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Optimizing Routes and Schedules of Occupational Health and Safety Specialists

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Abstract: According to the occupational health and safety law of 6331, companies employing a certain number of workers or focusing on a certain level of hazardous works must employ a full-time occupational health and safety (OHS) professional or be serviced by a part-time one for prespecified durations. Many companies prefer to be serviced by part-time specialists since it is more cost-effective. Specialists working for independent joint health and safety units visit companies and service during predefined times daily basis by starting and ending the tours from/to their homes or offices. They spend long times between visits in traffic. Therefore, minimizing the travel distances of specialists creates leisure times for rest and service. This problem is very similar to the Vehicle Routing Problem that has already been studied and applied in many areas varying from logistics to security for long years. In this study, the daily routing and scheduling activities of a specialist based on three scenarios are modeled with mixed-integer linear programming, frequently used to solve VRPs. Optimal routes and schedules for three scenarios are demonstrated and discussed. The study's main aim is to show decision-makers and specialists in the OHS area how to use operations research tools in their daily basis activities.

Keywords: Occupational Health and Safety, Vehicle Routing Problem, Mixed Integer Linear Programming, Operations Research

İş Sağlığı ve Güvenliği Uzmanlarının Rotalarının ve Çizelgelerinin Optimizasyonu

Öz: 6331 sayılı İş Sağlığı ve Güvenliği (İSG) Yasasına göre belirli sayıda işçi çalıştıran ve bazı tehlike sınıfında üretim yapan işletmeler ya tam zamanlı İSG uzmanı çalıştırmalı ya da yarı zamanlı bir İSG uzmanından aylık belirli sürelerde danışmanlık hizmeti almalıdır. Birçok işletme maliyet açısından daha uygun olduğundan yarı zamanlı uzmanları tercih etmektedir. Bağımsız ortak sağlık ve güvenlik birimlerinde çalışan uzmanlar günlük evlerinden veya ofislerinden başlayıp, yine evlerinde veya ofislerinde bitirmek üzere anlaşmalı işyerlerini sırayla ziyaret edip, hizmet sunmaktadırlar. Bu ziyaretler sırasında trafikte oldukça fazla vakit kaybı yaşanmaktadırlar. Uzmanların günlük katetikleri yolları en aza indirmenin hem dinlenme hem de hizmet süresine katkısı olacaktır. Bu problem, lojistikten güvenliğe birçok alanda uygulanmış olan Araç Rotalama Problemi 'ne (ARP) çok benzemektedir. Bu çalışmada, 3 farklı senaryoya göre İSG uzmanlarının rotalama ve çizelgeleme aktiviteleri, ARP'lerin çözümünde sıkça kullanılan karışık tam sayılı doğrusal programlama metodu ile modellenmiştir. Üç farklı senaryoya göre sonuçlar analiz edilip tartışılmıştır. Bu çalışmanın ana amacı İSG alanında çalışan karar vericilere ve uzmanlara, yöneylem araştırmaları metotlarının günlük operasyonlarda nasıl kullanılabileceğini göstermektedir.

Anahtar Kelimeler: İş Sağlığı ve Güvenliği, Araç Rotalama Problemi, Karışık Tam Sayılı Doğrusal Programlama, Yöneylem Araştırmaları

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1. Introduction

Vehicle Routing Problem (VRP) is basically to seek minimization of travel times of vehicles visiting the number of locations in a predetermined region by starting and finishing their tours from/to the same depot. The first VRP is carried out by Dantzig and Ramser [1], in the study entitled, “The Truck Dispatching Problem”, 1959. They aimed to minimize the travel distances of the number of tankers that carry gasoline from a central depot to stations in a city. Many different studies considering a variety of constraints such as time windows, capacity, heterogeneity, multi-depots, etc., a variety of objectives such as minimization of travel times, waiting times, lateness, maximization of customers` satisfactions, the utility of vehicles, single, bi, multi objectives, etc. have been carried out since then [2-3]. Not only different objectives and constraints but also a variety of application areas for VRP can be seen in the literature. Ambulance routing problems [4-5], the routing of police patrols [6-7], home caregiver routing problems [8-9], city courier routing problems [10], waste collection [11], online shopping [12], food delivery [13], taxi share [14], can be shown as examples of VRP applications. Since VRP literature is vast, we suggest interested readers to review the following studies [15-18].

