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A multi-depot vehicle routing problem with time windows for daily planned maintenance and repair service planning

Günlük planlanmış bakım ve onarım servis planlaması için zaman pencereli bir çok depolu araç rotalama problemi

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Abstract

A compressor manufacturer producing in Kocaeli/Dilovası region makes vehicle routing and employee planning daily to fulfill the maintenance and repair requests of the Marmara region and its surroundings the next day. The service types and times are agreed upon with the customer before service planning. The vehicles and their respective operators for a given planning day are known, with the service personnel's starting and ending points being the residences. All the planned services must be satisfied in the time windows customers give. We approach the issue as a multi-depot vehicle routing problem with time windows (MDVRPTW) and construct a mixed-integer linear programming framework. The solution is deemed adequate in resolving the company's service planning predicament. To tackle large instances, we formulate a clustering algorithm that yields a proficient solution in a concise duration.

Keywords: Multi depot, Vehicle routing problem, Time window.

Özet

Kocaeli/Dilovası bölgesinde üretim yapan bir kompresör üreticisi, Marmara bölgesi ve çevresinin ertesi günkü bakım ve onarım talebini karşılamak için günlük olarak araç rotalama ve personel planlaması yapmaktadır. Servis planlamasından önce servis türleri ve süreleri müşteri ile kararlaştırılır. Servis personelinin başlangıç ve bitiş noktaları ikametgah adresleri olmak üzere, belirli bir planlama günü için araçlar ve ilgili operatörleri bilinmektedir. Tüm talepler, müşteriler tarafından verilen zaman pencerelerinde karşılanır. Problem, Zaman Pencereli Çok Depolu Araç Rotalama problemi (MDVRPTW) olarak ele alınmaktadır ve bir karma tamsayılı doğrusal programlama modeli geliştirilmiştir. Matematiksel model çözümü şirketin problemini çözmeye yeterlidir. Büyük örnekleri çözmek için, kısa sürede yeterli bir çözüm sağlayan bir kümeleme algoritması geliştirilmiştir.

Anahtar kelimeler: Çoklu depo, Araç rotalama problemi, Zaman penceresi.

1 Introduction

Dalgakıran Compressor, established in 1965, is a renowned manufacturer of industrial compressors in Turkey with operations in three plants in Sancaktepe, Istanbul. The company exports 70% of its products to over 130 countries through its international branches in Russia, the USA, Ukraine, and Germany. The company strongly emphasizes after-sales service, aiming to promptly address customer maintenance and repair requests through competent service personnel. After-sales service is critical to a company's marketing strategy and can significantly impact customer loyalty and satisfaction. In today's competitive market, where products are becoming increasingly similar, companies must focus on providing high-quality pre-sales, customer experience, and after-sales services. After-sales service includes free services such as a return policy, technical support, installation, software support, shipping, and basic warranty coverage for maintenance and repair. After-sales service can be a crucial differentiator for a company and heavily influences consumer purchasing decisions.

The importance of services and service businesses has been increasing recently. After-sale service activities cannot be overstated, as they are critical in maintaining customer satisfaction and building long-term relationships. Companies can demonstrate their commitment to customer satisfaction and gain a competitive advantage by providing prompt and practical support and addressing any issues that arise after a sale. At this point, after-sales services stand out as an essential factor, especially in durable consumer goods. Customer satisfaction and loyalty are ensured through after-sales services, which are activities that reduce potential problems during use and increase consumption value after the sale of products. Consumers are interested in the after-sales services offered with the product, especially when purchasing durable consumer goods and choose accordingly.

Dalgakıran realizes that after-sales services have an essential role in the preference of the product over other brands and in repeating the purchases once purchased. One of the aims of the company is to provide reliable after-sales service. After-sales service plans are done with the experience of planners using their developed intuitive vehicle routing algorithms. These approaches are time-consuming and error-prone. The primitive processes result in excessive traveling and unmet customer service demand, which means extra costs for companies. Optimal guidance of vehicles requires scientific

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work and expert opinion. Scientific methods are sufficient to overcome these problems.

