Research Article GU J Sci 36(2): 705-718 (2023) DOI: 10.35378/gujs.962229

Gazi University

Journal of Science

http://dergipark.gov.tr/gujs

A Vehicle Routing Problem Arising in the Distribution of Higher Education Institutions Exam Booklets

Batuhan KOCAOGLU[1], Ayca OZCEYLAN[2,*]

[1] Department of Management Information Systems, Piri Reis University, İstanbul, Turkey
[2] Oğuzeli Vocational High School, Gaziantep University, Gaziantep, Turkey

Highlights

- A capacitated vehicle routing problem arising at exam booklet distribution problem is considered.
- A real life example including 134 schools with homogeneous capacities of vehicles is solved.
- The tools of ArcGIS and Google OR are applied in addition to the MIP solution.

Article Info

Received: 04 July 2021
Accepted: 22 Apr 2022

Keywords

Capacitated vehicle routing problem, Exam booklet distribution, Geographic information system, Mixed integer programming

Abstract

In this paper, the exam booklet distribution plan for the Higher Education Institutions Exam (HEIE) is studied. The accurate distribution plan is important to decrease the transportation cost and use the capacity efficiently. The exam booklets distribution should be considered as capacitated vehicle routing problem (VRP). In this context, the aim of this paper is minimizing the cost/distance of distribution from the depot where exam booklets are kept to the schools with capacitated vehicles. The case of Gaziantep city with 135 nodes (one depot and 134 schools) is considered. To model and solve the problem, a mixed integer programming (MIP) model is developed and applied. Due to large size of the problem, the VRP tool of Esri ArcGIS (well-known geographic information system (GIS) software) and OR-tool of Google are also applied to get an acceptable solution in a reasonable time. Finally, the proposed three distribution plans are compared each other and the results are discussed. Our numerical results show that the tools of Esri ArcGIS and OR-tool of Google decreases the total route distance by 8.21% and 3.02% compared to the MIP model, respectively. One of the main contributions of the paper is to show the applicability of network analyst tool of Esri ArcGIS and OR-tool of Google on a real-case CVRP.

1. INTRODUCTION

Distribution planning is an important issue that needs to be resolved for many businesses. The distribution plan needs to be optimized for purposes such as optimum resource use and low cost. Vehicle routing problem (VRP) is used in the literature for the solution of these route optimization problems. With vehicle routing, efficient routes provide fuel savings and time savings. Although VRPs have been used in different fields such as food delivery [1], solid waste collection [2], and vaccine distribution [3], the distribution of exam questions in national exams can also be considered as a typical VRP. Because, the university entrance exams or open education faculty exams are held every year in Turkey, as in many other countries (e.g. China, Greece, Iran, Japan, Russia, and Spain). Gaziantep is one the largest cities in Turkey and thousands of students take also these exams in hundreds of schools in Gaziantep. For instance, before the global outbreak (COVID-19), more than 50 national exams (including open education faculty exams) were organized in Gaziantep. Regardless of the exam, every exam needs a great organization and planning. The schools (where the exams are held in) must be reserved and the vehicles must be routed to distribute the exam booklets/boxes to the schools. Since the exams are constantly repeated, even the smallest improvements turn into great values when the year is hit. This point is the most important source of motivation for this study. In other words, if the exam distribution problem is considered as a VRP and

*Corresponding author, e-mail: ozceylan@gantep.edu.tr

solved, can better results be obtained in a shorter time than the existing distribution plans? This is the question this study seeks to answer.

In this paper, the distribution problem of higher education exam booklets in Gaziantep city is taken into consideration. The problem includes nodes (buildings/schools where exams will be held), and vehicles with homogeneous capacities. Therefore, the problem is considered as a capacitated vehicle routing problem (CVRP). There is a big depot in Gaziantep University campus where the exam booklets are stored and kept. A limited number of vehicles are responsible to distribute the exam boxes to the schools where demand is different and specific. Although a MIP formulation is applied to get the optimal solution, due to the size of the case (more than 130 nodes), only a feasible solution could be obtained under a certain solution time. Therefore, the tools of Esri ArcGIS and OR-tool of Google are also applied in addition to the MIP formulation.

In the following section, relevant literature is shared. In the third section, the problem is defined and the applied methodology is described. In the fourth section, the real data of the case is presented and the computational results are discussed. The study is concluded with future suggestions in the last section.

2. LITERATURE REVIEW

In the field of combinatorial optimization, the VRP is regarded as one of the most challenging problems. In its 70 years of life, several classes of VRP have been studied in the literature [4].The most basic VRP is the capacitated vehicle routing problem (CVRP) that assumes a fixed fleet of vehicles of uniform capacity housed in a central depot. It is indeed NP-hard, so that the task of finding the best set of vehicle tours by solving optimization models is computationally prohibitive for real-world applications. As a result, different types of heuristic, meta-heuristic and exact methodologies are usually applied [5].In this section, only the existing papers that consider CVRP within a real life problem are focused and mentioned below.

As one of the first real life examples, Moghadam et al. [6] apply robust optimization to a CVRP for a real case study medicine distribution. Then, Faulina et al. [7] study a CVRP with environmental criteria in road transportation. Traditional heuristic algorithms, namely Clarke and Wright or Mole and Jameson are applied to a real case in the agribusiness sector in Navarre (Spain). Soysal et al. [8] study the time-dependent two-echelon CVRP with environmental considerations for a case study on a Dutch supermarket chain. To solve the problem, a MIP model is applied. Yi and Bortfeldt [9] investigate CVRP with split delivery which is applied using real industrial data for a logistics company. A tabu search algorithm is used to handle their problem. Comert et al. [10] investigate a CVRP which seeks the minimum distance routes in a supermarket chain. Firstly, customers are clustered using different clustering algorithms with considering a vehicle capacity. Secondly, the routing problems for each cluster are solved using a branch and bound algorithm. Hannan et al. [2] apply particle swarm optimization (PSO) algorithm for a CVRP including solid waste collection and route optimization. Rabbani et al. [11] study CVRP for distribution of corruptible food in Tehran using simulated annealing (SA). Koç et al. [12] study a rich VRP variant concerns with the joint multiple depots, pickup and delivery, multi-trip, and homogeneous fixed vehicle fleet. Geographic Information System (GIS)-based solution method, which uses a tabu search heuristic optimization method, to a real dataset of one of the major banks is applied in their study. Redi et al. [13] study a capacitated VRP to find a set of vehicles routes with the minimum total transportation time for pharmaceutical distribution in West Jakarta. To solve the real case problem, a simulated annealing (SA) heuristic approach is proposed and applied in their study. Sandaruwan et al. [14] investigate a CVRP for a food manufacturing company located in Sri Lanka. To solve the real case problem, two-phased heuristic algorithm including genetic algorithm (GA) is applied. As a similar study, Ozkan et al. [15] study an exam distribution plan considering the problem as CVRP. However, the small problem size and the fact that they have only applied GIS-based solution are their biggest limitations. Sbai et al. [16] develop a hybrid meta-heuristic that embeds a variable neighborhood search (VNS) and genetic algorithm (GA) to solve a CVRP. A distribution problem arising in Tunisian Post Office is the case study of their approach. Feng et al. [17] investigate CVRP for package delivery. They applied an explicit evolutionary multitasking (EMT) algorithm to solve the real case problem. Finally, Ozkan and Atli [18] study capacitated unmanned aerial vehicles routing problem to transport polymerase chain reaction testing samples between hospitals and laboratories. A MIP model is developed and applied to a network includes 219 hospitals and 23 testing laboratories for the COVID-19 pandemic.