As we mentioned before, VRP is to seek optimal routes for multiple vehicles visiting several locations in a planning horizon. Each vehicle starts its journey from a central depot, visits a predetermined number of locations in a time interval, and returns to the central depot as can be seen in Figure 1. From the mathematical perspective, this problem can be described as a graph $G = \{V, A, C\}$ formed by a set of vertices, $V = \{v_0, v_1, \ldots, v_n\}$, a set of arcs connecting the vertices, $A = \{(v_i, v_j) | (v_i, v_j) \in V^2, i \neq j\}$, and a cost matrix, $C = (C_{ij})_{(v_i, v_j) \in A}$, in terms of distance or time cost between two locations. In this sense, VRP is a combinatorial optimization problem in NP-Hard class. Therefore, the number of feasible solutions exponentially rises when the number of locations increases. Many heuristic methods such as the nearest neighbor search, Clark and Wright algorithm, and metaheuristic methods such as simulated annealing, genetic algorithm, tabu search, ant colony optimization have been proposed as solution methods besides exact solution methods as integer, mixed-integer linear, stochastic programming approaches that find solutions for relatively small instances [19].

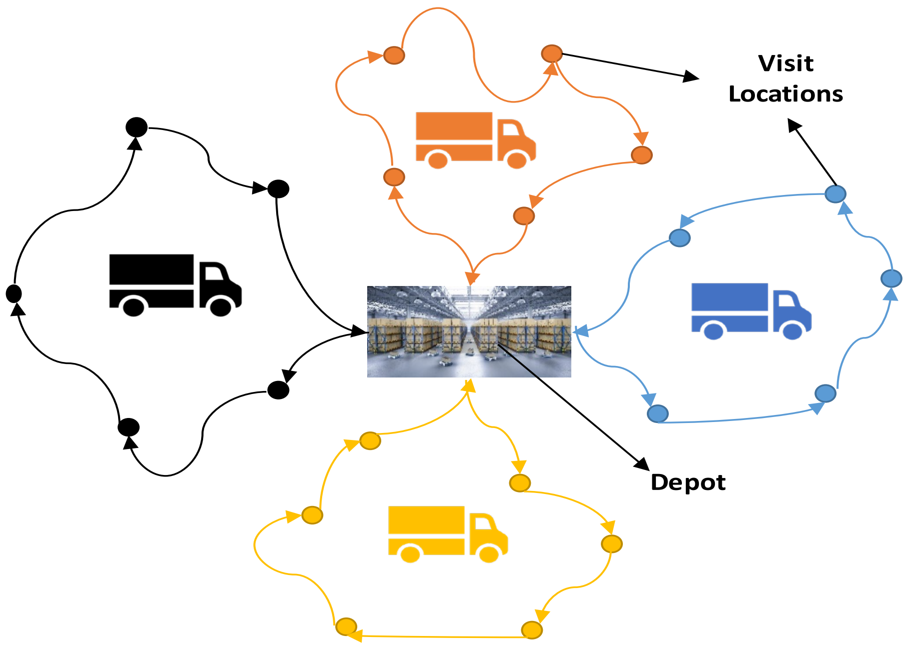

Figure 1. Vehicle Routing Problem

In this study, we consider a new problem related to VRP closely. According to the occupational health and safety law of 6331 [20], companies employing more than a certain number of workers or focusing on a certain level of hazardous works must employ a full-time occupational health and safety professional or be serviced by part-time occupational health and safety professional in a monthly prespecified durations [21]. Many companies that do not have to employ a full-time occupational health and safety professional prefer to be serviced by a part-time one who works in independent joint health and safety units since it is more cost-effective. Therefore, many professionals work in independent joint health and safety units to service a variety of companies daily. Each worker starts his/her tour from his/her home or workplace, visits and services the prespecified companies, and returns to his/her home or workplace at the end of the day. As we mentioned earlier, this problem is similar to VRP. Although VRP studies in the literature are vast, the only study we have found in the literature to consider optimizing routing activities of occupational health and safety professionals is the study of Etoz and Tulga [21]. They work with an independent joint health and safety unit that employs 3 professionals and services 20 companies in Antalya city in Turkey. First, all visit points are clustered in terms of the number of employees and optimal routes are constructed for each employee by considering daily working and travel times.

In this study, we consider a similar problem with different objectives and constraints. We collect necessary data from an occupational health and safety professional servicing 38 companies in Istanbul, the biggest city in Turkey. Our model is shaped based on his requirements demonstrated as followings:

- What is the minimum number of days in a month the specialist needs to service all companies by satisfying obligatory service times and ignoring travel times?
- How do the productivity levels and daily travel distances change when the number of working days increases from minimum to maximum for a month?