The main aim of this paper is to examine the after-sales service planning problem and to find the best vehicle routes that provide less transportation for Dalgakıran Company. The service planning department decides the service routes of each vehicle, regarding the location of customers, service time windows given by customers, and the service type that can be provided by service personnel to reduce distances traveled by vehicle (transportation costs). Each vehicle is assigned to a specific serviceman, and the service tour starts and ends at the same point - the residence of the service personnel. The problem described above is the Multiple Depot Vehicle Routing Problem with Time Windows (MDVRPTW). In this problem, vehicles commence their journeys from a designated depot, abide by predetermined time windows while serving, and ultimately conclude their tours by returning to their point of origin. The MDVRPTW presents a more complex and demanding challenge than other forms of the VRP, mainly because of the inclusion of multiple depots, time windows, and the dynamic nature of the problem. Thus, solving the MDVRPTW requires sophisticated algorithms and optimization techniques.

We develop a mathematical model to solve the MDVRPTW given problem. The proposed model serves as an effective tool for improving the efficiency and effectiveness of the company's service operations. The company meets the demands of 10-15 customers daily. The mathematical model solution is sufficient to solve the company's problem. To solve large instances, we develop a clustering algorithm that clusters the customers regarding the service capacity of vehicles and provides a good, quick solution. The developed algorithm is an effective solution that works well when customers are high.

The remaining sections of this paper are organized as follows. Section 2 comprises the literature review and our original contributions. Section 3 provides a comprehensive definition of the problem at hand. The developed mathematical model and heuristic are given in Section 4. In Section 5, the computational experiments are presented. The subsequent sections will provide the conclusion and potential avenues for future research outlined in Section 6.

2 Literature review

The Vehicle Routing Problem (VRP) is a complex issue within integer programming, and finding the most optimal solutions can be a significant challenge. The Vehicle Routing Problem (VRP) is commonly acknowledged as one of the most complex challenges in integer programming and was proven to be NP-hard by Lenstra and Rinnooy Kan [1]. The Vehicle Routing Problem with Time Windows (VRPTW) is a widely recognized combinatorial optimization problem that involves serving customers in different geographical locations while adhering to specific time constraints [2]. The Multi Depot Vehicle Routing Problem with Time Windows (MDVRPTW) is an extension of the VRP that adds a layer of intricacy by integrating time windows and multiple depots, thereby establishing its NP-hardness in the strong sense [2].

MDVRPTW is an extension of the VRP that adds a layer of intricacy by integrating time windows and multiple depots [2]. MDVRPTW is a challenging combinatorial optimization problem, which requires the identification of the most efficient fleet routes that meet the delivery requirements of a given customer set while accounting for time window constraints across multiple depots situated at distinct locations [2]. Owing to the formidable computational complexity of achieving an optimal solution for the MDVRPTW, numerous heuristic methodologies have been devised to tackle this problem [3],[4]. Bea and Moon [3] developed the MDVRPTW model for scheduling delivery vehicles to minimize fixed costs, travel distance-related fees and labor costs. The authors develop a constructive heuristic approach with a genetic algorithm to identify the near-optimal solutions. Li et al. [4] study a new variant of MDVRPTW in which the depot where the end of vehicle services is flexible, enabling vehicles to conclude their routes at a different depot than their starting point. An integer programming model is developed, and an algorithm with adaptive local search is proposed. Lenstra and Rinnooy Kan [1] introduced a heuristic technique and a genetic algorithm to tackle the MDVRPTW, which considers the installation of vehicles and dual time constraints for customers. Numerous researchers, including Sim et al. [5] and Kim et al. [6], study the MDVRPTW and propose distinct heuristic algorithms to address this problem, such as the endosymbiotic evolutionary algorithm, ant colony algorithm, and genetic algorithm. These algorithms have been applied in the practical settings of logistics companies to find optimal solutions. Various heuristic methods such as local search, tabu search, genetic algorithm, and hierarchical hybrid meta-heuristic have been developed to resolve this problem.

The MDVRPTW (Multi-Depot Vehicle Routing Problem with Time Windows) is distinct from other variants of the VRP (Vehicle Routing Problem) in several ways.

- Multiple Depots: The MDVRPTW involves multiple depots, which adds complexity to the problem as vehicles must be assigned to specific depots, and routes must be optimized accordingly. Moreover, the complexity of the problem is exacerbated by the additional constraint that the vehicles initiate and terminate their courses at distinct locations,
- Time windows: Besides the usual constraints of the VRP, such as vehicle capacity and distance, the MDVRP also involves time windows. There are specific time intervals during which customers must be visited, adding an extra constraint to the problem,
- Dynamic nature: The MDVRPTW can also be dynamic, meaning that the customers and their demands can change over time. It requires a more adaptive and flexible approach to the problem, as the routes need to be adjusted in real-time to account for the changes,
- Optimization goals: The optimization goals in the MDVRPTW can also be different from those in other variants of the VRP. For instance, the optimization objective of the VRP can take on various forms, such as minimizing the overall travel time, maximizing the number of serviced customers, or minimizing the number of vehicles utilized.

