Sigma J Eng & Nat Sci 36 (3), 2018, 741-766

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

A GIS-BASED OPTIMIZATION METHOD FOR A VEHICLE ROUTING PROBLEM ARISING AT A SUPERMARKET STORE CHAIN

Eren ÖZCEYLAN*[1], Çağrı KOÇ[2], Mehmet ERBAŞ[3]

[1]*Gaziantep University, Department of Industrial Engineering, GAZİANTEP;* ORCID: 0000-0002-5213-6335
[2]*Social Sciences University of Ankara, Department of Business Administration, ANKARA;*
ORCID: 0000-0002-7377-204X
[3]*Ministry of National Defense, General Directorate of Mapping, ANKARA*; ORCID: 0000-0002-3002-6135

Received: 24.02.2018 Revised: 23.05.2018 Accepted: 30.07.2018

ABSTRACT

This paper describes a Multi-Trip Heterogeneous Fixed Fleet Vehicle Routing Problem (MTHFFVRP) arising at one of the major retail chain in Turkey. The paper presents a GIS-based optimization method, based on a tabu search algorithm, that can be used to store, analyze and visualize all data as well as model solutions in geographic format. The solution method is applied on a real dataset of the supermarket store chain operates in Turkey. The paper presents computational and managerial results by analyzing the trade-offs between various parameters such as demand, number of vehicles, vehicle speed and capacity, and also a single-trip version of the problem. According to the one of the results, the total en-route time is increased by 5.18%, 4.25% and 1.82%, when the capacity of each vehicle type is decreased by 30%, 20% and 10%, respectively.
Keywords: Geographical information system, vehicle routing, multi-trip, heterogeneous fleet, tabu search.

1. INTRODUCTION

Fulfilling consumer demand for diverse and premium products is a challenge in logistics operations. A key strategy to increase the number of customers served and the margin and the basket size in many businesses is to offer premium services and a variety of products that meet the needs and desires of consumers (Yanik et al., 2014). In the classical Vehicle Routing Problem (VRP), the aim is to determine an optimal routing plan for a fleet of homogeneous vehicles to serve a set of customers, such that each vehicle route starts and ends at the depot, each customer is visited once by one vehicle, and some side constraints are satisfied. In the last sixty years, many variants and extensions of the VRP have intensively studied in the literature (Laporte, 2009; Toth and Vigo, 2014). For example, Yu et al. (2013) proposed an improved ant colony algorithm to solve the dynamic multi-depot VRP. Cattaruzza et al. (2014) developed an iterated local search algorithm for the multi-commodity multi-trip VRP with time windows. Koç et al. (2015) developed a unified evolutionary algorithm to solve four variants of the heterogeneous VRP with time windows, including the fixed fleet. Crainic et al. (2015) studied the multi-zone multi-trip VRP with time windows. The authors developed a decomposition-based heuristic as well as

* Corresponding Author: e-mail: erenozceylan@gmail.com, tel: (342) 317 26 18

lower-bound procedures. Koç et al. (2015) studied the green VRP and developed an exact algorithm based on branch-and-cut. Min et al. (2016) studied a model-based decision support system to solve routing and scheduling problems under hours of service regulations. The multi-period fleet size and mix VRP is studied by Pasha et al. (2016) where the authors proposed simple heuristics including a tabu search. Cust´odio and Oliveira (2006) considered a real-world application concerning the distribution in Portugal of frozen products of a world-wide food and beverage company. The authors considered integrating inventory management and vehicle routes design.

In most practical distribution problems, heterogeneous fleet of vehicles are used to serve for customer demands (Baldacci et al., 2008; Koç et al., 2016). Fleet dimensioning or composition is a common problem in industry. Fleet dimensioning decisions predominantly involve choosing the number and types of vehicles to be used, where the latter choice is often characterized by vehicle capacities. These decisions are affected by several market variables such as transportation rates, transportation costs and expected demand. In the multi-trip VRP, vehicles can perform several trips per day, because of their limited number and capacity (Olivera and Viera, 2007; Cattaruzza et al., 2014).

Several Geographical Information System (GIS)-based solution methods have been used to solve several optimization problems and also for the VRP and its variants. Casas et al. (2007) developed an automated network generation procedure for routing of unmanned aerial vehicles in a GIS environment. Bozkaya et al. (2010) studied the competitive multi-facility location-routing problem and presented a hybrid heuristic algorithm. Genetic algorithm is used for the location part, and tabu search of GIS-based solution method is used for the VRP part. The authors applied the method on a case study arising at a supermarket store chain in Istanbul, Turkey. Samanlioglu (2013) developed a multi-objective location-routing mathematical model and implemented it in the Marmara region of Turkey. The author used a GIS software to obtain the data related to the Marmara region. Krichen et al. (2014) presented a GIS solution method to solve the VRP with loading and distance constraints. Yanik et al. (2014) studied the capacitated VRP with multiple pickup, single delivery and time windows. The authors developed a hybrid metaheuristic approach that integrates a genetic algorithm for vendor selection and allocation, and a GIS-based solution method which uses a modified savings algorithm for the routing part. Demirel et al. (2017) designed a spatiotemporal model for detecting the interaction between accessibility and land use before implementing a transport infrastructure investment and after its completion. In order to test the designed GIS-based model, a study area composed of eleven districts with high traffic density is selected at the European side of Istanbul. Fried et al. (2018) analyzed inter-ounty grain trucking in the grain supply chain utilizing ArcGISs network analyst. The model is used to further inform an ongoing infrastructure development project in the Twin Cities metro area by contextualizing road usage within the economic framework of the grain supply chain.

This paper is concerned with the joint Multi-Trip Heterogeneous Fixed Fleet VRP (MTHFFVRP). To our knowledge, Prins (2002) is the only author who studied the MTHFFVRP. Without proposing any mathematical model, the author developed several heuristics, namely sequential heuristics, a new merge heuristic, steepest descent local search and tabu search. The heuristic is applied to the case of a furniture manufacturer located near Nantes on the Atlantic coast of France, with 775 destination stores and 71 trucks.

In this paper, we first formally define the MTHFFVRP and propose a mixed integer programming formulation. To solve the MTHFFVRP, we present a GIS-based solution method employs a tabu search algorithm which can be used to store, analyze and visualize all data as well as model solutions in geographic format. We then considered a real dataset of a company which is one of the major supermarket store chain in Turkey. We finally provide several managerial insights by exploring the trade-offs between various parameters such as demand, number of vehicles, vehicle speed and capacity, and also single-trip problem extension.

The remainder of this paper is structured as follows. Section 2 formally defines the problem and presents a mathematical formulation. Section 3 provides a detailed description of the solution methodology. Section 4 presents a case study and the solutions we propose. Section 5 presents the conclusions.

2. PROBLEM DEFINITION AND MATHEMATICAL FORMULATION

The MTHFFVRP is defined on a complete directed graph $G = (N, A)$, where $A = \{(i, j): i \in N, j \in N, i \neq j\}$ is the set of arcs. $N = 0 \cup N_c$ is a set of nodes in which "0" is the depot node and N_c is a set of shop nodes. Each arc $(i, j) \in A$ has a nonnegative distance d_{ij}. The distance matrix is asymmetric if for some pair (i, j), $d_{ij} \neq d_{ji}$. Each arc $(i, j) \in A$ has a nonnegative travel time c_{ij} which is calculated as $c_{ij} = d_{ij}$/Speed. Each shop $i \in N_c$ has a demand q_i and a service time p_i. The index set of vehicle types is denoted by H and for each vehicle type a fixed number of limited identical vehicles m^h are available. The index set of routes is denoted by $R = \{1, \ldots, r, ,,,\}$. The capacity of a vehicle of type $h \in H$ is denoted by Q^h. The maximum allowed working duration is T_{max} for each vehicle.

In the MTHFFVRP, one considers a fixed fleet of heterogeneous vehicles with various capacities as well as a set of shops with known demands. The problem consists of determining a set of vehicle routes such that all vehicles start and end their routes at the depot, each shop is visited exactly once by a vehicle, and the load of each vehicle does not exceed its capacity. Vehicles can perform several trips per day. Figure 1 presents an illustration of the MTHFFVRP, where Lightduty vehicle only serves to Route 1, Medium-duty vehicle serves to Routes 2 and 3, and finally Heavy-duty vehicle only serves to Route 4.

To formulate the MTHFFVRP, we define the following decision variables. Let x^h_{ijr} be equal to 1 if a vehicle of type $h \in H$ travels directly from node i to node j on route $r \in R$. Let f^h_{ijr} be the amount of commodity flowing on arc $(i, j) \in A$ by a vehicle of type $h \in H$ on route $r \in R$.