- If one more professional is employed, what is the minimum number of days in a month they need to work by considering daily working and travel times, and what are the schedules of the two specialists?

These requirements are not limited to a specialist, but also many independent joint health and safety units and workers are dealing with similar problems daily. Therefore, it is important to answer these questions from the perspective of VRP and operations research methods. Mixed Integer Linear Programming models are constructed and solved based on a variety of constraints raised by the above requirements. We believe that our study raises awareness of VRP and operations research methods among companies and professionals for solutions to daily problems.

In the next section, necessary data, scenarios, and the solution method are presented. In Section 3, the results for each scenario are shown and discussed. We conclude our study and discuss future research possibilities in Section 4.

2. Experimental Methods

2.1. Model Data

The specialist services 38 companies with different hazard classes and workers as can be seen in Figure 2. According to the law of 6331 [22], each specialist must service 10 minutes per worker in less hazardous workplaces, 20 minutes per worker in hazardous workplaces, and 40 minutes per worker in very hazardous workplaces. Table 1 shows the number of workers, hazard classes, and associated service times for each company.

Figure 2. Locations of companies and the office

Table 1. The number of workers, hazard classes, and associated service times for each company

Companies	Workers	Hazard Class	Service Time (Min.)	Companies	Workers	Hazard Class	Service Time (Min.)
1	29	Hazardous	580	**20**	5	Hazardous	100
2	25	Hazardous	500	**21**	4	Hazardous	80
3	15	Hazardous	300	**22**	7	Hazardous	140
4	5	Hazardous	100	**23**	5	Hazardous	100
5	10	Hazardous	200	**24**	42	Hazardous	840
6	28	Hazardous	560	**25**	1	Very Hazard.	40
7	10	Hazardous	200	**26**	30	Hazardous	600
8	6	Hazardous	120	**27**	29	Hazardous	580
9	13	Hazardous	260	**28**	10	Hazardous	200
10	14	Hazardous	280	**29**	3	Hazardous	60
11	17	Hazardous	340	**30**	32	Less Hazard.	320
12	20	Hazardous	400	**31**	14	Hazardous	280
13	3	Very Hazard.	120	**32**	1	Hazardous	20
14	2	Very Hazard.	80	**33**	3	Hazardous	60
15	5	Less Hazard.	50	**34**	25	Hazardous	500
16	2	Less Hazard.	20	**35**	19	Very Hazard.	760
17	32	Less Hazard.	320	**36**	16	Hazardous	320
18	9	Hazardous	180	**37**	22	Hazardous	440
19	5	Less Hazard.	50	**38**	23	Hazardous	460

A specialist has a 480-minute working time and a 30-minute overtime daily based on the associated law. We consider both 480- and 510-minute service times according to the aforementioned requirements. Since some companies need to be serviced longer than the maximum daily service time, service times for these companies are divided into two parts. For example, the specialist must work 510 minutes in a day and 330 minutes on another day for Company 24 which needs to be served a total of 840 minutes in a month. If 480-minute daily working times are taken into consideration, the specialist must work 480 and 360 minutes on two different days. Since the companies whose service times exceed the daily working times for the specialist must be visited for at least two days, a dummy visit point is created for each of them. Total 44 visit points for 510-minute daily working times and 46 visit points for 480-minute daily working times are defined by considering dummy visit points.