The primary objective of the MDVRPTW is to identify the most efficient routes for the vehicles to serve customers while complying with time window constraints and minimizing the total cost of transportation [6]. The complexity of MDVRPTW further increases with the inclusion of heterogeneous service vehicles and additional service level constraints. MDVRPTW is intrinsically interconnected with other combinatorial optimization problems, notably the Location Routing Problem (LRP) [7]. The LRP revolves around pinpointing the most favorable locations for depots and their optimal operational timetables, taking into account the specific routes taken by the vehicles. The Fleet Size and Mix Vehicle Routing Problem (FSMVRP) is another variant that considers the presence of vehicles with varying fixed costs within a given fleet [8]. The Vehicle Routing Problem with Release Dates (VRPRD) is a recent extension to the Vehicle Routing Problem literature [8]. In this variant, the arrival time of products at the depot, known as the release date, is incorporated into the problem formulation as a crucial constraint.

The literature has addressed the issue of the skill level of technicians on board, particularly in the context of solving Heterogeneous Vehicle Routing Problems (HVRPs), such as technician routing and home care schedules [9]. Although many realistic attributes such as backhauls, multi-depots, split delivery, pickup and delivery, carbon emissions, site dependency, open routes, and time windows have been thoroughly investigated in the literature, the current problem under consideration distinguishes itself by centering on the optimization of dispatching technicians through skill matching, presenting a unique challenge [10]. A comparison between VRP versus MDVRP is shown in Figure 1.

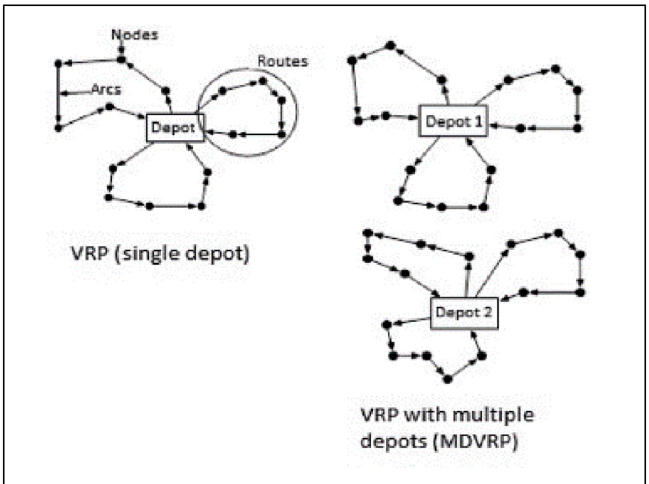

Figure 1. Comparison between VRP versus MDVRP.

3 Multi depot vehicle routing problem

The problem is defined regarding the necessary constraints and objectives to ensure the best solutions for the company's service routing operations. Each vehicle originates from the corresponding maintenance technician's residence and terminates at the technician's home after completing their service routes. This unique characteristic of the problem, in which each vehicle starts and ends at a different location, justifies using the term "multiple depots" in the problem's name, MDVRP, and with given time window constraints, the problem is classified as MDVRPTW.

First, there are planned maintenance offer agreements made with the customers, based on usage hours specific to the machine, apart from these repair requests, including part replacement and breakdown requests. The maintenance and repair order process is clarified between the company and the customer, depending on the customer's preference and conditions, agreed-on parts, and price issues. The date and appropriate time frame for maintenance and repair are negotiated with the customer. The after-sales service planning department combines maintenance and repair demands into a single-vehicle routing plan.

The coordination and execution of scheduled maintenance and customer repair requests are the responsibility of the planning department. The planned maintenance schedules are determined based on the usage of the machines, with maintenance intervals established at 3000 hours and 6000 hours. The maintenance times for different machine groups are standardized, considering the machine's size and KW information. The standard work times are calculated based on the size and workload of the compressors.