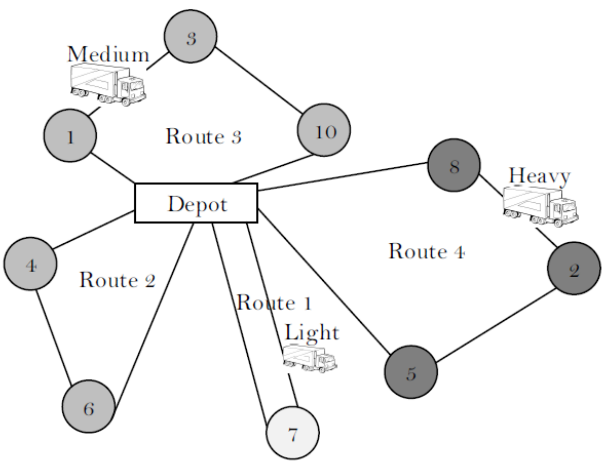


Figure 1. An illustration of the MTHFFVRP.

$$\text{Minimize} \sum_{h\in\mathcal{H}} \sum_{(i,j)\in\mathcal{A}} \sum_{r\in\mathcal{R}} c_{ij} x_{ijr}^h \qquad (1)$$

subject to

$$\sum_{j\in\mathcal{N}_c} x_{0j1}^h \leq m^h \qquad h \in \mathcal{H} \qquad (2)$$

$$\sum_{h\in\mathcal{H}} \sum_{j\in\mathcal{N}} \sum_{r\in\mathcal{R}} x_{ijr}^h = 1 \qquad i \in \mathcal{N}_c \qquad (3)$$

$$\sum_{h\in\mathcal{H}} \sum_{i\in\mathcal{N}} \sum_{r\in\mathcal{R}} x_{ijr}^h = 1 \qquad j \in \mathcal{N}_c \qquad (4)$$

$$\sum_{h\in\mathcal{H}} \sum_{j\in\mathcal{N}_c} x_{0jr}^h \geq \sum_{h\in\mathcal{H}} \sum_{j\in\mathcal{N}_c} x_{0j,r+1}^h \qquad r \in \mathcal{R} : r < |\mathcal{R}| \qquad (5)$$

$$\sum_{h\in\mathcal{H}} \sum_{j\in\mathcal{N}} \sum_{r\in\mathcal{R}} f_{jir}^h - \sum_{h\in\mathcal{H}} \sum_{j\in\mathcal{N}} \sum_{r\in\mathcal{R}} f_{ijr}^h = q_i \qquad i \in \mathcal{N}_c \qquad (6)$$

$$q_j x_{ijr}^h \leq f_{ijr}^h \leq (Q^h - q_i) x_{ijr}^h \qquad (i,j) \in \mathcal{A}, h \in \mathcal{H}, r \in \mathcal{R} \qquad (7)$$

$$x_{ijr}^h + \sum_{q\in\mathcal{H}, q\neq h} \sum_{u\in\mathcal{N}, j\neq u} x_{jur}^q \leq 1 \qquad h \in \mathcal{H}, i \in \mathcal{N}, j \in \mathcal{N}_c, i \neq j, r \in \mathcal{R} \qquad (8)$$

$$\sum_{(i,j)\in\mathcal{N}} \sum_{r\in\mathcal{R}} (c_{ij} + p_j) x_{ijr}^h \leq T_{max} \qquad h \in \mathcal{H} \qquad (9)$$

$$x_{ijr}^h \in \{0,1\} \qquad (i,j) \in \mathcal{A}, h \in \mathcal{H}, r \in \mathcal{R} \qquad (10)$$

$$f_{ijr}^h \geq 0 \qquad (i,j) \in \mathcal{A}, h \in \mathcal{H}, r \in \mathcal{R}. \qquad (11)$$

The objective function (1) minimizes the total en-route time. Constraints (2) bounds the numberof vehicles for each type. Constraints (3) and (4) ensure that each customer is visited exactly once. Constraints (5) impose that a vehicle cannot start the next route (r + 1) before finishing the router. Constraints (6) and (7) define the flows. Constraints (8) state that each customer is assigned to only one vehicle type. Constraints (9) ensure that the total travel and service times cannot exceed the maximum allowed working duration. Finally, constraints (10) and (11) enforce the integralityand nonnegativity restrictions on the variables.

The formulation presented above is that of a multi-trip heterogeneous fixed fleet VRP, which is hard to solve optimally as it requires the joint solution several difficult subproblems. To overcome this barrier, we present a GIS-based solution method in the next section.

3. SOLUTION METHODOLOGY

The literature of solution methods for the VRP is extensive with many commercial applications. We choose to use the ArcGIS software platform commercial GIS package for this purpose and also for building our GIS-based decision support framework. The ArcGIS is commonly used in many broad areas where spatially-enabled data need to be stored, retrieved, analyzed, visualized and even served online ArcGIS (2016).

In this paper, we first use the ArcGIS as a platform to store all MTHFFVRP data in geographic format and visualize them as well as the solutions we obtain through our heuristic approach. We then use it for running the Network Analyst Extension repeatedly to solve the MTHFFVRP. The Network Analyst Extension allows us to define the problem and specify its parameters such as costs, demands, vehicle capacities, network restrictions, and type of output. Figure 2 shows several examples from the interface of the Network Analyst.

For the MTHFFVRP, a tabu search metaheuristic is used by the ArcGIS where it follows the classical tabu search principles such as non-improving solutions are accepted along the way, but cycling of solutions are avoided using tabu lists and tabu tenure parameters (see Glover and Laguna, 1998).

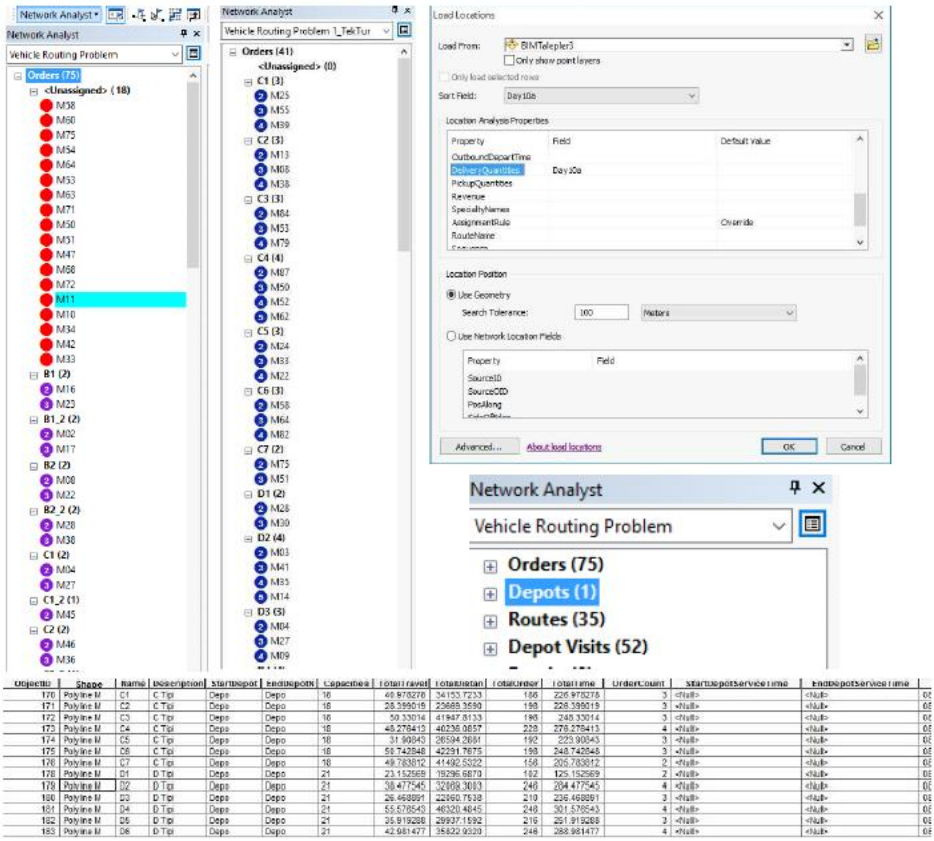


Figure 2. Several examples from the Network Analyst interface.

In the initialization phase, the ArcGIS first creates an origin-destination matrix of shortest travel costs between all locations that must be visited by a route. It then generates a feasible initial solution by inserting each location one at a time into the most suitable route. In the improvement phase, the algorithm aims to obtain better solution by applying the following three procedures.

- Changing the sequence nodes on a single route.
- Moving a single node from its current route to a better route.
- Swapping two nodes between their respective routes.

For further details about the ArcGIS, the Network Analyst extension and its application on the VRP, but not much details on the mechanics of the metaheuristic algorithm since solver is proprietary software, the reader is referred to the ArcGIS (2016).

4. A CASE STUDY

In this section, we present an application of the solution method on a case study arising in one of the major supermarket store chain in Turkey. We will first describe the case study in more detail, including the input data used, and then present the associated results obtained with the ArcGIS.

4.1. Input data

The company, BİM Inc., is known for offering a limited range of basic food items and consumer goods at competitive prices but with highest quality. BİM Inc. limits its product portfolio to approximately 600 items and aims at having diverse private label products. Products that are offered to consumers at the stores are selected in such a way that they satisfy 80% of the basic daily requirements of a household. Products are displayed on pallets and not on shelves in such a way as to provide easy access for the customer. It makes sure that customers reach to what they need without getting lost between huge shelves and lanes. At stores, they do not cater to fancy interior designs or expensive product marketing, instead these savings appear as reduced prices for their products. Stores have a minimalist interior design, simple systems with store-related costs kept at a minimum. Store sizes, positioning, lighting systems and direction signs have been designed to reflect a cozy and comfortable shopping atmosphere. BİM Inc. aims to provide a non-stressful and no hassle environment for customers. In terms of product selection and pricing, the company has employed a detailed and well-thought out mode of operation. Products that are offered to consumers at the stores are selected in such a way that they satisfy the basic Daily requirements of a household. BİM Inc. carries out effective controls on quality standards, thus assisting customers to buy products at the most reasonable price possible. BİM Inc. is the Pioneer of this discount store model in Turkey where it began in 1995 with 21 stores and by the end of 2016 had reached 5530 stores, making it the country's leading food retailer. For more than twenty years, BİM Inc. continued to pursue the policy of opening new stores and continuously increase its turnover. BİM Inc. does not offer franchises, all stores are owned and operated by the company itself (BİM Inc., 2017).

