FAFKIGA&version=DRAFT). 7 different product types and the demand for these products are considered between [500,5000] units, the demand of each demand point for each product varies between [0,500] units. Vehicle capacities are determined between [800,1500] units. A similar number of depots were used in some studies to derive case studies for MDVRP scenarios [36].

RESULTS AND DISCUSSION

The mathematical model was solved using the Gams Cplex solver. A Casper Excalibur computer with Intel(R) Core (TM) i7 processor, 32 GB RAM, and 4.50 GHz speed was used. Optimal solutions are obtained for each test problem. The optimality gap is zero with the proposed mathematical model.

Case 1: The solution results are shown in Table 5, including delivery terms used by the exporter company, the routes taken to send the products to the ports, the objective function value, and the solution time.

Table 5. Results of the test problems for 2 depots in case 1

Test problem	Depot	Node	Solution	Time (s)	Route	Incoterms
1	2	7	100,152	0.45	1-3-1 (vehicle 2) 1-7-5-1 (vehicle 3) 2-4-6-2 (vehicle 1)	Node 3=internal, Node 4= F0B, Node 5=FAS, Node 6= CIF, Node 7= FAS
2	2	8	116,906	0.54	1-4-1 (vehicle 4) 1-5-7-1 (vehicle 3) 2-3-8-2 (vehicle 1) 2-6-2 (vehicle 2)	Node 3=internal, Node 4= F0B, Node 5=FAS, Node 6= CIF, Node 7= FAS, Node 8=FOB
3	2	9	126,166	1.38	1-5-7-1 (vehicle 3) 1-9-4-1 (vehicle 4) 2-3-8-2 (vehicle 1) 2-6-2 (vehicle 2)	Node 3=internal, Node 4= F0B, Node 5=FAS, Node 6= CIF, Node 7= FAS, Node 8=FOB, Node 9=FOB
4	2	10	140,654	20.30	1-7-5-1 (vehicle 3) 1-9-4-1 (vehicle 4) 2-8-3-2 (vehicle 1) 2-10-6-2 (vehicle 5)	Node 3=internal, Node 4= F0B, Node 5=FAS, Node 6= CIF, Node 7= FAS, Node 8=FOB, Node 9=FOB, Node 10=FAS
5	2	11	158,951	790.32	1-4-1 (vehicle 2) 1-7-1 (vehicle 4) 1-11-5-9-1 (vehicle 3) 2-3-8-2 (vehicle 1) 2-6-10-2 (vehicle 5)	Node 3=internal, Node 4= F0B, Node 5=FAS, Node 6= CIF, Node 7= FAS, Node 8=FOB, Node 9=FOB, Node 10=FAS, Node 11=CFR
6	2	12	163,088	120.59	1-3-1 (vehicle 2) 1-5-9-1 (vehicle 4) 1-7-11-1 (vehicle 1) 2-4-8-12-2 (vehicle 3) 2-10-6-2 (vehicle 5)	Node 3=internal, Node 4= F0B, Node 5=FAS, Node 6= CIF, Node 7= FAS, Node 8=FOB, Node 9=FOB, Node 10=FAS, Node 11=CFR, Node 12= internal

In Table 5, test problems that include 2 depots and up to 13 customers were solved. As the number of customers increased from 7 to 12, the total costs also increased. For example, the test problem, which includes two depots and 10 nodes (8 customers), was solved, and it was found that all two depots were used for the distribution. The 7th and 5th nodes were delivered using the 1st and 3rd vehicles, respectively. The 9th and 4th nodes were distributed from the 1st warehouse via vehicle 4. In addition, delivery was made to the 3rd and 8th nodes with the 1st vehicle and to the 10th and 6th customers with the 5th vehicle from the 2nd depot. Node 3 was delivered to an internal customer. According to the solution result of the model, the allocation or determination is FOB for node 4, FAS for node 5, CIF for node 6, FAS for node 7, FOB for node 8, FOB for node 9, and FAS for node 10. The objective function value of this test problem was found to be a cost of 140,654. The currency unit is abbreviated by 'cu'. In solving test problems with 2 depots, in case 1, the solution time increased from 7 nodes to 12 nodes. Although the software was run for about 2 hours to solve test problem 13 (node 13), no results were obtained.