On each planning day, each vehicle and technician are allocated 10 hours (0-600 minutes). The starting points of the vehicles are the residence addresses of the employees, and the vehicles aim to provide service in a minimum way, starting from the first service points according to their proximity to customer locations. After completing their assigned delivery tasks, the vehicles in the MDVRPTW return to their designated depots or starting points. The distance and travel time between depots and customers are calculated using Google API integrated into the model, considering highway information for creating distance and travel time matrices.

The following assumptions are made.

- Every vehicle within the fleet is unrestricted by travel distance on its designated route and initiates and terminates its journey at the exact residential location, namely the depot.
- A vehicle can only visit a customer within the time window.
- Vehicle and service personnel can perform the services when the competence of the service personnel is sufficient.
- The service types and corresponding service durations are predetermined before the commencement of the vehicle routes.
- The data on the type of service that vehicles can provide customers and the duration of the services are known.

The location of the customers and residence of servicemen is shown in Figure 2.

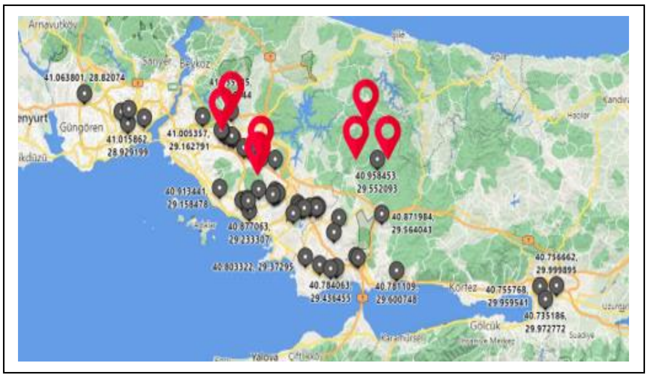

Figure 2. Location of customer and residence of servicemen.

4 Mathematical model formulation and solution approach

We present a comprehensive formulation of the MDVRPTW that applies to the real-world after-sales service planning operations of Dalgakıran Compressor Manufacturer Company.

The problem is formulated on an Euclidean Graph *G=(V, E)* where V denotes a collection of nodes, and E indicates a set of arcs or edges that connect node pairs. V is partitioned into two subsets: $V_c = V_1, V_2, \ldots, V_N$, which corresponds to the customers in need of service, and $V_d = V_{N+1}, \ldots, V_{N+M}$, which signifies the depots available for service. Each arc within the set E is assigned a cost function, distance metric, or travel time parameter, denoted by T_{ij}. Distances of these arcs are defined as $Dist_{ij}$, and Q_{ik} indicates whether the customer i can be served with vehicle k. The vehicles commence their routing operations from the respective depots and return to their respective depots upon completing their service operations. The primary objective of the problem is to determine a collection of vehicle routes that meet the following conditions: (i) every vehicle commences and completes its journey at the same depot, (ii) each customer receives service precisely once from a vehicle, and (iii) the overall distribution cost is minimized. The parameters and their respective definitions are provided below.

4.1 Mathematical model

The definition of parameters, decision variable parameters, and mathematical models are below.

Parameters

V_c	Set of customers' nodes, $V_c = (V_1, V_2, \ldots, V_N)$
V_d	Set of servicemen node, $V_d = (V_{(N+1)}, V_{(N+2)}, \ldots, V_{(N+M)})$
K	Sets of all vehicles k, (∀k ∈ K)
S_i	Service processing time of service requested by customers i (∀i∈N)
T_{ij}	Travel time from node i to node j (∀i, j ∈ N + M, i ≠ j)
$Dist_{ij}$	Distance between node i and node j (∀i, j ∈ N+M, i ≠j)
Q_{ik}	Indicate if vehicle k can serve customer i or not (∀i ∈ N, ∀k ∈ K)
E_i	Earliest time to visit the customer i (∀i ∈ N)
L_i	The latest time to visit the customer i (∀i ∈ N)
M	Big M

Decision Variables

$x_{ijk} \in \{0,1\}$	1, if vehicle k travels from node i to node j; 0, otherwise (∀i, j∈N+M, ∀k∈K)
$y_{ik} \in \{0, 1\}$	1, if node i is visited by vehicle k; 0, otherwise (∀i∈N, ∀k∈K)
$st_{ik} \in Z^+$	Service start time of vehicle k to customer i (∀i∈N+M, ∀k∈K)
$u_{ik} \in Z^+$	Auxiliary variable for sub-tour elimination (∀i∈N, ∀k∈K)