As mentioned above, heuristic and exact algorithms were developed to deal with the CVRP but application to a real life case is still a challenging problem. Lacking of GIS application is another observation from the review above. To support the literature in the aforementioned points, a real life case (exam booklets distribution) is modeled as a CVRP problem in this paper. To solve the problem, three different solution methodologies namely MIP, network analyst tool of Esri ArcGIS and OR-tool of Google are applied. The contributions of the paper to the relevant literature can be thought as: (*i*) considering a large size exam distribution plan and providing significant improvements in travelled distance and capacity utilization rates, and (*ii*) showing the applicability of network analyst tool of Esri ArcGIS and OR-tool of Google on a CVRP.

3. PROBLEM DEFINITION AND METHODOLOGY

Let $G = (V, E)$ be a directed graph with vertices $V = \{0, 1, \dots i\}$ and edges $E = \{1, \dots m\}$. The depot is represented by vertex 0, and each remaining vertex *i* represents a customer with a positive demand d_i. Each edge $e \in E$ has a nonnegative length c_{ij}. The capacitated vehicle routing problem (CVRP) considers of finding routes for K vehicles satisfying the following constraints: (*i*) each customer is visited by an only one vehicle, (*ii*) each route starts at the depot and returns to the depot, and (*iii*) the total demand of all customers must be answered without exceeding the capacity of vehicles. The goal is to minimize the sum of the lengths of all routes. An illustration of capacitated VRP is presented in Figure 1. There are 16 customers and one depot on the left side of Figure 1. The numbers near nodes represent the demands. Optimal four routes are depicted on the rights side of the Figure 1 [19].

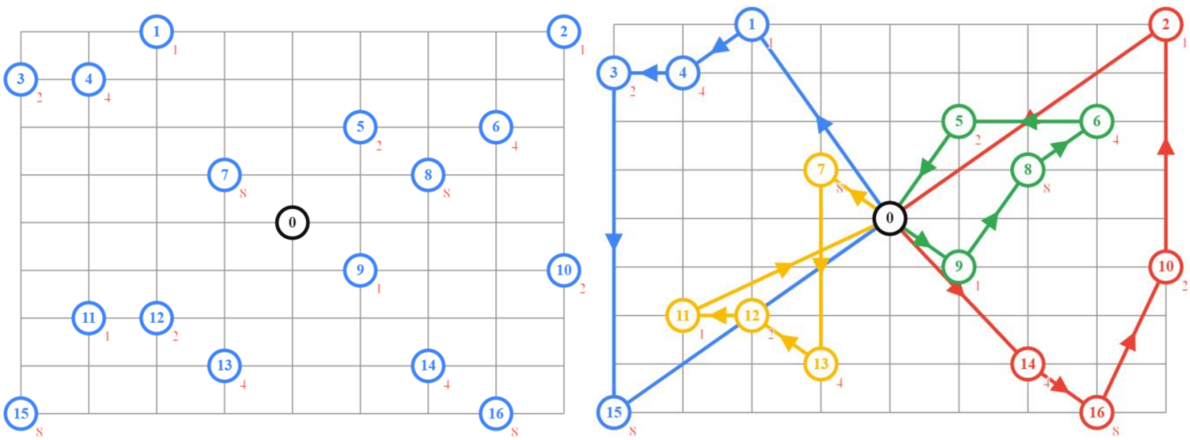

Figure 1. *An example of capacitated VRP with one depot, 16 customers and 4 vehicles*

The CVRP was first proposed in 1959 by Dantzig and Ramser [20] and has received close attention from the optimization community since then. The mathematical formulation which is used in this study is described below [21].

Indices
i, j nodes

Decision variables
x_{ij} takes value 1 if edge belongs to the optimal solution, and value 0 otherwise, $\forall\ i, j \in V: i \neq j$
u_i additional continuous variable representing the load of the vehicle after visiting customer i

Parameters
c_{ij} distance/cost between nodes i and j
Q vehicle capacity

K number of vehicles
V nodes
N_c customer nodes
d_i demand of customer

Objective function

$$Min\ Z = \sum_{(i,j)\in N} x_{ij} c_{ij} \quad (1)$$

Constraints

$$\sum_{i\in V} x_{ij} = 1 \quad \forall\, j \in V_c \quad (2)$$
$$\sum_{j\in V} x_{ij} = 1 \quad \forall\, i \in V_c \quad (3)$$
$$\sum_{i\in V} x_{i0} = K \quad (4)$$
$$\sum_{j\in V} x_{0j} = K \quad (5)$$
$$u_i - u_j + Qx_{ij} \le Q - d_i \quad \forall\, i,j \in V_c,\ i \ne j \quad (6)$$
$$d_i \le u_i \le Q \quad \forall\, i \in V_c \quad (7)$$
$$x_{ij} \in \{0,1\} \quad \forall i,j \in V \quad (8)$$

The CVRP consists of finding a collection of simple circuits (corresponding to vehicle routes) with minimum cost, defined as the sum of the costs of the arcs belonging to the circuits (Obj. func.). The problem in this paper is directed, x_{ij} and x_{ji} may represent the same or different variable. Constraints (2) and (3) (indegree and outdegree of nodes) impose that exactly one edge enters and leaves each vertex associated with a customer, respectively. Analogously, constraints (4) and (5) ensure the degree requirements for the vertex of depot. Constraints (6) and (7) impose the capacity requirements of CVRP while eliminating the sub-tours [22]. Finally, constraint (8) is the integrality conditions.