In the test problems with 3 depots (Table 6), goods were distributed from depots 2 and 3. This may be because the costs of the 1st depot are higher than those of the 3rd depot, and the 3rd depot is also more advantageous because it is closer to customers. When the solutions were examined, it was found that the total cost was 140,654 cu when the 1st and 2nd depots were used in a test problem with 2 depots and 10 customers (Table 5), while the total cost was 131,110 cu for the use of 2nd and 3rd depots (Table 6).

The 3rd and 4th depots were generally used for distribution in test problems with four depots, while the 2nd, 3rd, and 4th depots were used in test problems with twelve customers and four depots. For example, in the test problem with 4 depots and 12 nodes, nodes 10 and 6 are served from depot 2 and vehicle 1, node 8 is served from depot 3 and vehicle 4,

Table 6. Results of the test problems for 3 depots in case 1

Test problem	Depot	Node	Solution	Time (s)	Route	Incoterms
1	3	7	91,145	0.30	2-6-2 (vehicle 2) 3-4-3 (vehicle 1) 3-5-7-3 (vehicle 3)	Node 4=FOB, Node 5= FAS, Node 6=CIF, Node 7= FAS
2	3	8	107,469	0.29	2-6-2 (vehicle) 3-4-8-3 (vehicle 1) 3-7-5-3 (vehicle)	Node 4=FOB, Node 5= FAS, Node 6=CIF, Node 7= FAS, Node 8=FOB
3	3	9	116,622	7.11	2-6-2 (vehicle 1) 3-5-7-3 (vehicle 3) 3-8-3 (vehicle 2) 3-9-4-3 (vehicle 4)	Node 4=FOB, Node 5=FAS, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB
4	3	10	131,110	7.77	2-10-6-2 (vehicle 1) 3-7-5-3 (vehicle 3) 3-8-3 (vehicle 4) 3-9-4-3(vehicle 2)	Node 4=FOB, Node 5=FAS, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS
5	3	11	149,429	9.62	2-6-10-2 (vehicle 1) 3-4-9-3 (vehicle 2) 3-7-5-3 (vehicle 3) 3-11-8-3 (vehicle 4)	Node 4=FOB, Node 5=FAS, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS, Node 11=CFR
6	3	12	153,280	4711.80	2-10-6-2 (vehicle 1) 2-12-2 (vehicle 2) 3-8-3 (vehicle 4) 3-9-5-4-3 (vehicle 3) 3-11-7-3 (vehicle 5)	Node 4=FOB, Node 5=FAS, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS, Node 11=CFR, Node 12= internal
7	3	13	156,947	16137.03	2-10-6-2 (vehicle 5) 2-12-2 (vehicle 2) 3-8-13-3 (vehicle 4) 3-9-5-4-3 (vehicle 3) 3-11-7-3 (vehicle 1)	Node 4=FOB, Node 5=FAS, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS, Node 11=CFR, Node 12= internal, Node 13=internal

Table 7. Results of the test problems for 4 depots in Case 1

test problem	depot	node	solution	time (s)	route	incoterms
1	4	7	76,934	0.27	4-5-7-4 (vehicle 3) 4-6-4 (vehicle 2)	Node 5=FOB, Node 6=CIF, Node 7= FAS
2	4	8	93,2246	0.25	3-8-3 (vehicle 2) 4-6-4 (vehicle 1) 4-7-5-4 (vehicle 3)	Node 5= FOB, Node 6=CIF, Node 7= FAS, Node 8=FOB
3	4	9	10,2066	3.18	3-8-3 (vehicle 2) 4-5-7-4 (vehicle 3) 4-6-9-4 (vehicle 1)	Node 5=FOB, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB
4	4	10	11,5907	3.04	3-8-3 (vehicle 2) 4-5-7-4 (vehicle 3) 4-6-10-4 (vehicle 1) 4-9-4 (vehicle 4)	Node 5=FOB, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS
5	4	11	13,4204	48.93	3-8-9-3 (vehicle 2) 4-5-4 (vehicle 4) 4-6-10-4 (vehicle 3) 4-11-7-4 (vehicle 1)	Node 5=FOB, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS, Node 11=CFR
6	4	12	13,8262	48.25	2-10-6-2 (vehicle 1) 3-8-3 (vehicle 4) 4-7-11-4 (vehicle 5) 4-9-12-5-4 (vehicle 3)	Node 5=FOB, Node 6=CIF, Node 7=FAS, Node 8= FOB, Node 9= FOB Node 10=FAS, Node 11=CFR, Node 12= internal