Objective Function

$$min \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \sum_{k \in K} Dist_{ij} x_{ijk} \quad (1)$$

The objective function (1) aims to minimize the aggregate distance traversed by all vehicles. Constraints (2) and (3) guarantee that each customer is served by a single vehicle. Constraints (4) and (5) indicate which vehicle visits the customer. Constraints (6) represent route continuity. All vehicles can only pass from one customer to another. Constraints (7) and (8) ensure the vehicle departs and returns to the exact depot location. Constraints (9) and Constraints (10) ensure that all vehicles start from their depots and return to their depots. Constraints (11) eliminate sub-tours. Constraints (12) calculate the service start time of each customer. Constraints (13) ensure that each vehicle can serve the client within the given time window. Constraints (14) satisfy that vehicle k can be assigned to customers i and j if the vehicle can serve both customers.

$$\sum_{i=1}^{N+M} \sum_{k \in K} x_{ijk} = 1 \quad (\forall j \in N) \quad (2)$$

$$\sum_{j=1}^{N+M} \sum_{k \in K} x_{ijk} = 1 \quad (\forall i \in N) \quad (3)$$

$$\sum_{j=1}^{N+M} x_{ijk} = y_{ik} \quad (\forall i \in N, \forall k \in K) \quad (4)$$

$$\sum_{j=1}^{N+M} x_{jik} = y_{ik} \quad (\forall i \in N, \forall k \in K) \quad (5)$$

$$\sum_{i=1}^{N+M} x_{ihk} - \sum_{j=1}^{N+M} x_{hjk} = 0 \quad (\forall k \in K, \forall h, N + \mathrm{M} \mid Q_{hk} = 1) \quad (6)$$

$$\sum_{i=N+1}^{N+M} \sum_{j=1}^{N} x_{ijk} \leq 1 \quad (\forall k \in K) \quad (7)$$

$$\sum_{j=N+1}^{N+M} \sum_{i=1}^{N} x_{ijk} \leq 1 \quad (\forall k \in K) \quad (8)$$

$$\sum_{j=1}^{N+M} x_{ijk} = 0 \quad (\forall k \in K, i = N + 1, .., N + M) \quad (9)$$

$$\sum_{i=1}^{N+M} x_{ijk} = 0 \quad (\forall k \in K, j = N + 1, .., N + M) \quad (10)$$

$$u_i - u_j + (\mathrm{N} + \mathrm{M})\, x_{ijk} \leq \mathrm{N} + \mathrm{M} - 1 \quad (\forall \mathrm{i}, \mathrm{j} \in \mathrm{N}, \forall \mathrm{k} \in \mathrm{K}) \quad (11)$$

$$st_{ik} + T_{ij} + S_i - \mathrm{M}\ (1 - x_{ijk}) \leq st_{jk} \quad (\forall \mathrm{i}, \mathrm{j} \in \mathrm{N}, \forall \mathrm{k} \in \mathrm{K}) \quad (12)$$

$$E_i \leq st_{ik} \leq L_i \quad (\forall \mathrm{i} \in \mathrm{N}, \forall \mathrm{k} \in \mathrm{K}) \quad (13)$$

$$x_{ijk} \leq \mathrm{M}\ Q_{ik}\, Q_{jk} \quad (\forall \mathrm{k} \in \mathrm{K}, \forall \mathrm{i}, \mathrm{j} \in \mathrm{N} \mid i \neq j) \quad (14)$$

4.2 Clustering algorithm

To address the increased complexity of the problem for larger-scale instances, we have developed a clustering algorithm to reduce the number of variables involved in solving large-scale problems. Customers are clustered to a specific depot while minimizing total transportation and satisfying total travel time allowed for a serviceman.

Parameters

V_c	Set of customers' nodes, $V_c = (V_1, V_2, \ldots, V_N)$
V_d	Set of servicemen' nodes, $V_d = (V_{(N+1)}, V_{(N+2)}, \ldots, V_{(N+M)})$
S_i	Service processing time of service requested by customers i ($\forall$i ∈ N)
mT	Maximum service time for a planning day
avT	Average traveling time between nodes
$Dist_{ij}$	Distance between node i and node j ($\forall$i, j ∈ N + M, i ≠ j)
Q_{ij}	Indicate if depot j can serve customer I or not ($\forall$i ∈ V_c, $\forall$j ∈ V_d)
M	Big M