Due to NP-hardness of the described problem above, two additional solution approaches namely Esri ArcGIS and OR-tools of Google are considered in this study. ArcGIS is commonly used in many broad areas where spatially-enabled data need to be stored, retrieved, analyzed, and visualized [12]. The Network Analyst tool of ArcGIS 10.2 commercial package is used. A tabu search meta-heuristic 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 [23]. In addition to Esri ArcGIS VRP tool, Google optimization tool (OR-tools) that is one of the open sources is also used. The details about the structure of Google OR-tools can be found at the study of Perron [24] and at the link of Google OR-Tools [19]. The default version of Google OR-tools is considered in this paper. The parameters we call Google Optimization Tool's Routing library are given in Table 1.

Table 1. *Google optimization tools search parameters (Bujel et al. 2019)*

Parameter	**Value**	**Description**
first solution strategy	PATH_CHEAPEST_ARC	First solution strategies used as starting point of local search. Starting from a route "start" node, connect it to the node which produces the cheapest route segment, then extend the route by iterating on the last node added to the route.
optimization_step	1	Minimum step by which the solution must be improved in local search.
solution_limit	9223372036854775807	Limit to the number of solutions generated during the search.
time_limit_ms	5000	Limit in milliseconds to the time spent in the search.
use_light_propagation	true	Use constraints with light propagation in routing model. Extra propagation is only necessary when using depth-first search or for models which require strong propagation to finalize the value of secondary variables. Changing this setting to true will slow down the search in most cases and increase memory consumption in all cases.

In the following section, three different methodologies will be applied to the case study. The running time of MIP model is limited with three hours. To compare the feasible solutions and get acceptable solutions in a reasonable time, two different tools based on heuristic approaches are also applied. The flow of the applied methodology is given in Figure 2.

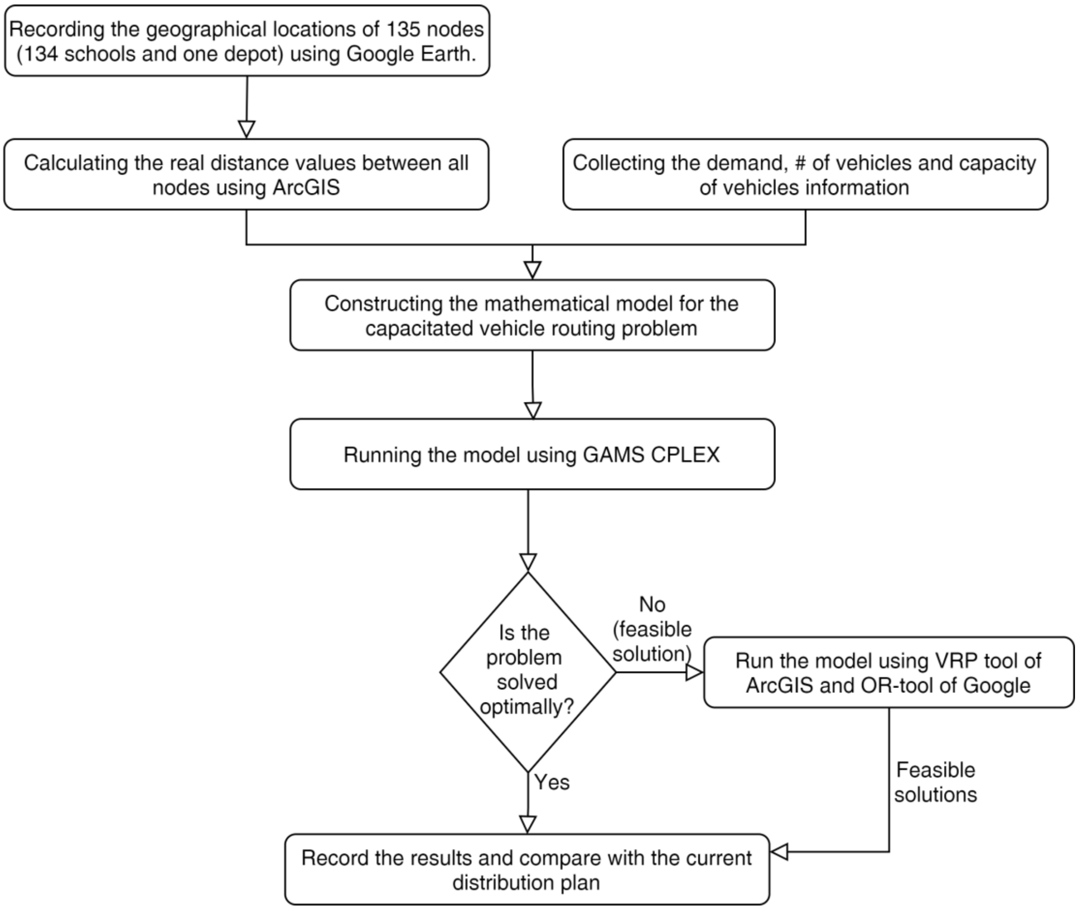

Figure 2. *The flow of the study*

4. CASE STUDY

In this section, the application of the solution methods on a real life exam booklet distribution case study is presented. We will first describe the case study in more detail, including the input data used, and then present the associated results obtained with the MIP model, Esri ArcGIS tool and OR-tool of Google.

4.1. Data

The HEIE is held with two main sessions in 81 cities of Turkey and abroad annually. To optimize the exam booklet distribution, the case of exam organization from city of Gaziantep is used. Gaziantep is the 9th city in Turkey in terms of population, and there are approximately 55,500 students registered to the HEIE in Gaziantep in 2020 [25]. Two main districts of Gaziantep, namely Şehitkamil and Şahinbey are the study area.

In Gaziantep, there are 134 schools where the exams are held in and one depot where the exam boxes and vehicles are located. The names of theses nodes with their codes and required demand amounts (exam boxes) are given in Table 2. While the codes started with 1 to 134 indicate the schools, the depot is shown as 0.