According to Table 1, the total time the specialist must work in a month is 10560 minutes. He must work at least 21 days (10560/510 = 20.71) in a month. The specialist mentions that he can work a maximum of 24 days a month. If one more specialist is employed, the least number of days each specialist must work is 11 (10560/(480*2) = 11). Note that travel times between visit points must be taken into consideration when the extra specialist is employed. According to the above conditions, three scenarios are generated as follows:

- Scenario 1: Minimizing travel distances of one specialist under 510-minute daily service times in 21 days and ignorance of travel times between visit points.
- Scenario 2: Observing daily travel distances and workloads of one specialist between the minimum (21 days) and maximum (24 days) monthly working days under 510-minute daily service times and ignorance of travel times between visit points.
- Scenario 3: Minimizing working days and travel distances of two specialists under 480-minute daily service times and consideration of travel times between visit points.

Note that ignorance of travel times among visit points in Scenario 1 and 2 is a preference of the OHS specialist. We have address information for each company and the office where the specialist starts and finishes his tours. Google Map Platforms and Geolocation Services are used to calculate travel distances among all visit points. By considering the office`s location as the starting point, we have 45x45 and 47x47 distance matrices.

2.2. Solution Method

We proposed mixed-integer linear programming models with different constraints based on the requirements of the specialist. Mixed-integer linear programming has been frequently used to solve a variety of VRPs. In this problem, the mathematical model is mainly derived from studies of Demirbilek [23-24] and Montane & Galvao [25]. For scenarios 1 and 2, variables, parameters, and the model are as follows:

Notations:

N: the number of companies
V: a set of companies
V_0: a set of companies and the office
D: a set of days
c_{ij}: distance between locations of Company i and j
T: working time limit for a day
S_i: service time for Company i

Decision Variables:
x_{ijk} = 1, if the specialist moves from customer *i* to *j* in day *k*. 0, otherwise.
u_i = The variable preventing sub-tour after node *i*

Minimize:

$$\sum_{k}^{D}\sum_{i}^{V_0}\sum_{j}^{V_0} c_{ij}x_{ijk} \quad i \neq j \tag{1}$$

Subject to:

$$\sum_{k}^{D}\sum_{i}^{V_0} x_{ijk} = 1, \quad \forall j \in \mathrm{V} \tag{2}$$

$$\sum_{j}^{V} x_{0jk} \leq 1, \quad \forall k \in D \tag{3}$$

$$\sum_{j}^{V} x_{j0k} \leq 1, \quad \forall k \in D \tag{4}$$

$$\sum_{i}^{V_0} x_{ijk} - \sum_{i}^{V_0} x_{jik} = 0, \ \forall j \in V_0, \forall k \in D, i \neq j \tag{5}$$

$$\sum_{i}^{V_0}\sum_{j}^{V} S_j x_{ijk} \leq T, \ \forall k \in D, i \neq j \tag{6}$$

$$u_i - u_j + n(x_{ijk}) \leq n-1, \quad \forall i, \forall j \in \mathrm{V}, \forall k \in D, i \neq j \tag{7}$$

$$x_{ijk} \in \{0,1\}, \ \forall i, \forall j \in \mathrm{V}_0, \forall k \in D, \ i \neq j \tag{8}$$

$$u_i \geq 0, \ \forall i \in \mathrm{V}, \ i > 1 \tag{9}$$

The objective is to minimize total travel distances among visits (1). Constraint 2 ensures that each company must be visited. Constraints 3 and 4 guarantee that the specialist starts the tour from his office and finishes it at the office at the end of the day. Constraint 5 provides that the specialist arrives and departs from each customer on the same day. Constraint 6 limits daily service times to the maximum daily working time. Constraint 7, the sub-tour elimination constraint of Miller, Tucker, and Zemlin [26], prohibits sub-tours while constraints 8 and 9 show boundaries of decision variables.