Decision Variables

$Z_{ij} \in \{0, 1\}$ 1, if depot j serves customer i; 0, otherwise ($\forall$i∈ V_c, $\forall$j ∈ V_d)

Objective Function

$$minZ \sum_{i=1}^{N} \sum_{j=N+1}^{N+M} Dist_{ij} z_{ij} \tag{15}$$

Constraints (16) enforce that customers are assigned to only one vehicle. Constraints (17) ensure that the vehicles can only be assigned to customers if the vehicle and service personnel have the competencies to serve the customer. Constraints (18) enforce the vehicle's service time constraint to prevent violations.

$$\sum_{j=N+1}^{N+M} z_{ij} = 1 \quad (\forall i \in V_c) \tag{16}$$

$$z_{ij} \le M\, Q_{ij} \quad (\forall j \in V_d, \forall i \in V_c) \tag{17}$$

$$\sum_{i \in N} z_{ij}\ (S_i + \text{avT}) \le \text{mT} \quad (\forall j \in V_d) \tag{18}$$

The algorithm clusters customer nodes and minimizes the traveling distance regarding the servicemen's starting point while satisfying time constraints. After identifying the clusters, the location problem is transformed into a traveling salesman problem. The clusters obtained are given as inputs for the mathematical model. This approach provides a practical and viable solution, allowing the company to streamline its operations and efficiently meet the demands of a growing customer base.

5 Numerical examples and results

This section reports the findings of computational experiments on the real-world problem to evaluate the effectiveness of the mathematical model and clustering algorithm in terms of their ability to provide high-quality solutions and computational efficiency. The proposed mathematical model is implemented using the Gurobi Python Application Programming Interface (API) and solved using Gurobi Optimizer 10, a commercial optimization software. Each algorithmic model is allocated a time limit of 3600 seconds (1 hour) to generate solutions. All solutions are obtained using a Windows 11 operating system with an Intel Core i9-9880H 2.3 GHz processor with 64 GB RAM. The main objective of this investigation is to devise a mathematical framework capable of addressing the problem at hand.

The company meets the 3000-6000 hours periodic maintenance requests of 10-20 customers on average and the demand of 10-15 additional breakdown service customers on average. Initially, the desired output is successfully obtained when constructing the model based on data from 20 customers. When the customer demands increase, the mathematical model does not give a solution in an hour. The clustering approach reduces the number of variables involved. The clustering algorithm method is utilized to analyze a dataset of 20-30-40 customers to demonstrate the effectiveness of this approach, and the results are given in Table 1 below.

Table 1. Comparison of results of multi depot VRPTW and clustering algorithm.

		Mathematical Model			Clustering Algorithm	
Number of Customers	Number of Depot	Solution Time (sec)	Gap %	Best Bound (km)	Solution Time (sec)	Best Bound (km)
20	7	1652	-	570.40	0.75	882.50
30	7	3600	5.04	599.36	10.81	916.32
40	7	3600	31.2	695.91	135.23	1010.12

Applying this clustering approach generated efficient and flexible solutions for many customer problems. The results show that the algorithm successfully forms depot-customer-depot tours, ensuring job start times are scheduled within the specified time windows.

The primary objective of the developed model is to address a real-world problem faced by the company. The firm's daily maintenance operations and the model's solution were compared to ensure the algorithm's compatibility. A one-week plan was obtained from the company to conduct this analysis, and a day-by-day comparison was made between the plan and the model's solution. This comparison aims to assess the developed model's effectiveness in meeting the company's operational requirements by providing efficient solutions. The evaluation focuses on the model's ability to deliver solutions that align with the company's operational needs. The comparison involved examining the quality of the solutions generated by the model, the degree of adherence to the specified constraints and objectives, and the level of computational efficiency achieved. A rigorous and systematic approach was adopted to ensure the comparison's accuracy and reliability. The performance of the model was assessed based on multiple criteria, including the time taken to generate solutions, the accuracy of the results, the ability to handle various constraints and objectives, and the model's ease of use. The comparison results demonstrated that the developed model effectively addressed the company's operational challenges. The model generated high-quality solutions that met the company's requirements while adhering to the specified constraints and objectives. Additionally, the model achieved high computational efficiency, enabling it to handle large-scale problems within a reasonable timeframe.