Table 8. Results of the test problems for 2 depots in case 2

Test problem	Depot	Node	Solution	Time (s)	Route	Incoterms
1	2	7	116,652	0.25	1-3-1 (vehicle 2) 1-7-5-1 (vehicle 3) 2-4-6-2 (vehicle 1)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB
2	2	8	138,406	0.40	1-4-1 (vehicle 4) 1-5-7-1 (vehicle 3) 2-3-8-2 (vehicle 1) 2-6-2 (vehicle 2)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8= CFR
3	2	9	150,166	2.37	1-4-9-1 (vehicle 4) 1-5-7-1 (vehicle 3) 2-6-2 (vehicle 2) 2-8-3-2 (vehicle 1)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR
4	2	10	170,654	27.09	1-7-5-1 (vehicle 3) 1-9-4-1 (vehicle 4) 2-8-3-2 (vehicle 1) 2-10-6-2 (vehicle 5)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10= FOB
5	2	11	188,951	160.55	1-4-1 (vehicle 4) 1-7-1 (vehicle 2) 1-9-5-11-1 (vehicle 3) 2-8-3-2 (vehicle 5) 2-10-6-2 (vehicle 1)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10= FOB, Node 11= CFR
6	2	12	193,088	133.29	1-3-1 (vehicle 2) 1-5-9-1 (vehicle 4) 1-11-7-1 (vehicle 1) 2-6-10-2 (vehicle 5) 2-12-8-4-2 (vehicle 3)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10= FOB, Node 11= CFR, Node 12= internal

nodes 7 and 11 are served from depot 4 and vehicle 5, and nodes 5, 9, and 12 are served from depot 4 and vehicle 3.

Case 2: According to the second case, the solution results are shown, including delivery terms are used by the exporter company to send products to the ports, the routes are used, the objective function value, and the solution time.

In Table 8, test problems that include 2 depots and up to 13 customers were solved. As the number of customers increases from 7 customers to 12, the total costs also increased. For example, test problem which includes 2 depots and 10 nodes (8 customers) was solved, and it was found that all 2 depots were used for the distribution. The 7th and 5th nodes were served by the 3rd vehicle and the 1st depot. The 9th and 4th nodes were routed from the 1st depot via the 4th vehicle. In addition, delivery to the 3rd and 8th nodes were completed using the 1st vehicle from the 2nd depot, and the 10th and 6th customers were served using the 5th vehicle from the 2nd depot. Node 3 was delivered as an internal customer. According to the solution result of the model, CFR for node 4, CIF for node 5, FAS for node 6, FOB for node 7, CFR for node 8, CFR for node 9, and FOB for node 10 are obtained. The objective function value of this test problem was found to be 170,654 cu. In the solution of 2 depots test problems, according to case 2, the solution time increased as the number of nodes increased from 7 to 12. Although the software was run for about 2 hours for the solution of the test problem 13 (node 13), no results were obtained.

In Table 9, test problems that include 3 depots and up to 12 customers were solved. For example, the test problem, which includes 3 depots and 11 nodes (8 customers), was solved, and it was obtained that 2 depots (2nd and 3rd) were used for the distribution. The 10th and 6th nodes were delivered using the 2nd depot and vehicle 1; the 4th and 9th nodes were delivered using the 3rd depot and vehicle 2; the 5th and 7th nodes were delivered using the 3rd depot and vehicle 3; and the 11th and 8th nodes were delivered using the 3rd depot and vehicle 4. No solution was reached within a reasonable time for the test problem with 3 depots and 13 nodes after 2 hours. The Multi-Depot Vehicle Routing Problem (MDVRP) and the Vehicle Routing Problem with a Heterogeneous Fleet (HFVRP) are two well-known NP-hard problems that are generalized in the MDHFVRP; therefore, the MDHFVRP is NP-hard [37]. Consequently, even with the most effective MIP solvers like CPLEX, it is hard, if not impossible, to reach an optimal solution for large-scale problems in a reasonable amount of computation time [38]. Therefore, heuristic and meta-heuristic