Table 2. *135 nodes (134 schools and one depot) of the study area*

Code	Node	Demand (d_i)
0	GAZİANTEP UNIVERSITY CIVIL ENGINEERING DEPARTMENT	–
1	ABDULKADİR KONUKOĞLU HIGH SCHOOL	2
2	ADNAN MENDERES MIDDLE SCHOOL	3
3	AHMET ÇELEBİ PRIMARY SCHOOL	3
4	AHMET ERKUL VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	4
5	AKKENT HIGH SCHOOL	2
6	AKŞEMSEDDİN HIGH SCHOOL	2
7	AKYOL MIDDLE SCHOOL	3
8	ALİ KÜNCÜLÜ MIDDLE SCHOOL	4
9	ALİ SÜZER HEARING IMPAIRED PRIMARY SCHOOL	3
10	ALİ TİRYAKİOĞLU VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	2
11	ANNELER MIDDLE SCHOOL	3
12	ASLI ALEVLİ PRIMARY SCHOOL	4
13	ATATÜRK ANATOLIAN HIGH SCHOOL	4
14	AYTEN KEMAL AKINAL ANATOLIAN HIGH SCHOOL	3
15	BAĞLARBAŞI ANATOLIAN HIGH SCHOOL	2
16	BAHATTİN KAYALI PRIMARY SCHOOL	1
17	BAYRAKTAR ANATOLIAN HIGH SCHOOL	2
18	BEDRİYE HALUK ÖZMEN TRADE VOCATIONAL HIGH SCHOOL	3
19	BEHİYE REŞAT KALEOĞLU PRIMARY SCHOOL	4
20	CEMIL ALEVLİ PRIMARY SCHOOL	3
21	CUMHURİYET ANATOLIAN HIGH SCHOOL	3
22	DR.NİLÜFER MUSTAFA ÖZYURT PRIMARY SCHOOL	2
23	DR.SADIK AHMET PRIMARY SCHOOL	2
24	DUMLUPINAR ANATOLIAN HIGH SCHOOL	3
25	DÜZTEPE PRIMARY SCHOOL	4
26	EMİNE FEVZİ USLU PRIMARY SCHOOL	4
27	EMİNE KONUKOĞLU ANATOLIAN HIGH SCHOOL	3
28	EMİRE MUSTAFA TEZEL MIDDLE SCHOOL	2
29	ERTUĞRULGAZİ PRIMARY SCHOOL	2
30	FADILOĞLU İMAM HATİP MIDDLE SCHOOL	2
31	FATİH SULTAN MEHMET PRIMARY SCHOOL	3
32	FEHİME GÜLEÇ MIDDLE SCHOOL	4
33	FERİDUN ORAL MIDDLE SCHOOL	4
34	FİTNAT NURİ TEKEREKOĞLU ANATOLIAN HIGH SCHOOL	3
35	GAZİ MUSTAFA KEMAL PRIMARY SCHOOL	2
36	GAZİ MIDDLE SCHOOL	2
37	GAZİANTEP ANATOLIAN HIGH SCHOOL	2
38	GAZİANTEP HIGH SCHOOL	3
39	GAZİANTEP CHAMBER OF COMMERCE VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	3
40	GAZİANTEP TÜRK TELEKOM ANATOLIAN HIGH SCHOOL	4
41	GAZİANTEP IMAM HATIP HIGH SCHOOL UNION OF CHAMBERS OF TURKEY	3
42	GÜLŞEN BATAR ANATOLIAN HIGH SCHOOL	2
43	HACI FEHIME GÜLEÇ MIDDLE SCHOOL	3
44	HACI SANİ KONUKOĞLU VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	4
45	HANİFE ŞİRECİ PRIMARY SCHOOL	3
46	HASAN ALİ YÜCEL ANATOLIAN HIGH SCHOOL	2
47	HASAN CELAL GÜZEL PRIMARY SCHOOL	1
48	HASAN KATIKÇI MIDDLE SCHOOL	3
49	HASAN SÜZER ANATOLIAN HIGH SCHOOL	2
50	HATİCE BÜYÜKBEŞE MIDDLE SCHOOL	2
51	HATİCE-LÜTFÜ AKCAN ANATOLIAN HIGH SCHOOL	2
52	HÜSEYİN VE MUSTAFA HÖSÜKOĞLU IMAM HATIP MIDDLE SCHOOL	3
53	İMKB ANATOLIAN HIGH SCHOOL	4
54	İNCİ KONUKOĞLU ANATOLIAN HIGH SCHOOL	3
55	İSMET İNÖNÜ MIDDLE SCHOOL	2
56	İSTİKLAL IMAM HATIP MIDDLE SCHOOL	2
57	İSTIKLAL MIDDLE SCHOOL	2
58	KADRİYE ABDULMECİT ÖZGÖZEN MIDDLE SCHOOL	1
59	KAPLAN KARDEŞLER IMAM HATIP MIDDLE SCHOOL	2
60	KARATAŞ İMKB PRIMARY SCHOOL	3
61	KAŞGARLI MAHMUT PRIMARY SCHOOL	3
62	KAŞIBEYAZ MIDDLE SCHOOL	2
63	KOCATEPE MIDDLE SCHOOL	2
64	KURTULUŞ PRIMARY SCHOOL	3
65	LİONS PRIMARY SCHOOL	4
66	MAHMUT GÜLEÇ PRIMARY SCHOOL	1
67	MEHMET AKİF ERSOY VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	2
68	MEHMET AKİF İNAN MIDDLE SCHOOL	3