As we mentioned before, two specialists and travel times between visits are taken into consideration for scenario 3. Furthermore, the same specialist must visit a company more than once if the obligatory service time for the company is longer than the daily working time. Under these circumstances, constraints and the decision variable for the scenario 3 are represented as follows:

Notations:
W: a set of workers
l: a coefficient turning travel distance (km) to travel time (minute)

Decision Variables:
x_{ijdk} = 1, if the specialist *d* moves from customer *i* to *j* in day *k*. 0, otherwise.

Minimize:

$$\sum_{k}^{D}\sum_{d}^{W}\sum_{i}^{V_0}\sum_{j}^{V_0} c_{ij}x_{ijdk} \quad i \neq j \tag{10}$$

Subject to:

$$\sum_{k}^{D}\sum_{d}^{W}\sum_{i}^{V_0} x_{ijdk} = 1, \quad \forall j \in \mathrm{V} \tag{11}$$

$$\sum_{j}^{V} x_{0jdk} \leq 1, \quad \forall k \in D, \forall d \in W \tag{12}$$

$$\sum_{j}^{V} x_{j0dk} \leq 1, \quad \forall k \in D, \forall d \in W \tag{13}$$

$$\sum_{i}^{V_0} x_{ijdk} - \sum_{i}^{V_0} x_{jidk} = 0, \ \forall j \in V_0, \forall k \in D, \forall d \in W, i \neq j \tag{14}$$

$$l\sum_{i}^{V}\sum_{j}^{V} c_{ij}x_{ijdk} + \sum_{i}^{V}\sum_{j}^{V} S_j x_{ijdk} \leq T, \ \forall k \in D, \forall d \in W, i \neq j \tag{15}$$

$$u_i - u_j + n(x_{ijdk}) \leq n - 1, \quad \forall i, \forall j \in \mathrm{V}, \forall k \in D, d \in W, i \neq j \tag{16}$$

$$\sum_{k}^{D}\sum_{i}^{V_0} x_{ijdk} \leq \sum_{k}^{D}\sum_{i}^{V_0} x_{ij+1dk}, \forall j \in \{1,3,8,27,30,32,40,42\}, \forall d \in W, i \neq j \tag{17}$$

$$x_{ijdk} \in \{0,1\}, \ \forall i, \forall j \in \mathrm{V}_0, \forall k \in D, \forall d \in W, \ i \neq j \tag{18}$$

$$u_i \geq 0, \ \forall i \in \mathrm{V}, \ i > 1 \tag{19}$$

The objective function (10) is to minimize the total travel distances of two specialists among visits similar to previous scenarios. Constraints 11 to 14 ensure that each company must be visited by starting from the office and ending daily visits into the office again. Constraint 14 guarantees that the same specialist arrives and departs from each company on the same day. Constraint 15 limits travel times between companies and service times to the daily working time for each specialist. Constraint 16, the sub-tour elimination constraint of Miller, Tucker, and Zemlin [26], prohibits sub-tours. Companies that need more than a visit due to the exceeding service times must be visited by the same specialist (17). Constraints 18 and 19 show the boundaries of decision variables.

Note that the coefficient *l* is calculated according to the dividing of the travel distance between two consecutive visit points by the average speed of specialists assumed at 70 km per hour in the study. First, the mixed-integer linear programming is coded with docplex library for Python programming language and solved with CPLEX 12.9. All tests are carried out in a PC with Intel i5 7200U 2.5 GHz CPU and 8 GB Ram.