BİM Inc. aims to speed up decision-making and implementation processes by establishing a welldesigned logistic network between depots and stores. In this study, we consider a depot and 90 stores which are located in the city of Gaziantep (see Figure 3). The locations of the depot and 90 stores are illustrated in Figure 4. Gaziantep with its 1,975,302. population in 2016 is the 8th most crowded city of Turkey. The city is an important commercial and industrial center for Turkey and considered stores are located in two districts cover 85% of total population of Gaziantep. BİM Inc. has four types of vehicles, A, B, C and D, each with a fixed number. The details about the current vehicle fleet is given in Table 1. The demand of each store is expressed as pallet and each vehicle are designed to satisfy these specific store demands. BİM Inc. has variable number of orders from stores which can be seen as several benchmark instances in this study. In total, there are 10 benchmark instances which includes from 36 to 75 shops. Each shop has a service time which includes the unloading time (6 minutes per pallet), and parking time and handling paperwork for shipment (30 minutes per shop). As a company policy, the maximum allowed working duration for each vehicle is 6 hours. Furthermore, the vehicle speed is fixed at 50 km/h.

We use the real network distances when we computing the cij values on each arc $(i, j) \in A$. Therefore, it is possible that $c_{ij} \neq c_{ji}$, i.e., asymmetric, which is illustrated in Figure 5. In Figure 5.a, the distance from shop MO5 to M62 is 1116.86 meters. On the other hand, in Figure 5.b, the distance from shop MO5 to M62 is 882.13 meters.

Table 1. The details of the vehicle fleet.

Type	Capasity (pallets)	Number
A	6	2
B	15	2
C	18	8
D	21	6

Figure 3. The location of city of Gaziantep in Turkey (Google Maps, 2017).

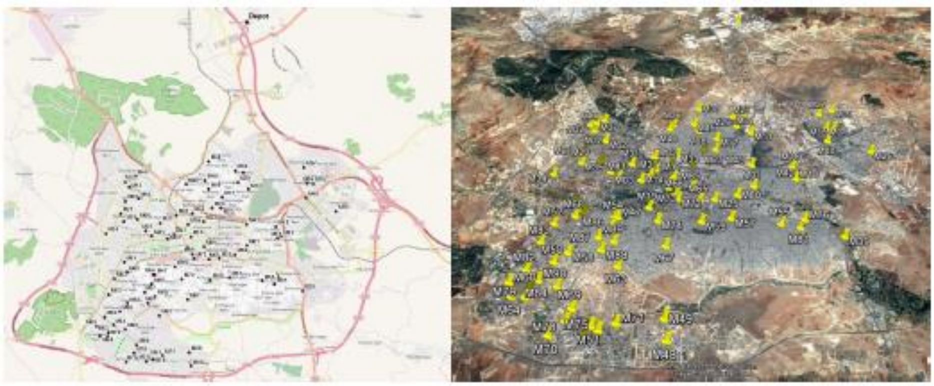
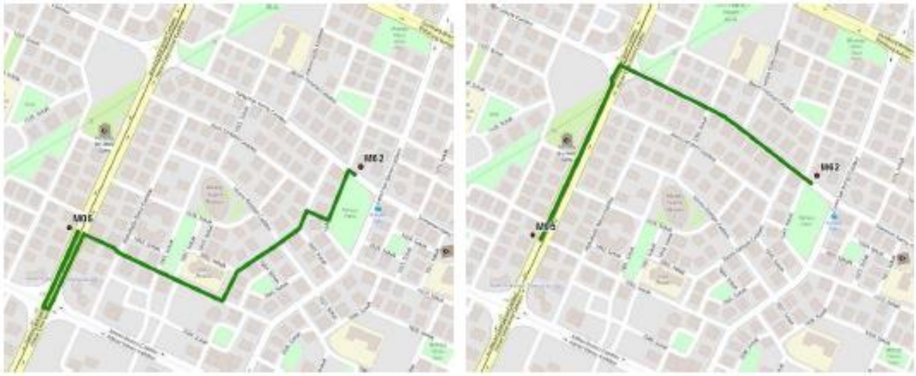


Figure 4. Locations of the depot and shops.



a) b)

Figure 5. Asymmetric paths between two nodes.

4.2. Computational experiments and analyses

We now present the results of our computational experiments. All experiments were conducted on a server with an Intel Core i7 CPU 3.07 Ghz processor. All solutions are solved less than 5 CPU seconds.

The analysis of the ArcGIS for the case study has considered fixed parameters, such as store demands or number of available vehicles. In our experiments, we will explore the effects of possible changes in the values of the main parameters on the total cost of the system. In particular, we will investigate whether the solution method yields cost-effective solutionswhen there is growth in the values of these parameters. The aim of the computational experiments is sixfold; 1) to solve the problem described in Section 2, and in particular to empirically calculate the effect of any changes in: 2) the shop demand, 3) vehicle capacity, 4) number of vehicles, 5) single-trip, and 6) vehicle speed.

4.2.1. Results obtained on the instances

Table 2 presents the average results obtained on benchmark instances of the BİM Inc.. The first column shows the instance name. The other columns display the number of shops (jNcj), fleet composition, vehicle capacity utilization rate, the total distance in kilometers, total travel time in minutes, total en-route time in minutes, and finally total CPU time in minutes. In column “Fleet composition”, shows the actual number of vehicles used where the letters A–D correspond to the vehicle types and the next number denote the number of each type of vehicle used. For example, “A2 B1” indicates that two vehicles of type A and one vehicle of type B are used in the solution. Vehicle capacity utilization rate displays the average percentage capacity utilization of the vehicle fleet, which is calculated as 100 (total demand of route)/(capacity of the vehicle) for each vehicle. Figure 6 presents an illustration of the routes of the instance Gaziantep-BIM-10.

Table 2 shows that for instances Gaziantep-BIM-1 to Gaziantep-BIM-8, mostly C and D vehicle types frequently used which indicates that types of vehicles are more suitable for medium-size instances. However, for large-size instances (Gaziantep-BIM-9 and Gaziantep-BIM-10) all vehicle types are frequently used since the shop demand requires larger fleet size. One can see that all computation times are below 0.15 seconds, which is quite fast for a problem that has rich VRP characteristic.

Table 2. Detailed results on 10 instances.

Instance	$\|N_c\|$	Fleet composition	Vehicle capacity utilization rate	Total distance (km)	Total travel time (min)	Total en-route time (min)	CPU time (min)
Gaziantep-BIM-1	41	C7 D6	92.06	435.89	523.00	3145.00	0.08
Gaziantep-BIM-2	37	B1 C4 D6	94.84	370.00	443.94	2765.94	0.07
Gaziantep-BIM-3	37	B1 C4 D6	95.31	365.02	437.97	2765.97	0.07
Gaziantep-BIM-4	37	C5 D6	95.37	369.00	442.74	2788.74	0.07
Gaziantep-BIM-5	36	A1 B1 C5 D5	94.44	403.29	483.87	2787.87	0.07
Gaziantep-BIM-6	40	C6 D6	96.58	416.93	500.24	3050.24	0.08
Gaziantep-BIM-7	42	B1 C4 D6	94.37	363.02	435.56	2871.56	0.07
Gaziantep-BIM-8	50	B1 C8 D6	93.33	449.21	538.98	3634.98	0.08
Gaziantep-BIM-9	70	A1 B2 C8 D6	78.96	826.14	991.22	5365.22	0.12
Gaziantep-BIM-10	75	A2 B2 C8 D6	81.35	951.21	1141.28	5851.28	0.14

Figure 6. Illustration of routes of the Gaziantep-BIM-10 instance.

4.2.2. The effect of the shop demand

In this section, we investigate the effect of the shop demand on solution quality. To do so, we decrease and increase the demand of each shop by 10%, 20%, and 30%. Table 3 presents the average results for these experiments. The column Dev (%) shows the percentage deviation in total en-route time of the each scenario over the base case. The detailed results of these experiments can be found in the Appendix. Figures 7 and 8 show an illustration of the effect of the shop demand on total distance and on vehicle capacity utilization, respectively.

Table 3 indicates that the total en-route time is decreased by -21.56%, -13.37% and -6.77%, when the shop demand is decreased by 30%, 20% and 10%, respectively. Similarly, the total en-route time increased by 7.24%, 10.88% and 15.09%, when the shop demand is increased by 10%, 20% and 20%, respectively. It is important to indicate that 10%, 20% or 30% increases in shop demand result in infeasible solutions for large-size (Gaziantep-BIM-9 and Gaziantep-BIM-10) instances. In other words, the vehicle fleet becomes insufficient when the total shop demand is higher than the base case. It is interesting to note that the same amount of increase or decrease in shop demand, do not result in very similar change in solution. For example, when we decrease the shop demand by 30%, the total en-route time is decreased by -21.56% which is almost 7% higher than the 30% increase case. As can be clearly seen in Table 3 and Figure 7, any changes in shop demand directly effects en-route time, travel time, as well as traveled distance in similar manner.