Table 2. *Continued*

69	MEHMET APİ VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	1
70	MEHMET ÇOLAKOĞLU PRIMARY SCHOOL	4
71	MEHMET HAYRİ AKINAL GIRL ANATOLIAN IMAM HATIP HIGH SCHOOL	3
72	MEHMET HÜMAYUN ÖZHELVACI MIDDLE SCHOOL	2
73	MEHMET NURETTİN HOROZ LOJİSTİK VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	3
74	MEHMET RÜŞTÜ UZEL VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	4
75	MEHMET UYGUN VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	3
76	MEHMETÇİK MIDDLE SCHOOL	2
77	MENNAN USTA VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	1
78	MİMAR SİNAN ANATOLIAN HIGH SCHOOL	2
79	MUSTAFA ERMAN MIDDLE SCHOOL	3
80	MUSTAFA GÜRBÜZ NECAT BAYEL ANATOLIAN HIGH SCHOOL	2
81	MÜNIFPAŞA MIDDLE SCHOOL	3
82	MÜNİRE KEMAL KINOĞLU MIDDLE SCHOOL	4
83	NECİP FAZIL KISAKÜREK ANATOLIAN HIGH SCHOOL	3
84	NEFİSE-NECİP TEYMUR PRIMARY SCHOOL	2
85	NESRİN MEHMET ABAR PRIMARY SCHOOL	2
86	NİLGÜN İSMET AKINALAN PRIMARY SCHOOL	3
87	23 NİSAN MIDDLE SCHOOL	3
88	NUREL ENVER TANER MIDDLE SCHOOL	2
89	NURİ PAZARBAŞI MIDDLE SCHOOL	4
90	NURİYE ZEKERİYA KINA MIDDLE SCHOOL	4
91	OSMANGAZİ MIDDLE SCHOOL	3
92	ÖMER ÖZMİMAR ANATOLIAN IMAM HATIP HIGH SCHOOL	2
93	ÖZDEMİR BEY PRIMARY SCHOOL	3
94	ÖZEL İDARE ANATOLIAN HIGH SCHOOL	2
95	ÖZEL İDARE PRIMARY SCHOOL	2
96	SANI KONUKOĞLU PRIMARY SCHOOL	1
97	SEBİHA RIFAT KALEOĞLU MIDDLE SCHOOL	2
98	SENA BÜYÜKKONUK PRIMARY SCHOOL	3
99	SERVİ ERDEMOĞLU VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	2
100	SEVİL ARİF DEVELİ MIDDLE SCHOOL	3
101	SEVİNÇ BAHATTİN TEYMUR GIRL ANATOLIAN IMAM HATIP HIGH SCHOOL	4
102	ŞAHİNBEY EMPATİ PRIMARY SCHOOL	3
103	ŞAHİNBEY VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	2
104	ŞAHİNBEY SÜLEYMAN ŞAH PRIMARY SCHOOL	2
105	ŞAİR NABİ MIDDLE SCHOOL	1
106	ŞEHİR ÖMER HARUN DEMİR GIRL ANATOLIAN IMAM HATIP HIGH SCHOOL	2
107	ŞEHİT ADEM YAVUZ PRIMARY SCHOOL	3
108	ŞEHIT FERHAN GÖZEN PRIMARY SCHOOL	2
109	ŞEHİT İSA KARAKAŞ MIDDLE SCHOOL	3
110	ŞEHİT MEHMET DEMİR GIRL ANATOLIAN IMAM HATIP HIGH SCHOOL	4
111	ŞEHİT ÖĞRETMEN HAYRİ KAYA MIDDLE SCHOOL	3
112	ŞEHİT SAMET KAYMAKÇI IMAM HATIP MIDDLE SCHOOL	2
113	ŞEHİT YUSUF ERİN MIDDLE SCHOOL	3
114	ŞEHİTKAMİL MIDDLE SCHOOL	2
115	TAHSİN YENTUR PRIMARY SCHOOL	1
116	TEPEBAŞI ANATOLIAN HIGH SCHOOL	2
117	TOBB SCIENCE HIGH SCHOOL	3
118	TURGUT ÖZAL MIDDLE SCHOOL	3
119	ÜLGAN KONUKOĞLU VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	2
120	ÜLGER KEPKEP MIDDLE SCHOOL	3
121	ÜNLER MIDDLE SCHOOL	4
122	VALİ M.LÜTFULLAH BİLGİN MIDDLE SCHOOL	3
123	VALİ MUAMMER GÜLER PRIMARY SCHOOL	2
124	VEDAT TOPÇUOĞLU ANATOLIAN HIGH SCHOOL	1
125	VEHBİ DİNÇERLER SCIENCE HIGH SCHOOL	2
126	YAHYA KEMAL BEYATLI ANATOLIAN HIGH SCHOOL	3
127	YASEMİN ERMAN BALSU ANATOLIAN HIGH SCHOOL	4
128	YAVUZ SULTAN SELIM VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	3
129	YEŞİLEVLER İMKB ANATOLIAN HIGH SCHOOL	3
130	YUNUS EMRE PRIMARY SCHOOL	2
131	19 MAYIS VOCATIONAL AND TECHNICAL ANATOLIAN HIGH SCHOOL	1
132	25 ARALIK MIDDLE SCHOOL	2
133	30 AĞUSTOS PRIMARY SCHOOL	2
134	100.YIL PRIMARY SCHOOL	3
	Total demand (number of exam boxes)	351

The exam booklets are transported via a box. Therefore, the demand unit is determined a box which is shown in Figure 3. There are 13 (K) vehicles and each vehicle has a capacity of 30 boxes (Q).

Figure 3. *The box of exam booklets*

To calculate the distances (meters) between all nodes, ESRI ArcGIS 10.2 software is used. To do so, the road network is vectored as line features. While the nodes are entered as a point layer, roads are entered as a line layer. Then, line-shape road layer is used to generate network between all nodes [12]. The distances (c_{ij}) (meters) between all nodes (135x135 matrix) are obtained by ESRI ArcGIS 10.2 software. The locations of all nodes are demonstrated in Figure 4.