3. Results

Table 2 shows daily tours, working times, productivity levels, and travel distances in 21 days. The specialist starts from and ends his tour of the office (0) each day. Since many visits need one-day service time, the specialist can only pay a visit for many days. The productivity level simply means the proportion of actual working time to the maximum working time in a day. For Scenarios 1 and 2, the specialist can work 510 minutes in a day. If the specialist works 460 minutes on Day 6, the productivity level is around 90% (460/510). This rate is important since it shows how intensely the specialist works each day. The average productivity level for 21 days is 98,6%. This result demonstrates that he will be very busy if all visits are scheduled on the minimum monthly working days. The total travel distance for 21 days is 1.048 km whereas the range through days is around 120 km.

Table 2. Daily tours, working times, productivity levels, and travel distances in 21 days (Scenario 1)

Days	Daily Tour	Daily Working Time (Minute)	Productivity (%)	Daily Distances (Km)
1	[0, 26, 0]	510	100	8,66
2	[0, 3, 0]	500	98	44,28
3	[0, 39, 0]	500	98	68,22
4	[0, 40, 0]	510	100	73,33
5	[0, 29, 0]	510	100	92,11
6	[0, 38, 14, 0]	460	90	25,69
7	[0, 4, 6, 0]	500	98	63,04
8	[0, 13, 22, 2, 0]	510	100	64,93
9	[0, 34, 19, 10, 0]	500	98	22,52
10	[0, 27, 20, 0]	510	100	27,87
11	[0, 8, 44, 0]	510	100	13,26
12	[0, 7, 0]	510	100	6,29
13	[0, 36, 5, 30, 28,	510	100	126,90
14	[0, 35, 25, 23, 0]	500	98	86,76
15	[0, 24, 12, 16, 0]	500	98	41,72
16	[0, 31, 0]	510	100	19,31
17	[0, 1, 0]	510	100	44,39
18	[0, 11, 21, 9, 0]	510	100	21,24
19	[0, 33, 37, 41, 0]	470	92	75,95
20	[0, 17, 18, 43, 0]	510	100	81,05
21	[0, 42, 32, 15, 0]	510	100	40,98
	Total	**10560**	**98,6**	**1048,49**

Figure 3 shows comparisons of total distances and productivity levels for 21, 22, 23, and 24 working days as in Scenario 2. First, total travel distance decreases significantly when all visits are scheduled in 22 days instead of 21 as represented with green bars. In this condition, the specialist spends around 12% less time during travel under consideration of the constant speed. However, when monthly working days extend to 23 and 24, declines in total travel distances are relatively low compared to the previous case. On the other hand, the productivity levels reduce more when the number of working days increases.

Figure 3. The changes in total travel distances and average productivity levels of the specialist through different working days (Scenario 2)

Table 3. Daily tours, working times, productivity levels, and travel distances for two specialists (Scenario 3)

Days	Specialists	Tour	Working Time (Minute)	Productivity (%)	Distances (Km)
1	**Specialist 1**	[0, 35, 20, 22, 0]	430	90	19,04
	Specialist 2	[0, 36, 29, 23, 0]	460	96	50,19
2	**Specialist 1**	[0, 11, 13, 0]	400	83	24,28
	Specialist 2	[0, 44, 25, 0]	460	96	23,64
3	**Specialist 1**	[0, 40, 0]	480	100	68,22
	Specialist 2	[0, 42, 0]	480	100	73,33
4	**Specialist 1**	[0, 15, 0]	400	83	10,93
	Specialist 2	[0, 27, 0]	480	100	8,66
5	**Specialist 1**	[0, 8, 0]	480	100	6,29
	Specialist 2	[0, 14, 0]	340	71	21,56
6	**Specialist 1**	[0, 37, 38, 33, 0]	400	83	35,24
	Specialist 2	[0, 39, 18, 19, 43, 0]	410	85	128,14
7	**Specialist 1**	[0, 4, 2, 41, 5, 0]	440	92	73,62
	Specialist 2	[0, 30, 0]	480	100	92,11
8	**Specialist 1**	[0, 46, 0]	460	96	12,47
	Specialist 2	[0, 10, 7, 0]	400	83	42,76
9	**Specialist 1**	[0, 3, 0]	480	100	44,28
	Specialist 2	[0, 34, 12, 0]	460	96	34,12
10	**Specialist 1**	[0, 21, 16, 17, 9, 0]	460	96	22,77
	Specialist 2	[0, 26, 31, 6, 24, 0]	400	83	115,94
11	**Specialist 1**	[0, 32, 0]	480	100	19,31
	Specialist 2	[0, 45, 0]	440	92	10,62
12	**Specialist 1**	[0, 1, 0]	480	100	44,39
	Specialist 2	[0, 28, 0]	360	75	8,66
	Specialist 1	**Total**	**5390**	**93,6%**	**380,85**
	Specialist 2	**Total**	**5170**	**89,8%**	**609,71**