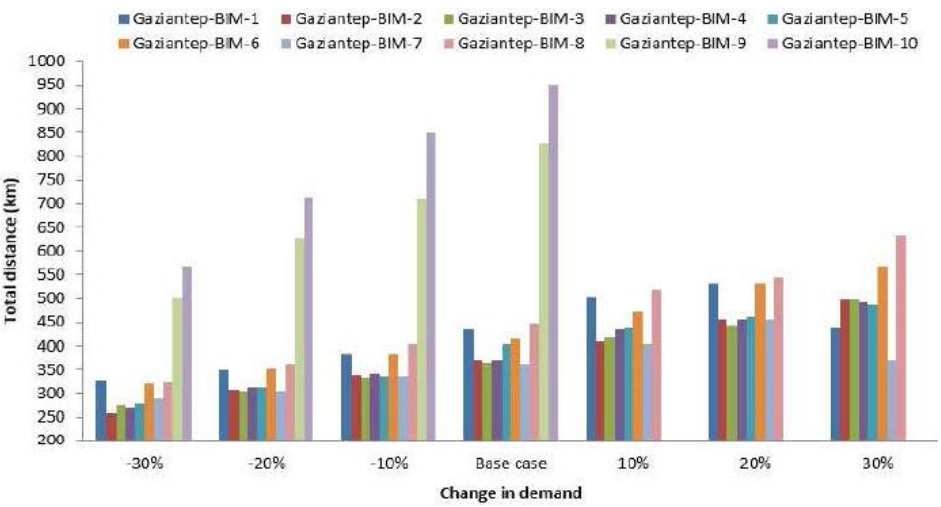


Figure 7. Illustration of the effect of shop demand on total distance.

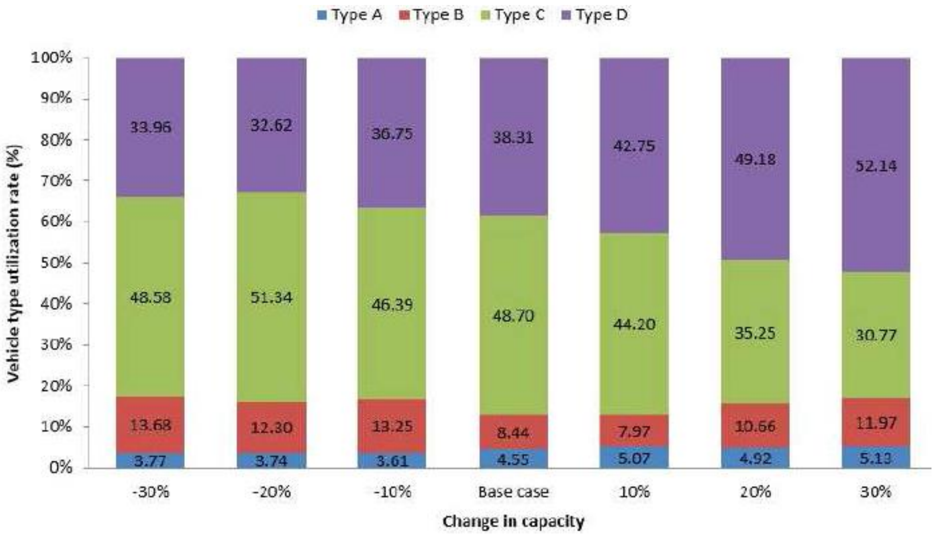


Figure 8. Illustration of the effect of shop demand on vehicle capacity utilization.

Table 3. Average results of the effect of the shop demand.

Change in shop demand	Average distance (km)	Average travel time (min)	Average en-route time (min)	Dev (%)
−30%	341.17	409.34	2881.34	−21.56
−20%	394.76	473.64	3089.64	−13.37
−10%	441.87	530.17	3280.57	−6.77
Base case	494.97	593.88	3502.68	0.00
10%	450.12	540.07	3208.57	7.24
20%	484.96	581.87	3339.62	10.88
30%	497.85	597.33	3505.08	15.09

4.2.3. The effect of the vehicle capacity

This section analyzes the effect of the vehicle capacity on solution quality. To do so, we decrease and increase the capacity of each vehicle type by 10%, 20%, and 30%. Table 4 presents the average results for these experiments. The detailed results of each experiments can be found in the Appendix. Figures 9 shows an illustration of the effects of changing capacity on vehicle type utilization rate.

Table 4 shows that the total en-route time is increased by 5.18%, 4.25% and 1.82%, when the capacity of each vehicle type is decreased by 30%, 20% and 10%, respectively. It is important to indicate that 10%, 20% or 30% decreases in vehicle capacity result in infeasible solutions for large-size instances which means that the vehicle fleet becomes insufficient to satisfy the shop demands. The total en-route time is decreased by -1.60%, -3.24% and -3.80%, when the capacity of each vehicle type is increased by 10%, 20% and 30%, respectively. These results demonstrates that any changes in vehicle capacity directly effects en-route time, travel time, as well as traveled distance in opposite manner. Figure 9 indicates that when we increase the vehicle capacity by 10%, 20% and 30%, the utilization rates of type D vehicle are 42.75%, 49.18% and 52.14%, respectively. Similarly, the utilization rates of type A vehicle are 5.07%, 4.92% and 5.13%, when we increase the vehicle capacity by 10%, 20% and 30%, respectively. These results show that when there is an increase in the capacity, the model prefers to use more A and D type vehicle than C type.

Table 4. Average results of the effect of the vehicle capacity.

Change in vehicle capacity	Average distance (km)	Average travel time (min)	Average en-route time (min)	Dev (%)
−30%	557.63	669.06	3138.81	5.18
−20%	506.57	607.79	3108.29	4.25
−10%	442.55	530.99	3031.49	1.82
Base case	494.97	593.88	3502.68	0.00
10%	449.11	538.86	3447.66	−1.60
20%	403.46	484.08	3392.88	−3.24
30%	388.09	465.65	3374.45	−3.80

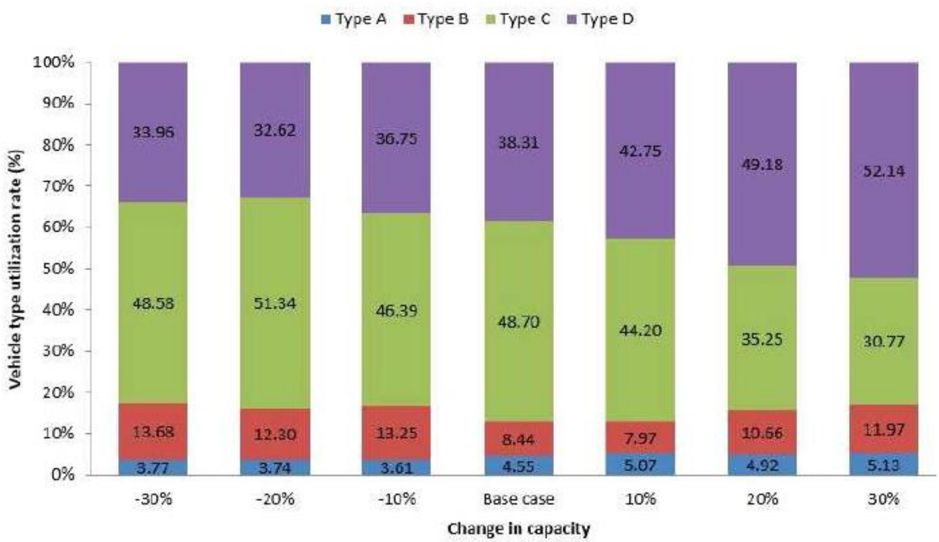


Figure 9. Illustration of the effects of changing capacity on vehicle type utilization rate.

4.2.4. The effect of the number of vehicles

In this section, we investigate the effect of the number of vehicles on solution quality. To do so, we decrease and increase the fixed numbers of each vehicle type by "1" and "2". Table 5 presents the average results for these experiments. The detailed results of each experiments can be found in the Appendix.

Table 5 shows that the total en-route time is increased by 1.97% and 0.23%, when the number of each vehicle type decreased by "2" and "1", respectively. It is important to indicate that "2" and "1" decreases in the number of each vehicle type result in infeasible solutions for instances with have 50 or more shops. In other words, the vehicle fleet becomes insufficient to satisfy the shop demands when the number of vehicles decrease. The total en-route time is decreased by -0.79% and -2.26%, when the number of each vehicle type is increased by "1" and "2", respectively. These results demonstrates it is required to increase the fixed number of vehicles for solving the instances which has more than 50 shops. Furthermore, our results show that any increase in fixed number of vehicles can reduce the total en-route time.

Table 5. Average results of the effect of the number of vehicles.