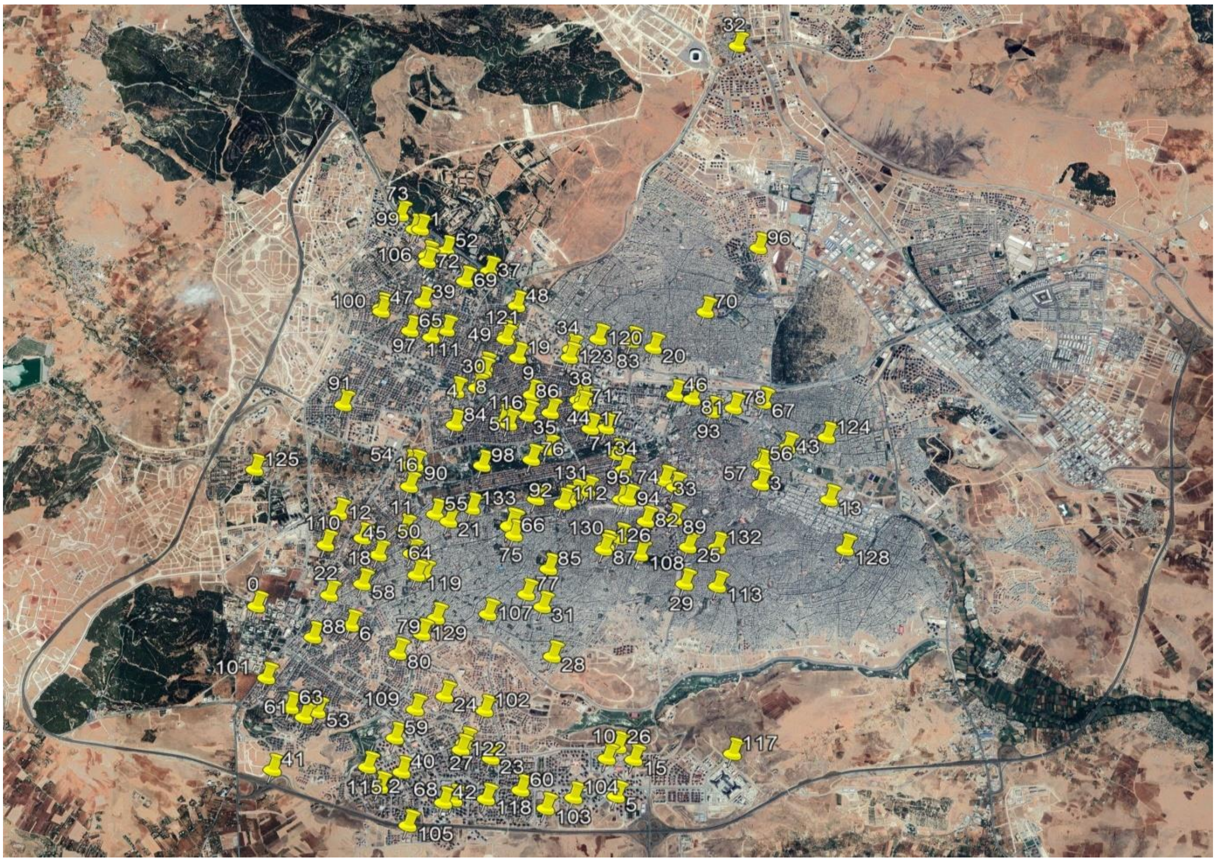

Figure 4. *Locations of nodes*

4.2. Computational Results

In this section, the mathematical formulation for the problem is solved using GAMS-CPLEX 23.8 version. It must be noted that all runs were completed on a PC with 2.8 GHz Intel Core i7 processor and 8 GB of RAM. Due to large size of the problem, a time limit of three hours is set to terminate the model. A feasible solution with 12 routes is obtained with a total distance of 248,629.00 meters. The routes are given in Table 3. According to the Table 3, all schools are visited with 12 vehicles. All demand is satisfied. While the vehicles #1 to 4, 7 and 9 used their capacities fully, the capacity utilization of the vehicle in route #11 is only 86.67%. The routes of vehicles #1 and 11 are illustrated in Figure 5. It is clear to see that among 13 vehicles, 12 of them are enough to distribute all demand. While 11 vehicles use their capacities at least 97%, only one vehicle which has lowest number of boxes and visited schools stays at 86.67%. The main drawback of this solution is computational time. VRP is an operational decision that requires quick decision. Thus, faster solution approaches are needed.

Table 3. *The feasible routes obtained by GAMS-CPLEX*

Vehicle	Route	Traveled distance (m)	# of boxes	# of schools	Capacity Utilization (%)
1	0→12→8→19→49→127→4→30→116→62→84→0	16,374.00	30	10	100.00
2	0→18→98→133→21→55→16→54→90→111→97→65→0	17,657.00	30	11	100.00
3	0→27→122→42→68→118→103→60→2→40→115→41→0	22,114.00	30	11	100.00
4	0→29→113→3→57→56→43→124→13→128→132→25→58→0	25,690.00	30	12	100.00
5	0→35→51→17→44→7→108→130→126→87→114→66→75→0	19,287.00	29	12	96.67
6	0→76→9→121→48→34→120→123→14→38→71→0	20,076.00	29	10	96.67
7	0→86→70→32→96→67→78→93→81→46→83→20→0	36,008.00	30	11	100.00
8	0→88→6→80→129→79→107→77→28→31→85→11→45→0	16,068.00	29	12	96.67
9	0→134→33→74→89→82→94→95→36→131→92→112→0	16,588.00	30	11	100.00
10	0→109→24→102→104→5→117→15→26→10→23→105→59→0	25,346.00	29	12	96.67
11	0→101→63→53→61→22→64→119→50→110→0	12,067.00	26	9	86.67
12	0→91→39→72→69→37→52→1→99→73→106→47→100→125→0	21,354.00	29	13	96.67
	Average	20,719.00	29.25	11.17	97.50
	Total	248,629.00	351	134	