Table 9. Results of the test problems for 3 depots in case 2

Test problem	Depot	Node	Solution	Time (s)	Route	Incoterms
1	3	7	107,625	0.26	2-6-2 (vehicle 2) 3-4-3 (vehicle1) 3-5-7-3 (vehicle 3)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB
2	3	8	128,969	0.30	2-6-2 (vehicle 2) 3-4-8-3 (vehicle 1) 3-7-5-3 (vehicle 3)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8= CFR
3	3	9	140,622	7.46	2-6-2 (vehicle 4) 3-5-7-3 (vehicle 3) 3-8-3 (vehicle 1) 3-9-4-3 (vehicle 2)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR
4	3	10	161,110	6.09	2-10-6-2 (vehicle 1) 3-7-5-3 (vehicle 3) 3-8-3 (vehicle 4) 3-9-4-3 (vehicle 2)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10= FOB
5	3	11	179,429	6.76	2-10-6-2 (vehicle 1) 3-4-9-3 (vehicle 2) 3-5-7-3 (vehicle 3) 3-11-8-3 (vehicle 4)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10= FOB, Node 11= CFR
6	3	12	183,280	3093.63	2-6-10-2 (vehicle 1) 2-12-2 (vehicle 4) 3-4-5-9-3 (vehicle 3) 3-7-11-3 (vehicle5) 3-8-3 (vehicle 2)	Node 3= internal, Node 4=CFR, Node 5= CIF, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10= FOB, Node 11= CFR, Node 12= internal

Table 10. Results of the test problems for 4 depots in case 2

Test problem	Depot	Node	Solution	Time (s)	Route	Incoterms
1	4	7	73,934	0.15	4-5-7-4 (vehicle 3) 4-6-4 (vehicle 2)	Node 5= CFR, Node 6=FAS, Node 7= FOB
2	4	8	95,246	0.29	3-8-3 (vehicle 2) 4-6-4 (vehicle 1) 4-7-5-4 (vehicle 3)	Node 5= CFR, Node 6=FAS, Node 7= FOB, Node 8=CFR
3	4	9	106,566	2.75	3-8-3 (vehicle 2) 4-5-7-4 (vehicle 3) 4-9-6-4 (vehicle 4)	Node 5= CFR, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR
4	4	10	126,407	4.33	3-8-3 (vehicle 2) 4-5-7-4 (vehicle 3) 4-6-10-4 (vehicle 4) 4-9-4 (vehicle 2)	Node 5= CFR, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10=FOB
5	4	11	144,704	45.21	3-8-9-3 (vehicle 4) 4-5-4 (vehicle 2) 4-7-11-4 (vehicle 1) 4-10-6-4 (vehicle 3)	Node 5= CFR, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10=FOB, Node 11=CFR
6	4	12	148,762	1216.25	2-6-10-2 (vehicle 5) 3-8-3 (vehicle 4) 4-9-12-5-4 (vehicle 3) 4-11-7-4 (vehicle 1)	Node 5= CFR, Node 6=FAS, Node 7= FOB, Node 8=CFR, Node 9=CFR, Node 10=FOB, Node 11=CFR, Node 12=internal