Change in # of vehicles	Average distance (km)	Average travel time (min)	Average en-route time (min)	Dev (%)
−2	437.17	524.53	2939.96	1.97
−1	402.27	482.65	2983.15	0.23
Base case	494.97	593.88	3502.68	0.00
1	472.22	566.58	3475.38	−0.79
2	455.44	546.45	3425.25	−2.26

4.2.5. The effect of the single-trip

In this section, we investigate the impact of the single-trip on solution quality. To do so, we did not allowed vehicles to serve more than one route such as in the classical VRP. Table 6 presents the detailed results for these experiments. The column Dev (%) shows the percentage deviation in total en-route time of the single-trip case over the base case. The penultimate column shows the number of unserved shops. Figure 10 shows an illustration of unserved shops in Gaziantep-BIM-9 (yellow) and in Gaziantep-BIM-10 (yellow and blue) for the case of the single-trip. Figure11 shows an illustration of the ratio of the traveled distance in single-trip case to traveled distance in multi-trip case.

The percentage deviation in the total en-route time is variable from one instance to another. For the instances Gaziantep-BIM-9 and Gaziantep-BIM-10, 11 and 14 shops could not served, respectively. These results clearly indicate that when the number of shops are higher the current vehicle fleet is not able to satisfy all shops demands which shows the importance of multi-trip case for the company. Figure 11 indicates that the multi-trip case decreased the total traveled distance when compared with the single-trip case, which indicates the importance of the multi-trip attitude.

4.2.6. The effect of the vehicle speed

We finally analyze the effect of the vehicle speed on solution quality. To this end, we set vehicle fixed speed at 35, 40, 45, 55, 60 and 65 km/h. Table 7 presents the average results for these experiments. The detailed results of each experiments can be found in the Appendix. Figure 12 shows an illustration of the effects of speed on total en-route time utilization rate.

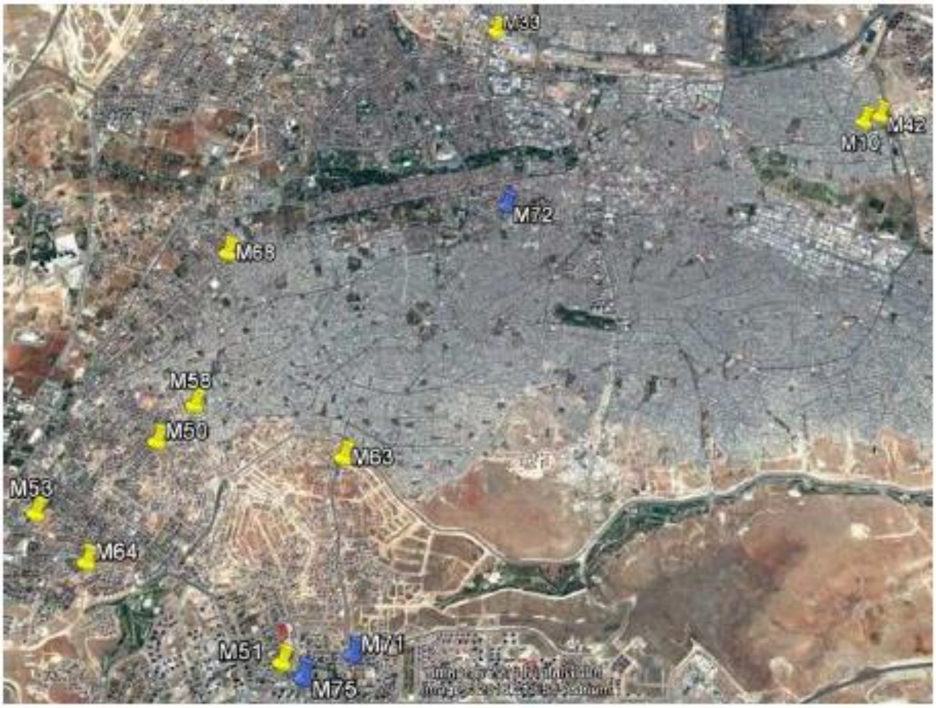


Figure 10. Illustration of unserved shops in Gaziantep-BIM-9 (yellow) and in Gaziantep-BIM-10 (yellow and blue) for the case of the single-trip.

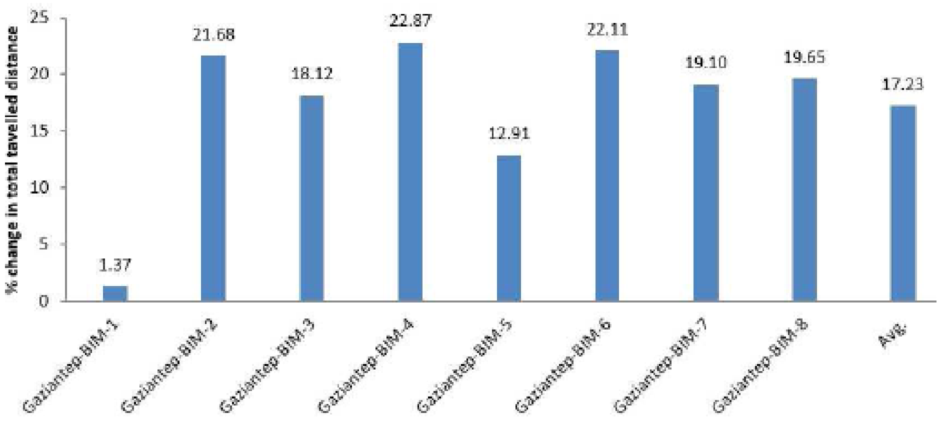


Figure 11. Illustration of the ratio of the travelled distance in single-trip case to travelled distance in multi-trip case.

Table 6. Results for the single-trip case.

Instance	$\lvert N_c \rvert$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	41	441.86	530.16	3152.16	–	0.23
Gaziantep-BIM-2	37	450.20	375.22	2772.20	–	0.23
Gaziantep-BIM-3	37	431.17	359.36	2759.17	–	−0.25
Gaziantep-BIM-4	37	453.39	377.88	2799.39	–	0.38
Gaziantep-BIM-5	36	455.36	379.52	2759.36	–	−1.03
Gaziantep-BIM-6	40	509.13	424.33	3059.13	–	0.29
Gaziantep-BIM-7	42	432.36	360.35	2868.36	–	−0.11
Gaziantep-BIM-8	50	537.47	447.96	3633.47	–	−0.04
Gaziantep-BIM-9	70	–	–	–	11	–
Gaziantep-BIM-10	75	–	–	–	14	–

Table 7 shows that the total en-route time is increased by 6.74%, 4.13% and 2.24%, when the vehicle speed is fixed at 35, 40 and 45 km/h, respectively. We can observe from the detailed results that when vehicles travels with lower speed than the base case, the method cannot provide any feasible solutions for large-size instances. The total en-route time decreased by -1.15%, -2.94% and -4.23%, when the vehicle speed is fixed at 55, 60 and 65 km/h, respectively. These results demonstrates that any changes in vehicle speed directly effects en-route time, travel time, as well as traveled distance. Furthermore, Figure 12 indicates that the total en-route time utilization rate is decreased when the vehicle speed is increased for the medium-size instances. However, it significantly increased for large-size instances.

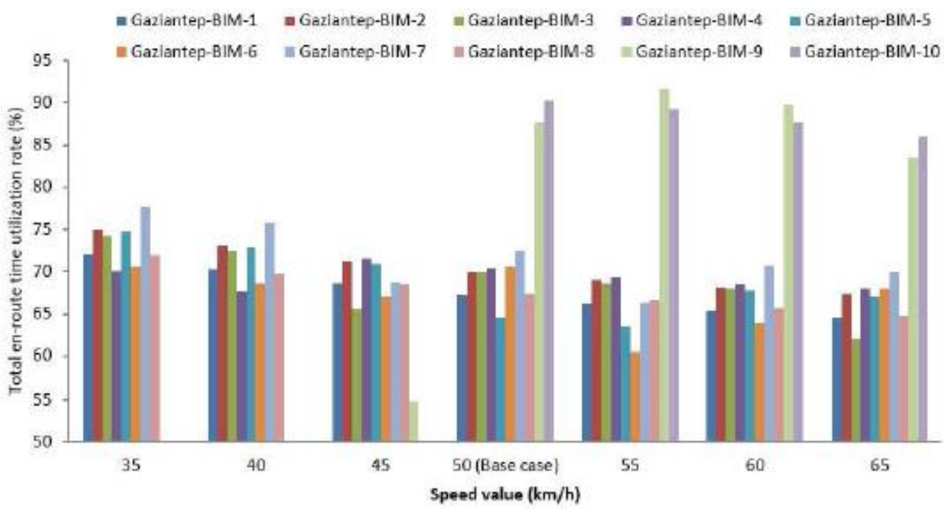


Figure 12. Illustration of the effects of speed on total en-route time utilization rate.

Table 7. Average results of the effect of the vehicle speed.

Vehicle speed (km/h)	Average distance (km)	Average travel time (min)	Average en-route time (min)	Dev (%)
35	403.02	690.78	3191.28	6.74
40	402.71	603.98	3104.48	4.13
45	455.50	607.24	3315.91	2.24
Base case	494.97	593.88	3502.68	0.00
55	507.93	554.02	3462.82	−1.15
60	494.03	493.95	3402.75	−2.94
65	489.56	451.84	3360.64	−4.23

5. CONCLUSIONS

We have formally described the Multi-Trip Heterogeneous Fixed Fleet Vehicle Routing Problem (MTHFFVRP), and we have proposed a mixed integer programming formulation. To solve the MTHFFVRP, we have used the ArcGIS software platform commercial GIS package, which employs a tabu search algorithm which can be used to store, analyze and visualize all data as well as model solutions in geographic format. We have applied the method on a real dataset of a company which is one of the major supermarket store chain in Turkey. We have finally provided several managerial insights by exploring the trade-offs between various parameters such as demand, number of vehicles, vehicle speed and capacity, and also single-trip problem variant.