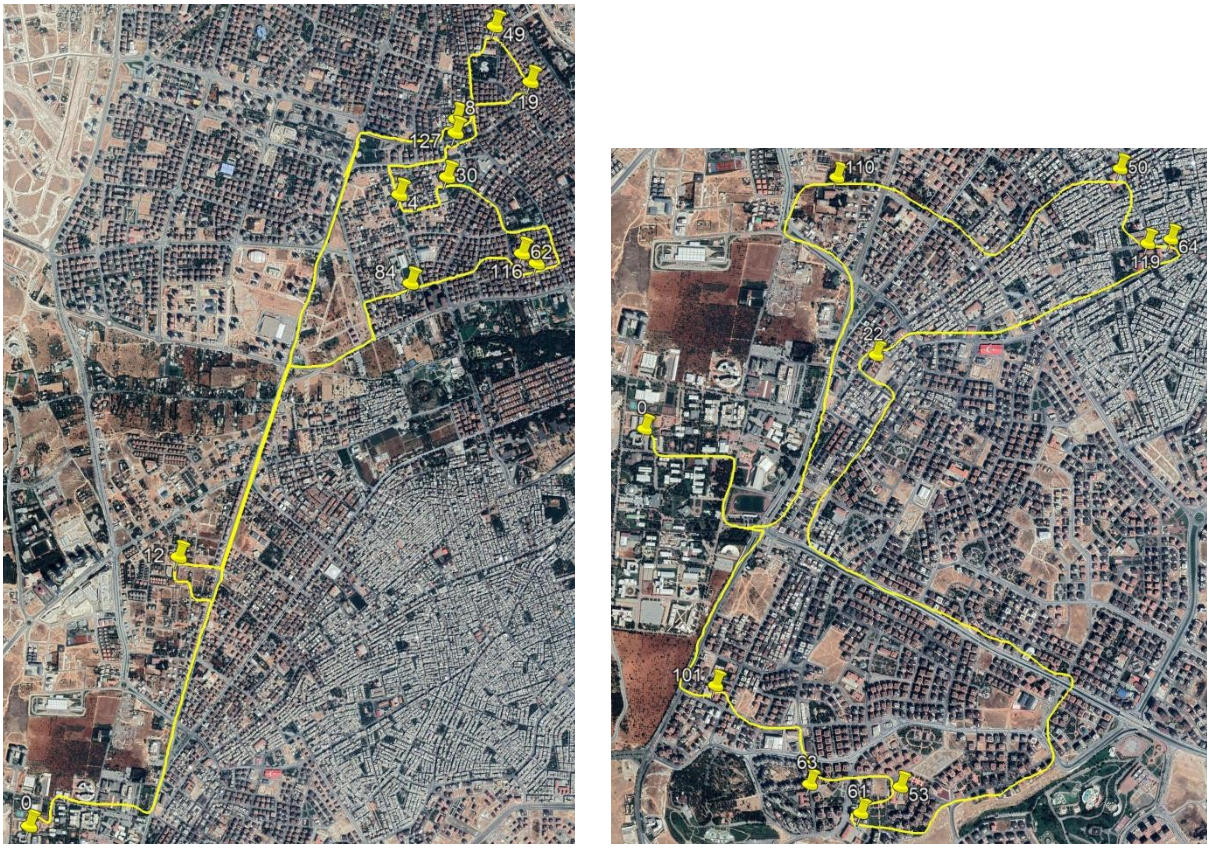

Figure 5. *Feasible routes of vehicle #1 (left) and #11 (right) obtained by GAMS-CPLEX*

In addition to the MIP solution, the case is solved using ArcGIS network analyst tool. Due to running of tabu search approach in the background of ArcGIS, a feasible solution is obtained in 30 seconds. Obtained 12 routes are given in Table 4 and the illustrations of the routes are presented in Figure 6. As can be seen from Table 4, ArcGIS provides 228,211.74 meters that is 8.21% shorter than MIP solution. Similar to the MIP solution, the same number of vehicles (12) is also used in the solution of ArcGIS. Although the average capacity utilization rate is the same with the MIP solution, the number of vehicles with 100% capacity utilization rate is eight that is bigger than the MIP solution.

Table 4. *The feasible routes obtained by ArcGIS network analyst tool*

Vehicle	Route	Traveled distance (m)	# of boxes	# of schools	Capacity Utilization (%)
1	0→22→58→45→50→119→64→79→129→80→6→88→0	10,615.69	25	11	83.33
2	0→33→56→57→13→128→117→15→26→10→5→104→0	30,116.12	30	11	100.00
3	0→81→46→20→83→120→34→48→121→49→19→0	21,594.91	30	10	100.00
4	0→114→36→3→43→124→78→93→67→70→96→32→37→69→0	36,154.32	30	13	100.00
5	0→27→122→40→2→115→59→53→61→63→101→0	12,952.30	29	10	96.67
6	0→18→55→21→133→98→90→54→16→12→110→0	11,651.10	29	10	96.67
7	0→84→62→116→51→9→8→127→30→4→91→125→0	16,670.69	30	11	100.00
8	0→109→24→102→23→60→103→118→68→42→105→41→0	17,339.52	28	11	93.33
9	0→11→66→75→112→92→131→95→94→130→126→85→31→77→107→0	15,365.45	30	14	100.00
10	0→76→35→7→134→44→17→71→38→14→123→86→0	17,975.01	30	11	100.00
11	0→87→108→82→89→74→25→132→113→29→28→0	19,184.83	30	10	100.00
12	0→47→100→106→73→99→1→52→72→39→65→97→111→0	18,591.80	30	12	100.00
	Average	19,017.65	29.25	11.17	97.50
	Total	228,211.74	351	134	

Figure 6. *Feasible routes of vehicle #5 (left) and #6 (right) obtained by ArcGIS*

As a final approach, the OR-tool of Google is also tested on the same case. On the web page of Google OR-tools [19], Python code is directly used with only data modification. The code is run on Python 3.7 and the feasible result is obtained in 1 second. The details of obtained routes are given in Table 5 and the illustrations are shared in Figure 7. According to Table 5, the total distance of 12 routes is calculated as 241,110.00 meters that is 3.02% shorter than MIP solution and 5.35% longer than ArcGIS solution. When looking at capacity utilization rates, the maximum number of vehicles with 100% rates is obtained in the solution of Google OR-tool.

Table 5. *The feasible routes obtained by Google OR-tools*

Vehicle	Route	Traveled distance (m)	# of boxes	# of schools	Capacity Utilization (%)
1	0→4→30→8→19→49→121→96→32→37→52→0	31,601.00	30	10	100.00
2	0→125→69→48→34→120→83→20→70→124→67→78 →7→0	28,776.00	30	12	100.00
3	0→107→28→29→74→33→134→44→17→71→84→0	20,742,00	29	10	96.67
4	0→114→131→36→95→94→82→89→25→132→128→11 3→58→0	20,984.00	30	12	100.00
5	0→38→14→123→46→81→93→56→57→43→13→3→0	24,425.00	30	11	100.00
6	0→6→77→31→85→87→108→130→126→92→112→75 →66→133→50→0	16,101.00	30	14	100.00
7	0→26→15→10→117→5→104→103→60→118→68→105 →41→0	23,111.00	30	12	100.00
8	0→91→65→97→111→39→72→1→99→73→106→100→ 47→0	19,100.00	30	12	100.00
9	0→110→127→9→86→51→62→116→35→76→98→18→ 0	15,846.00	30	11	100.00
10	0→12→54→90→16→55→21→11→45→0	9,737.00	23	8	76.67
11	0→101→63→61→53→59→115→2→40→42→109→88→ 0	14,537.00	30	11	100.00
12	0→119→64→79→129→102→23→122→27→24→80→22 →0	15,150.00	29	11	96.67
	Average	20,092.50	29.25	11.17	97.50
	Total	241,110.00	351	134	