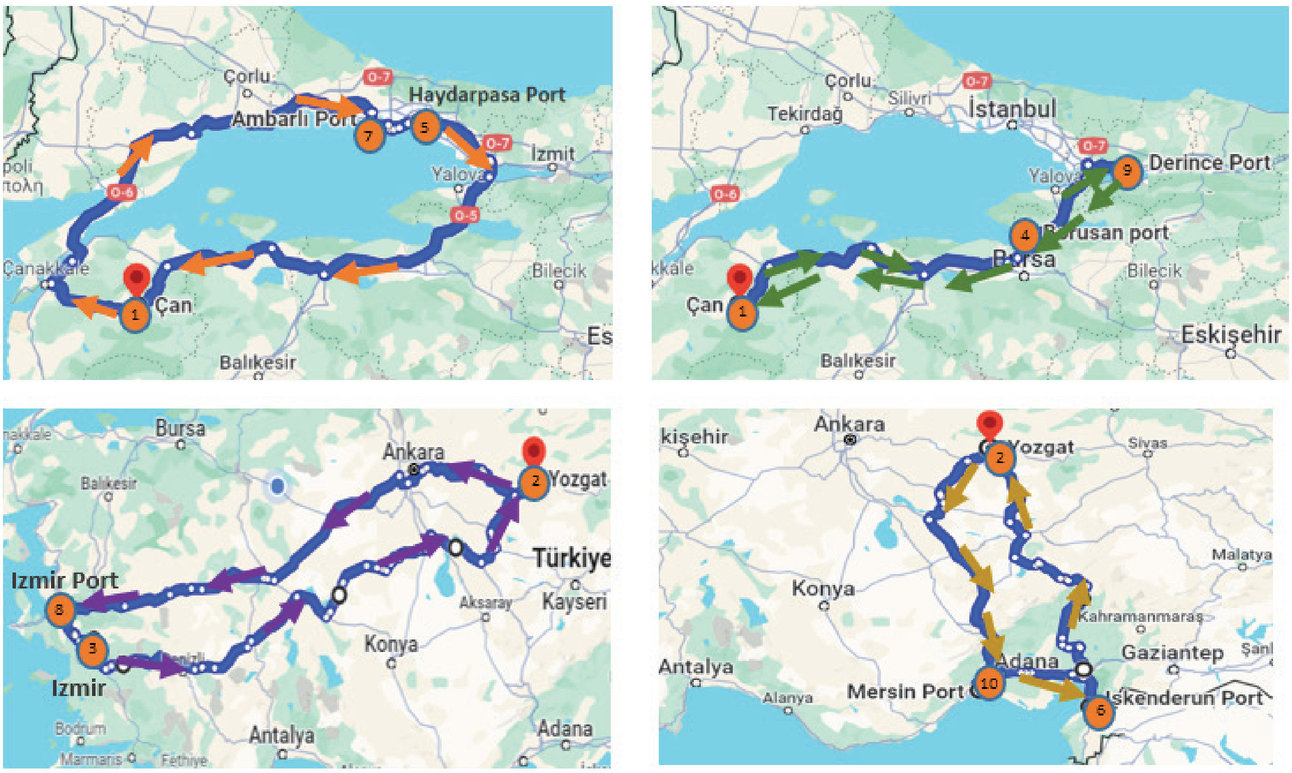

Figure 3. Solution to test problem 2 depot 10 nodes for case 2 on the Türkiye map.

algorithms are proposed to address this group of large-scale problems [39].

In Table 10, test problems featuring 4 depots and up to 12 customers were solved. For example, a test problem that includes 4 depots and 10 nodes (6 customers) was solved, and it was found that both depots (2nd and 3rd) were used for the distribution. The 3rd node, was delivered using the 3rd depot and vehicle 4, the 5th and 7th nodes, were delivered using the 4th depot and vehicle 3, the 6th and 10th nodes, were delivered using the 4th depot and vehicle 4, and the 9th node was delivered using the 4th depot and vehicle 2.

In Figure 3, the test problem which includes 2 depots and 10 nodes (8 customers) was solved. The 7th and 5th nodes were serviced by the 1st depot and 3rd vehicle (orange lines). The 9th and 4th nodes were serviced by the 4th vehicle from the 1st depot (green lines). In addition, delivery to the 3rd and 8th nodes were distributed using the 1st vehicle (purple lines) and the 10th and 6th customers using the 5th vehicle (yellow lines) from the 2nd depot.

The specified problem structure and mathematical model can be integrated into different industries, besides ceramic industry products. For example, its use in different sectors such as distribution of agricultural products [40] in exports (considering cold chain costs), distribution of automobile service parts [41], and distribution of consumer durable goods will provide convenience and ideas to logistics service providers or companies. Cold chain transportation equipment requires different vehicle types suitable for the conditions of the route. Therefore, the costs of cold chain transportation are significant for industrial products. Transportation practices and transportation costs of different industries will be useful to consider when determining new distribution models.

CONCLUSION

In this study, a multi-depot, multi-product and heterogeneous fleet vehicle routing problem with delivery methods and costs based on the responsibilities of the seller and buyer is considered. A distribution model is presented for companies with production facilities and warehouses in different regions to conduct export operations using incoterms delivery methods.

- Investigations were conducted in terms of distribution costs under different scenarios (in case of different delivery terms to different customers).
- Vehicle routes are determined using different delivery terms according to the depot's and customer locations of the manufacturers who deliver to international companies.
- It is observed how the distribution system works in the case of using vehicles of different capacities and product types.

In future research, heuristic and meta-heuristic algorithms can be used to solve large-scale test problems. In the multi-product problem structure, different palletization systems of different sizes can be considered. New applications can be realized for various sectors, such as automotive, agricultural products, and consumer durable products, by considering due dates and time windows.

AUTHORS' CONTRIBUTIONS

All authors contributed to the study. Problem description G.O.G and S.K. Design and implementation of the model G.O.G. Analyses of the results and discussion G.O.G and S.K. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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