We have shown that if current vehicle fleet travels with lower speed than the base case (50 km/h), it is not possible to obtain feasible solutions for large-size instances. We have also shown that the current vehicle fleet will be insufficient if the shop demands are higher. We have demonstrated the importance of multi-trip case for the company which makes it possible to satisfy all shops demands. We have also shown that the multi-trip case decreased the total traveled distance when compared with the single-trip case.

Beyond the computational comparisons we have just made, we stress the importance of the availability of a flexible decision support tool, such as ArcGIS, capable of analyzing the trade-offs that can be established between various parameters within quite short computation time.

Consideration of the parameters as deterministic, developing the model without time windows and running the proposed model with a limited area are the limitations and shortcomings of the paper. For the future researches, we recommend the following directions: (i) different heuristics can be investigated as solution approaches when the complexity issue becomes a challenge, (ii) fuzzy extension of the model can be worked on in order to cope with the fuzzy demand and finally (iii) environmental issues can be considered.

Acknowledgements

The authors would like to thanks to İlker Gündüz, BİM Inc. Gaziantep Depot Manager, for his contributions to this study. First author was supported by the BAGEP Award of the Science Academy in Turkey. Thanks are due to three referees for their valuable comments.

Appendix

Tables A.1 and A.2 presents the detailed results of the effect of decreasing and increasing the shop demand, respectively. Tables A.3 and A.4 presents the detailed results of the effect of decreasing and increasing the vehicle capacity, respectively. Tables A.5 presents the detailed results of the effect of the number of vehicles. Tables A.6 and A.7 presents the detailed results of the effect ofdecreasing and increasing the vehicle speed, respectively.

Table A.1. Detailed results of the effect of decreasing the shop demand.

Instance	Change in shop demand	$\|N_c\|$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	−30%	41	328.41	394.03	2614.03	–	−20.31
Gaziantep-BIM-2	−30%	37	259.07	310.83	2278.83	–	−21.38
Gaziantep-BIM-3	−30%	37	275.24	330.24	2304.24	–	−20.04
Gaziantep-BIM-4	−30%	37	270.35	324.37	2304.37	–	−21.02
Gaziantep-BIM-5	−30%	36	279.33	335.15	2291.15	–	−21.68
Gaziantep-BIM-6	−30%	40	320.27	384.27	2550.27	–	−19.60
Gaziantep-BIM-7	−30%	42	289.65	347.53	2435.53	–	−17.90
Gaziantep-BIM-8	−30%	50	322.41	386.83	3026.83	–	−20.09
Gaziantep-BIM-9	−30%	70	499.48	599.28	4319.28	–	−24.22
Gaziantep-BIM-10	−30%	75	567.45	680.84	4688.84	–	−24.79
Gaziantep-BIM-1	−20%	41	348.74	418.43	2770.43	–	−13.52
Gaziantep-BIM-2	−20%	37	308.05	369.61	2469.61	–	−12.00
Gaziantep-BIM-3	−20%	37	304.24	365.04	2471.04	–	−11.94
Gaziantep-BIM-4	−20%	37	313.11	375.68	2505.68	–	−11.30
Gaziantep-BIM-5	−20%	36	312.98	375.52	2457.52	–	−13.44
Gaziantep-BIM-6	−20%	40	351.76	422.06	2720.06	–	−12.14
Gaziantep-BIM-7	−20%	42	305.38	366.40	2580.40	–	−11.28
Gaziantep-BIM-8	−20%	50	362.61	435.07	3207.07	–	−13.34
Gaziantep-BIM-9	−20%	70	627.31	752.66	4658.66	–	−15.17
Gaziantep-BIM-10	−20%	75	713.39	855.94	5055.94	–	−15.73
Gaziantep-BIM-1	−10%	41	384.34	461.14	2927.14	–	−7.44
Gaziantep-BIM-2	−10%	37	339.13	406.90	2596.90	–	−6.51
Gaziantep-BIM-3	−10%	37	333.62	400.28	2596.28	–	−6.54
Gaziantep-BIM-4	−10%	37	341.32	409.53	2611.53	–	−6.79
Gaziantep-BIM-5	−10%	36	337.36	404.77	2576.77	–	−8.19
Gaziantep-BIM-6	−10%	40	383.18	459.75	2865.75	–	−6.44
Gaziantep-BIM-7	−10%	42	335.04	401.99	2735.99	–	−4.96
Gaziantep-BIM-8	−10%	50	403.75	484.43	3424.43	–	−6.15
Gaziantep-BIM-9	−10%	70	711.99	854.26	4994.26	–	−7.43
Gaziantep-BIM-10	−10%	75	848.96	1018.61	5476.61	–	−6.84

Table A.2. Detailed results of the effect of increasing the shop demand.

Instance	Change in shop demand	$\|N_c\|$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	10%	41	503.42	604.02	3412.02	–	7.83
Gaziantep-BIM-2	10%	37	410.53	492.57	2964.57	–	6.70
Gaziantep-BIM-3	10%	37	420.27	504.25	2994.25	–	7.62
Gaziantep-BIM-4	10%	37	435.61	522.65	3036.65	–	6.86
Gaziantep-BIM-5	10%	36	437.65	525.11	2991.11	–	6.79
Gaziantep-BIM-6	10%	40	470.75	564.82	3300.82	–	7.59
Gaziantep-BIM-7	10%	42	402.93	483.44	3045.44	–	5.71
Gaziantep-BIM-8	10%	50	519.81	623.68	3923.68	–	7.36
Gaziantep-BIM-9	10%	70	–	–	–	3	–
Gaziantep-BIM-10	10%	75	–	–	–	8	–
Gaziantep-BIM-1	20%	41	531.08	637.20	3541.20	–	11.19
Gaziantep-BIM-2	20%	37	456.94	548.24	3110.24	–	11.07
Gaziantep-BIM-3	20%	37	442.96	531.47	3099.47	–	10.76
Gaziantep-BIM-4	20%	37	456.07	547.21	3115.21	–	10.48
Gaziantep-BIM-5	20%	36	460.88	552.98	3102.98	–	10.15
Gaziantep-BIM-6	20%	40	532.70	639.15	3453.15	–	11.67
Gaziantep-BIM-7	20%	42	454.87	545.76	3221.76	–	10.87
Gaziantep-BIM-8	20%	50	544.22	652.96	4072.96	–	10.75
Gaziantep-BIM-9	20%	70	–	–	–	6	–
Gaziantep-BIM-10	20%	75	–	–	–	12	–
Gaziantep-BIM-1	30%	41	438.09	525.63	3579.63	–	12.14
Gaziantep-BIM-2	30%	37	496.86	596.14	3290.14	–	15.93
Gaziantep-BIM-3	30%	37	497.87	597.36	3309.36	–	16.42
Gaziantep-BIM-4	30%	37	491.84	590.12	3326.12	–	16.16
Gaziantep-BIM-5	30%	36	488.37	585.96	3267.96	–	14.69
Gaziantep-BIM-6	30%	40	568.57	682.19	3658.19	–	16.62
Gaziantep-BIM-7	30%	42	369.18	442.95	3250.95	–	11.67
Gaziantep-BIM-8	30%	50	632.01	758.31	4358.31	–	16.60
Gaziantep-BIM-9	30%	70	–	–	–	12	–
Gaziantep-BIM-10	30%	75	–	–	–	18	–

Table A.3. Detailed results of the effect of decreasing the vehicle capacity.

Instance	Change in vehicle capacity	$\|N_c\|$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	−30%	41	635.74	762.78	3384.78	–	7.08
Gaziantep-BIM-2	−30%	37	529.57	635.39	2957.39	–	6.47
Gaziantep-BIM-3	−30%	37	524.84	629.71	2957.71	–	6.48
Gaziantep-BIM-4	−30%	37	517.01	620.32	2966.32	–	5.99
Gaziantep-BIM-5	−30%	36	531.87	638.15	2942.15	–	5.24
Gaziantep-BIM-6	−30%	40	531.87	638.15	2942.15	–	−3.67
Gaziantep-BIM-7	−30%	42	516.23	619.38	3055.38	–	6.02
Gaziantep-BIM-8	−30%	50	673.93	808.59	3904.59	–	6.91
Gaziantep-BIM-9	−30%	70	–	–	–	5	–
Gaziantep-BIM-10	−30%	75	–	–	–	11	–
Gaziantep-BIM-1	−20%	41	559.96	671.85	3293.85	–	4.52
Gaziantep-BIM-2	−20%	37	464.94	557.85	2879.85	–	3.96
Gaziantep-BIM-3	−20%	37	481.21	577.37	2905.37	–	4.80
Gaziantep-BIM-4	−20%	37	483.88	580.58	2926.58	–	4.71
Gaziantep-BIM-5	−20%	36	487.99	585.50	2889.50	–	3.52
Gaziantep-BIM-6	−20%	40	526.89	632.18	3182.18	–	4.15
Gaziantep-BIM-7	−20%	42	460.24	552.21	2988.21	–	3.90
Gaziantep-BIM-8	−20%	50	587.43	704.82	3800.82	–	4.36
Gaziantep-BIM-9	−20%	70	–	–	–	6	–
Gaziantep-BIM-10	−20%	75	–	–	–	10	–
Gaziantep-BIM-1	−10%	41	482.19	578.55	3200.55	–	1.74
Gaziantep-BIM-2	−10%	37	407.25	488.62	2810.62	–	1.59
Gaziantep-BIM-3	−10%	37	421.87	506.18	2834.18	–	2.41
Gaziantep-BIM-4	−10%	37	430.59	516.64	2862.64	–	2.58
Gaziantep-BIM-5	−10%	36	424.88	509.78	2813.78	–	0.92
Gaziantep-BIM-6	−10%	40	472.91	567.41	3117.41	–	2.15
Gaziantep-BIM-7	−10%	42	403.85	484.55	2920.55	–	1.68
Gaziantep-BIM-8	−10%	50	496.87	596.16	3692.16	–	1.55
Gaziantep-BIM-9	−10%	70	–	–	–	3	–
Gaziantep-BIM-10	−10%	75	–	–	–	5	–

Table A.4. Detailed results of the effect of increasing the vehicle capacity.