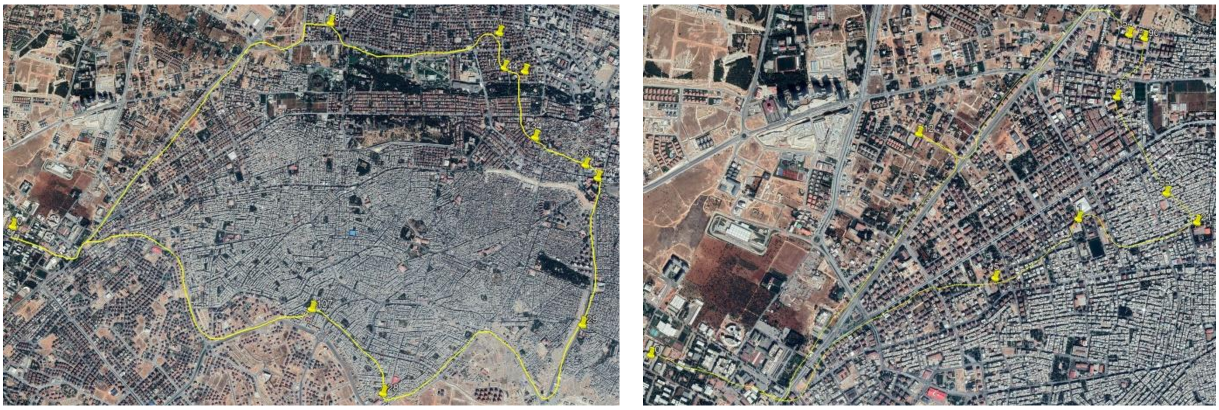

Figure 7. *Feasible routes of vehicle #3 (left) and #10 (right) obtained by Google OR-tools*

The main performance indicators obtained by three different approaches – namely GAMS-CPLEX, ArcGIS and Google OR-tool – are summarized in Figure 8 and Table 6. The values in Figure 8 are the normalized. According to the Figure 8, Esri ArcGIS provides the minimum traveled distance among other approaches. On the other hand, the number of vehicles that are used fully is highest in the solution of Google OR-tool. In terms of the solution time, although Esri ArcGIS and Google OR-tool can find a feasible solution in a very short time (less than 30 seconds), Google OR-tool is faster than Esri ArcGIS. GAMS-CPLEX is not a good option to get a feasible solution according to the three performance indicators due to the size of the problem. As a result, while decision-makers should choose the Google OR-tool to make decisions very quickly, ArcGIS is an option to reach the minimum traveled distance.

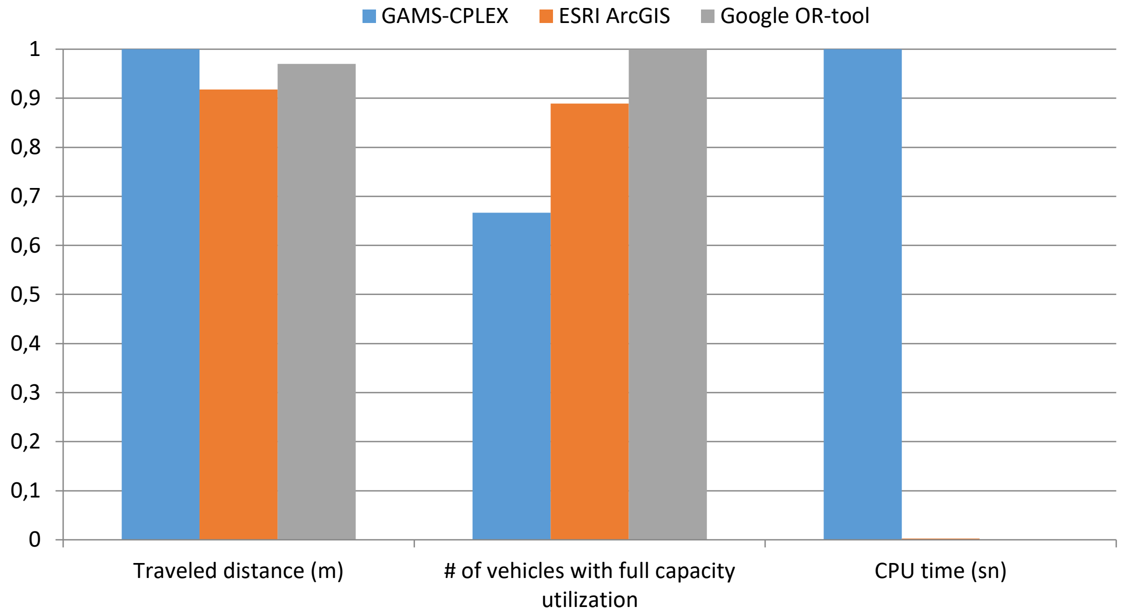

Figure 8. *General comparison of three approaches*

Table 6. *Comparative results of three approaches*

	GAMS-CPLEX	ESRI ArcGIS	Google OR-tool
Traveled distance (m)	248,629.00	228,211.74	241,110.00
CPU time (s)	10,800.00	30.00	1.00

To evaluate the performance of ESRI-ArcGIS and Google OR-tool, the small portion of the case problems is used. A small problem that includes the first 12 schools is solved with three approaches. The optimal solution obtained by GAMS-CPLEX is given in Table 7. The other two heuristic approaches also provide the optimal solution in less than one second.

Table 7. *The result of small sized problem*

	Optimal routes	Total Traveled Distance (m)
Vehicle#1 (Route#1)	0→2→10→5→3→7→9→8→1→4→12→0	41,236.00
Vehicle#2 (Route#2)	0→6→11→0	

5. CONCLUSION

This study has been motivated by the problem of exam booklet distribution arising in the city of Gaziantep. Due to the structure of the problem, the case is defined as a CVRP that includes 135 nodes and 13 identical vehicles. To solve the problem, a MIP formulation is applied and a feasible solution is obtained under a time limit (three hours). Although it is a feasible solution, the MIP solution reduces the required number of vehicles by 1. To get an acceptable solution in a reasonable time, two different approaches namely ArcGIS network analyst and OR-tool of Google are also applied to the same problem. Both approaches provide shorter distances than the MIP solution in less than 30 seconds. While ArcGIS network analyst tool results the minimum total distance, OR-tool of Google is the fastest approach in terms of central process unit (CPU) time. In all three results indicated that 12 vehicles are enough to satisfy the exam booklet demand of schools. Therefore, one vehicle is saved. To test the optimality of ArcGIS and Google OR-tools, a small portion (including the first 12 schools) of the case problem is solved. All three approaches provide the optimal solution in less than 1 second. The maximum number of nodes for which the mathematical model gives the optimum solution is also investigated. The problem with 34 nodes is solved optimally in three hours. The running times of the approaches (except MIP solution) are so small that the proposed approaches can be used in practice.

For the future studies, (*i*) exact solutions such as branch-price-and-cut algorithms can be applied to obtain the optimal solution; (*ii*) a web-based decision support system can be developed to provide real time guidance; and (*iii*) time windows for each school can be added to the model.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

ACKNOWLEDGEMENT

The authors thank three anonymous reviewers and section editor whose comments have been helpful in improving an earlier version of the paper.

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