Table 3 shows daily tours, working times, productivity levels, and travel distances for two specialists in 12 days. As we calculated in Model Data Section, each specialist needs around 11 days to service around half of the companies. Of course, we must consider travel times between visit points according to Scenario 3. Each specialist must work around 12 days when travel times are taken into consideration. According to the results, the service times of specialists are quite close to each other. The balance between working times of employees is always preferable. Moreover, the average productivity levels of the two specialists are proximate. However, one specialist spends almost 60% more time than the other in the traffic.

4. Conclusions

Many companies must employ a full-time occupational health and safety professional or be serviced by part-time occupational health and safety professional in a monthly prespecified durations due to the law of 6331. Most of them prefer to be serviced by a part-time occupational health and safety professional since it is more cost-effective. Therefore, a lot of independent joint health and safety units are running to satisfy the demand of companies. Each specialist visits companies and services on a mandatory time daily basis. During visits, specialists spend a great amount of time on the roads.

In this study, Vehicle Routing Problem (VRP), already applied in many areas such as logistics, health, security, etc., is used to minimize travel distances of occupational health and safety specialists. Under consideration of some important restrictions such as daily working times and monthly working days, the problem raised from the daily activities of the specialists is formulized with a mixed linear integer programming approach and solved with CPLEX 12.9 solver. Based on the different needs of a specialist, three scenarios are created and formulized. In the first scenario, minimizing travel distances of one specialist under 510-minute daily service times in 21 days and ignorance of travel times between visit points, results show that OHS specialist has very hectic operation schedules in 21 days with a productivity level of 98%. In the second scenario, observing daily travel distances and workloads of one specialist between the minimum (21 days) and maximum (24 days) monthly working days under 510-minute daily service times and ignorance of travel times between visit points, it can be seen that productivity levels and daily travel distances gradually decrease when the monthly working days incline 21 to 24 days. Finally, in the third scenario, minimizing working days and travel distances of two specialists under 480-minute daily service times and consideration of travel times between visit points, we observed daily optimum schedules for two specialists in terms of travel distances. The workload balance seems good with a difference of 4% between average productivity levels whereas one specialist spends significant time during customer visits compared to the other.

One of the aims of this study is to show how to apply operations research tools to the problem many specialists encountered during daily basis activities. Results show optimum schedules and routes in terms of total travel distances for specialists by satisfying their daily and monthly working times. Moreover, daily and average productivity levels are provided to the specialist to decide the distribution of visits on different working days.

Since many specialists are not familiar with operations research tools, user-friendly software can be developed to schedule the daily basis activities of specialists by seeking minimum travel distances and satisfying working constraints. This ensures that decision-makers can evaluate different alternatives in terms of travel distances, the number of professionals, and productivity levels.

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Authors' Contributions

MD and SÖD designed the structure. SÖD inspected and evaluated the associated laws and data. Moreover, she helps write the publication. MD created and modeled scenarios, and solved problems.

Both authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

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