Instance	Change in vehicle capacity	$\|N_c\|$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	10%	41	402.76	483.24	3105.24	–	−1.28
Gaziantep-BIM-2	10%	37	344.54	413.39	2735.39	–	−1.12
Gaziantep-BIM-3	10%	37	332.06	398.41	2726.41	–	−1.45
Gaziantep-BIM-4	10%	37	342.23	410.61	2756.61	–	−1.17
Gaziantep-BIM-5	10%	36	351.09	421.25	2725.25	–	−2.30
Gaziantep-BIM-6	10%	40	392.96	471.48	3021.48	–	−0.95
Gaziantep-BIM-7	10%	42	340.31	408.31	2844.31	–	−0.96
Gaziantep-BIM-8	10%	50	402.00	482.33	3578.33	–	−1.58
Gaziantep-BIM-9	10%	70	735.26	882.18	5256.18	–	−2.07
Gaziantep-BIM-10	10%	75	847.91	1017.34	5727.34	–	−2.16
Gaziantep-BIM-1	20%	41	359.73	431.61	3053.61	–	−2.99
Gaziantep-BIM-2	20%	37	311.62	373.89	2695.89	–	−2.60
Gaziantep-BIM-3	20%	37	307.05	368.41	2696.41	–	−2.58
Gaziantep-BIM-4	20%	37	309.43	371.26	2717.26	–	−2.63
Gaziantep-BIM-5	20%	36	339.27	407.07	2711.07	–	−2.83
Gaziantep-BIM-6	20%	40	354.95	425.88	2975.88	–	−2.50
Gaziantep-BIM-7	20%	42	311.38	373.61	2809.61	–	−2.21
Gaziantep-BIM-8	20%	50	376.51	451.75	3547.75	–	−2.46
Gaziantep-BIM-9	20%	70	624.62	749.44	5123.44	–	−4.72
Gaziantep-BIM-10	20%	75	740.05	887.92	5597.92	–	−4.53
Gaziantep-BIM-1	30%	41	350.75	420.83	3042.83	–	−3.36
Gaziantep-BIM-2	30%	37	291.46	349.70	2671.70	–	−3.53
Gaziantep-BIM-3	30%	37	307.51	368.96	2696.96	–	−2.56
Gaziantep-BIM-4	30%	37	299.55	359.41	2705.41	–	−3.08
Gaziantep-BIM-5	30%	36	292.25	350.65	2654.65	–	−5.02
Gaziantep-BIM-6	30%	40	334.02	400.76	2950.76	–	−3.37
Gaziantep-BIM-7	30%	42	301.34	361.56	2797.56	–	−2.65
Gaziantep-BIM-8	30%	50	362.54	434.98	3530.98	–	−2.95
Gaziantep-BIM-9	30%	70	598.68	718.32	5092.32	–	−5.36
Gaziantep-BIM-10	30%	75	742.84	891.28	5601.28	–	−4.46

Table A.5. Detailed results of the effect of the number of vehicles.

Instance	Change in # of vehicles	$\lvert N_c \rvert$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	−2	41	518.82	622.49	3244.49	–	3.07
Gaziantep-BIM-2	−2	37	398.51	478.14	2800.14	–	1.22
Gaziantep-BIM-3	−2	37	404.01	484.75	2812.75	–	1.66
Gaziantep-BIM-4	−2	37	414.87	497.77	2843.77	–	1.94
Gaziantep-BIM-5	−2	36	412.05	494.39	2798.39	–	0.38
Gaziantep-BIM-6	−2	40	514.29	617.06	3167.06	–	3.69
Gaziantep-BIM-7	−2	42	397.67	477.13	2913.13	–	1.43
Gaziantep-BIM-8	−2	50	–	–	–	5	–
Gaziantep-BIM-9	−2	70	–	–	–	23	–
Gaziantep-BIM-10	−2	75	–	–	–	27	–
Gaziantep-BIM-1	−1	41	437.73	525.20	3147.20	–	0.07
Gaziantep-BIM-2	−1	37	378.03	453.57	2775.57	–	0.35
Gaziantep-BIM-3	−1	37	366.76	440.05	2768.05	–	0.08
Gaziantep-BIM-4	−1	37	371.84	446.14	2792.14	–	0.12
Gaziantep-BIM-5	−1	36	383.21	459.78	2763.78	–	-0.87
Gaziantep-BIM-6	−1	40	439.06	526.80	3076.80	–	0.86
Gaziantep-BIM-7	−1	42	369.60	443.46	2879.46	–	0.27
Gaziantep-BIM-8	−1	50	471.89	566.19	3662.19	–	0.74
Gaziantep-BIM-9	−1	70	–	–	–	8	–
Gaziantep-BIM-10	−1	75	–	–	–	12	–
Gaziantep-BIM-1	1	41	421.90	506.20	3128.20	–	−0.54
Gaziantep-BIM-2	1	37	367.20	440.57	2762.57	–	−0.12
Gaziantep-BIM-3	1	37	355.52	426.56	2754.56	–	−0.41
Gaziantep-BIM-4	1	37	371.67	445.94	2791.94	–	0.11
Gaziantep-BIM-5	1	36	379.26	455.05	2759.05	–	−1.04
Gaziantep-BIM-6	1	40	418.63	502.29	3052.29	–	0.07
Gaziantep-BIM-7	1	42	367.72	441.19	2877.19	–	0.20
Gaziantep-BIM-8	1	50	447.20	536.56	3632.56	–	−0.07
Gaziantep-BIM-9	1	70	739.20	886.91	5260.91	–	−1.98
Gaziantep-BIM-10	1	75	853.93	1024.56	5734.56	–	−2.04
Gaziantep-BIM-1	2	41	371.60	445.86	2767.86	–	−13.63
Gaziantep-BIM-2	2	37	371.60	445.86	2767.86	–	0.07
Gaziantep-BIM-3	2	37	359.60	431.46	2759.46	–	−0.24
Gaziantep-BIM-4	2	37	372.91	447.43	2793.43	–	0.17
Gaziantep-BIM-5	2	36	379.74	455.62	2759.62	–	−1.02
Gaziantep-BIM-6	2	40	412.40	494.81	3044.81	–	−0.18
Gaziantep-BIM-7	2	42	368.31	441.91	2877.91	–	0.22
Gaziantep-BIM-8	2	50	443.87	532.57	3628.57	–	−0.18
Gaziantep-BIM-9	2	70	709.12	850.82	5224.82	–	−2.69
Gaziantep-BIM-10	2	75	765.27	918.20	5628.20	–	−3.96

Table A.6. Detailed results of the effect of decreasing the vehicle speed.

Instance	Vehicle speed (km/h)	$\lvert N_c \rvert$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	35	41	437.21	749.39	3371.39	–	6.72
Gaziantep-BIM-2	35	37	378.17	648.19	2970.19	–	6.88
Gaziantep-BIM-3	35	37	357.64	613.00	2941.00	–	5.95
Gaziantep-BIM-4	35	37	397.06	680.57	3026.57	–	7.86
Gaziantep-BIM-5	35	36	383.39	657.15	2961.15	–	5.85
Gaziantep-BIM-6	35	40	438.64	751.85	3301.85	–	7.62
Gaziantep-BIM-7	35	42	373.08	639.47	3075.47	–	6.63
Gaziantep-BIM-8	35	50	458.95	786.65	3882.65	–	6.38
Gaziantep-BIM-9	35	70	–	–	–	4	–
Gaziantep-BIM-10	35	75	–	–	–	7	–
Gaziantep-BIM-1	40	41	445.78	668.57	3290.57	–	4.42
Gaziantep-BIM-2	40	37	382.64	573.87	2895.87	–	4.49
Gaziantep-BIM-3	40	37	359.93	539.82	2867.82	–	3.55
Gaziantep-BIM-4	40	37	384.70	576.97	2922.97	–	4.59
Gaziantep-BIM-5	40	36	386.61	579.84	2883.84	–	3.33
Gaziantep-BIM-6	40	40	439.64	659.37	3209.37	–	4.96
Gaziantep-BIM-7	40	42	376.11	564.08	3000.08	–	4.28
Gaziantep-BIM-8	40	50	446.26	669.29	3765.29	–	3.46
Gaziantep-BIM-9	40	70	–	–	–	4	–
Gaziantep-BIM-10	40	75	–	–	–	6	–
Gaziantep-BIM-1	45	41	444.13	592.09	3214.09	–	2.15
Gaziantep-BIM-2	45	37	372.38	496.44	2818.44	–	1.86
Gaziantep-BIM-3	45	37	377.37	503.09	2831.09	–	2.30
Gaziantep-BIM-4	45	37	365.47	487.22	2833.22	–	1.57
Gaziantep-BIM-5	45	36	377.09	502.72	2806.72	–	0.67
Gaziantep-BIM-6	45	40	444.95	593.18	3143.18	–	2.96
Gaziantep-BIM-7	45	42	399.83	533.03	2969.03	–	3.28
Gaziantep-BIM-8	45	50	452.05	602.65	3698.65	–	1.72
Gaziantep-BIM-9	45	70	866.20	1154.77	5528.77	–	2.96
Gaziantep-BIM-10	45	75	–	–	–	1	–

Table A.7. Detailed results of the effect of increasing the vehicle speed.