A comprehensive analysis has been conducted to evaluate the breakdown and repair requests received by Dalgakıran Company from its customers. The research includes an assessment of the company's routing solution and the solution provided by the mathematical model. 5 days of data are examined to assess the performance of the developed algorithm in various customer scenarios. The results in Table 2 indicate that the developed algorithm and mathematical model consistently outperform the company's routing solution, showing an improvement ranging from 5 to 15 percent. Notably, these improvements become more significant when customers exceed 30. The mathematical model demonstrates effective performance up to a customer count of 20; however, for larger customer counts, additional support is required to obtain results. The model has been enhanced by including a clustering algorithm to address this challenge for improved support and performance. Table 2 provides a detailed comparison between the company's implemented solution, including the distance traveled, and the solution proposed by the mathematical model. The table visually represents the performance differences between the two approaches, highlighting the mathematical model's advantages in optimizing the routing process and reducing the distance traveled. By utilizing the mathematical model, Dalgakıran Company can benefit from improved efficiency and cost savings in their daily maintenance and repair operations. The model's ability to generate more optimized routes enhances the company's ability to meet customer demands within specified time windows while minimizing transportation costs.

Overall, the comparison confirmed the effectiveness of the developed model in addressing the real-world problem faced by the company. A day-by-day comparison is made between the company's plan and the algorithm's solution. The algorithm's proposed number of depots and total travel distance are much better than the company's plan in Table 2. The algorithm provides a flexible and efficient framework that can easily be integrated into the company's operations. The comparison results demonstrated the developed model's potential to enhance the efficiency and effectiveness of the company's maintenance and repair operations, thus improving customer satisfaction and increasing profitability.

6 Conclusion

Practitioners in the Turkish industry need to pay more attention to scientific methods and instead plan distribution routes in non-scientific ways, resulting in increased transportation costs and customer dissatisfaction. This research analyzes current industry VRPs that many companies suffer from disorganized after-sales service planning problems and intends to help everyday logistic operations for a high number of customers.

Solution methods have been developed for this real-life problem. An actual data set in Istanbul is used to reflect a real-life road network. The initial mathematical model developed addresses the vehicle routing problem of Dalgakıran Compressor Manufacturer Company. However, due to the complexity of the problem, particularly with an increasing number of customers, the mathematical model may not provide a reasonable solution; thus, a clustering algorithm is implemented to obtain solutions for larger-sized instances, which considers constraints such as customer distances and vehicle capacities. As the problem size increases, it has been observed that the mathematical model fails to generate results in a reasonable amount of time and with the desired quality.

5-days service planning and vehicle routing data was taken from the company and then compared with the solution of the model. In summary, the analysis demonstrates the effectiveness of the mathematical model in improving the company's routing solution for breakdown and repair services. The model's performance surpasses the company's solution, particularly in scenarios with more customers. By leveraging the model's capabilities, Dalgakıran Company can achieve greater operational efficiency, cost savings, and improved customer satisfaction.

The proposed algorithm can efficiently meet all the constraints outlined in the study where the number of customers is high. The mathematical model and clustering algorithm are highly adaptable to various situations without requiring adjustments. Considering the information gathered and produced for this research, it intends to contribute to the VRP literature through many good-quality solutions generated from the algorithm. The research enables academia and practitioners to observe the performance of a heuristic model that tries to solve a real-life case. The developed algorithm provides accuracy, simplicity, fastness, and flexibility.

7 Author contributions

Elif TORU contributed to the idea's conception, problem formulation, and literature review in the present study. In contrast, Görkem YILMAZ was responsible for evaluating the obtained results and analyzing the outcomes.

8 Approval from the ethics committee and statement of conflict of interest

Approval from an ethics committee is not deemed necessary for the present article. Furthermore, no conflicts of interest exist with any individuals or institutions mentioned in this work.

Table 2. Comparison of a weekly mathematical model solution with the factory's solution.

		Clustering Algorithm			Dalgakıran Planning		
Date	Number of Customers	Number of Depot	Solution Time(sec)	Distance (km)	Number of Depot	Distance (km)	Rate of Change
17.04.23	15	4	0.27	393.51	5	426.11	-7,7%
18.04.23	32	5	49.25	530.54	5	612.70	-13,4%
19.04.23	22	4	1.19	437.38	4	438.23	-0,2%
24.04.23	35	5	61.05	944.14	6	996.82	-5,3%
25.04.23	39	6	25.25	580.71	7	619.8	-9,2%

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