Instance	Vehicle speed (km/h)	$\lvert N_c \rvert$	Total distance (km)	Total travel time (min)	Total en-route time (min)	# of unserved shops	Dev (%)
Gaziantep-BIM-1	55	41	438.22	477.99	3099.99	–	−1.45
Gaziantep-BIM-2	55	37	378.90	413.28	2735.28	–	−1.12
Gaziantep-BIM-3	55	37	359.50	392.13	2720.13	–	−1.69
Gaziantep-BIM-4	55	37	369.23	402.74	2748.74	–	−1.46
Gaziantep-BIM-5	55	36	403.09	439.67	2743.67	–	−1.61
Gaziantep-BIM-6	55	40	457.15	498.63	3048.63	–	−0.05
Gaziantep-BIM-7	55	42	396.28	432.24	2868.24	–	−0.12
Gaziantep-BIM-8	55	50	459.89	501.63	3597.63	–	−1.04
Gaziantep-BIM-9	55	70	831.05	906.46	5280.46	–	−1.61
Gaziantep-BIM-10	55	75	985.95	1075.42	5785.42	–	−1.14
Gaziantep-BIM-1	60	41	435.33	435.27	3057.27	–	−2.87
Gaziantep-BIM-2	60	37	374.79	374.74	2696.74	–	−2.57
Gaziantep-BIM-3	60	37	365.24	365.19	2693.19	–	−2.70
Gaziantep-BIM-4	60	37	369.00	368.95	2714.95	–	−2.72
Gaziantep-BIM-5	60	36	379.36	379.31	2683.31	–	−3.90
Gaziantep-BIM-6	60	40	438.96	438.89	2988.89	–	−2.05
Gaziantep-BIM-7	60	42	363.44	363.39	2799.39	–	−2.58
Gaziantep-BIM-8	60	50	450.98	450.91	3546.91	–	−2.48
Gaziantep-BIM-9	60	70	797.70	797.58	5171.58	–	−3.74
Gaziantep-BIM-10	60	75	965.45	965.31	5675.31	–	−3.10
Gaziantep-BIM-1	65	41	432.82	399.46	3021.46	–	−4.09
Gaziantep-BIM-2	65	37	373.41	344.64	2666.64	–	−3.72
Gaziantep-BIM-3	65	37	380.79	351.45	2679.45	–	−3.23
Gaziantep-BIM-4	65	37	374.07	345.25	2691.25	–	−3.62
Gaziantep-BIM-5	65	36	380.97	351.62	2655.62	–	−4.98
Gaziantep-BIM-6	65	40	421.78	389.28	2939.28	–	−3.78
Gaziantep-BIM-7	65	42	361.90	334.01	2770.01	–	−3.67
Gaziantep-BIM-8	65	50	440.98	407.00	3503.00	–	−3.77
Gaziantep-BIM-9	65	70	798.48	736.95	5110.95	–	−4.97
Gaziantep-BIM-10	65	75	930.45	858.75	5568.75	–	−5.07

REFERENCES

[1] ArcGIS, 2016. ArcGIS Network Analyst Tutorial. <http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/about-the-network-analyst-tutorial-exercises.htm>.

[2] Baldacci, R., Battarra, M., Vigo, D. 2008. Routing a heterogeneous fleet of vehicles. In B. L. Golden, S. Raghavan, E. A. Wasil, eds. The Vehicle Routing Problem: Latest Advances and New Challenges (pp. 1–25). Springer, New York.

[3] BİM Inc., 2017. B˙IM Inc.'s hard-discount concept. <http://english.bim.com.tr/Category/627/bim-philosophy.aspx>.

[4] Bozkaya, B., Yanik, S., Balcisoy, S., 2010. A GIS-based optimization framework for competitive multi-facility location-routing problem. Networks and Spatial Economics 10, 297–320.

[5] Casas, I., Malik, A., Delmelle, E. M., Karwan, M. H., Batta, R., 2007. An automated network generation procedure for routing of unmanned aerial vehicles (UAVs) in a GIS environment. Networks and Spatial Economics 7, 153–176.

[6] Cattaruzza, D., Absi, N., Feillet, D., Vidal, T., 2014. A memetic algorithm for the multi trip vehicle routing problem. European Journal of Operational Research 236, 833–848.

[7] Cattaruzza, D., Absi, N., Feillet, D., 2016. Vehicle routing problems with multiple trips. 4OR, 1–37.

[8] Crainic, T. G., Gajpal, Y., Gendreau, M., 2015. Multi-zone multi-trip vehicle routing problem with time windows. INFOR: Information Systems and Operational Research 53, 49–67.

[9] Custodio, A. L., Oliveira, R. C., 2006. Redesigning distribution operations: a case study on integrating inventory management and vehicle routes design. International Journal of Logistics: Research and Applications 9, 169–187.

[10] Demirel, H., Korkutan, M., Shoman, W., Alganc, U., 2017. Geographic information system (GIS) based accessibility analysis for highway transportation. Sigma Journal of Engineering and Natural Sciences 8, 339–344.

[11] Fried, T., Munnich, L., Horan, T., Hilton, B., 2018. Evolving supply chains and local freight flows: A geographic information system analysis of Minnesota cereal grain movement. Transportation Research Record, <https://doi.org/10.1177/0361198118759952>.

[12] Glover, F.W., Laguna, M., 1998. Tabu search. Kluwer Academic, Massachusetts. Google Maps, 2017. <https://maps.google.com>.

[13] Koç C.¸ Karaoglan, I., 2016. The green vehicle routing problem: A heuristic based exact solution approach. Applied Soft Computing 39, 154–164.

[14] Koç C.¸ Bektas, T., Jabali, O., Laporte, G., 2015. A hybrid evolutionary algorithm for heterogeneous fleetvehicle routing problems with time windows. Computers & Operations Research, 64, 11–27.

[15] Koç C., Bektas, T., Jabali, O., Laporte, G., 2016. Thirty years of heterogeneous vehicle routing. European Journal of Operational Research 249, 1–21.

[16] Krichen, S., Faiz, S., Tlili, T., Tej, K., 2014. Tabu-based GIS for solving the vehicle routing problem. Expert Systems with Applications 41, 6483–6493.

[17] Laporte, G. 2009. Fifty years of vehicle routing. Transportation Science 43, 408–416.

[18] Min, H., Melachrinoudis, E., 2016. A model-based decision support system for solving vehicle routing and driver scheduling problems under hours of service regulations. International Journal of Logistics Research and Applications 19, 256–277.

[19] Mingozzi, A., Roberti, R., Toth, P., 2013. An exact algorithm for the multitrip vehicle routing problem.

[20] INFORMS Journal on Computing 25, 193–207.

[21] Olivera, A., Viera, O., 2007. Adaptive memory programming for the vehicle routing problem with multiple trips. Computers & Operations Research 34, 28–47.

[22] Pasha, U., Hoff, A., Hvattum, L. M., 2016. Simple heuristics for the multi-period fleet size and mix vehicle routing problem. INFOR: Information Systems and Operational Research 54, 97–120.

[23] Prins, C., 2002. Efficient heuristics for the heterogeneous fleet multitrip VRP with application to a large-scale real case. Journal of Mathematical Modelling and Algorithms 1, 135–150.

[24] Samanlioglu, F., 2013. A multi-objective mathematical model for the industrial hazardous waste locationrouting problem. European Journal of Operational Research 226, 332–340.

[25] Toth, P. Vigo, D., eds. 2014. Vehicle routing: Problems, methods, and applications. MOS-SIAM Series on Optimization, Philadelphia.

[26] Yanik, S., Bozkaya, B., deKervenoael, R., 2014. A new VRPPD model and a hybrid heuristic solution approach for e-tailing. European Journal of Operational Research 236, 879–890.

[27] Yu, B., Ma, N., Cai, W., Li, T., Yuan, X., Yao, B., 2013. Improved ant colony optimisation for the dynamic multi-depot vehicle routing problem. International Journal of Logistics Research and Applications 16, 144–157.