A New Method for Routing in Home Health Care Services

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Abstract: *Home Health Care Service (HHC) is a continuously growing new model in the healthcare sector. In HHC, patients are treated in their homes rather than at a healthcare provider. Treatment of patients in their own homes reduces health expenditures and increases the patient satisfaction at the same time. In HHC, the patients to be visited during the work day are determined in advance, necessary visits are made to the patient addresses, and treatment and care are provided to the patients at home. In this study, it was demonstrated that HHC problem can be solved by modeling it in a manner similar to Capacity Restricted Vehicle Routing Problem (C-VRP). In the new model obtained, the vehicles included in C-VRP, healthcare teams, the number of vehicles on hand, the number of healthcare teams active, customer addresses, patient addresses, vehicle capacity, daily working time of healthcare workers, the amount of load to be delivered to the customer, time to be spent for patient care or treatment at patient addresses were all included. Then, the obtained model was tried to be solved by using a heuristic approach. Experimental studies have shown that it is possible to prepare routes for patient visits in a way that does not exceed the daily working time of health workers.*

Keywords: *home health care routing; vehicle routing problem; optimization; heuristic; saving algorithim.*

1. Introduction

Vehicle Routing Problem (VRP), which covers many different areas of application such as the distribution of cargo, newspaper, mail and medical needs, and chemical waste collection, cannot be easily solved with classical methods (Ünsal & Yigit, 2018). VRP basically refers to the process of moving between points on a road network. The presence of multiple routes and transportation options between the points has prompted studies on the shortest distance or the least costly route for navigation between the points. Home healthcare Vehicle Routing Service (HHC-VRP) is a sub-branch of the classical VRP. The aim of HHC-VRP is to offer treatment and care to patients and the elderly in need of care with home visits by a mobile healthcare team. HHC-VRP was first developed in developed countries such as USA and France and it is a service that was initiated in Turkey in the recent years.

The expected average life expectancy at birth in Turkey has increased: according to the data of Turkey Statistical Institute (TSE), the rate of people over 65 to the total population was 5.7% in 2000 and this number has increased to 7.2% in 2010 and reached 8.3% in 2016. According to the predictions of TSE, population over 65 will reach to a point between 10.1 - 10.2% by 2023 and a point between 17.6 - 20.8% by 2050 (TSE, 2018). These figures demonstrate that our country is aging. This increase in the expected life expectancy at birth raises the issue of increase in chronic diseases and care problems (Fikar & Hirsch, 2017). The increasing number of people in need of care also drives up the costs in healthcare expenditures related to short-term and long-term care. Many countries around the world have developed home health care systems to reduce short and long-term care costs. Home health care has emerged for the first time in the United States (USA) and has developed rapidly and became a sector in which many people are employed. Figure 1.1 displays a graphic that demonstrates the development of home health care sector in USA between 2006 and 2017.
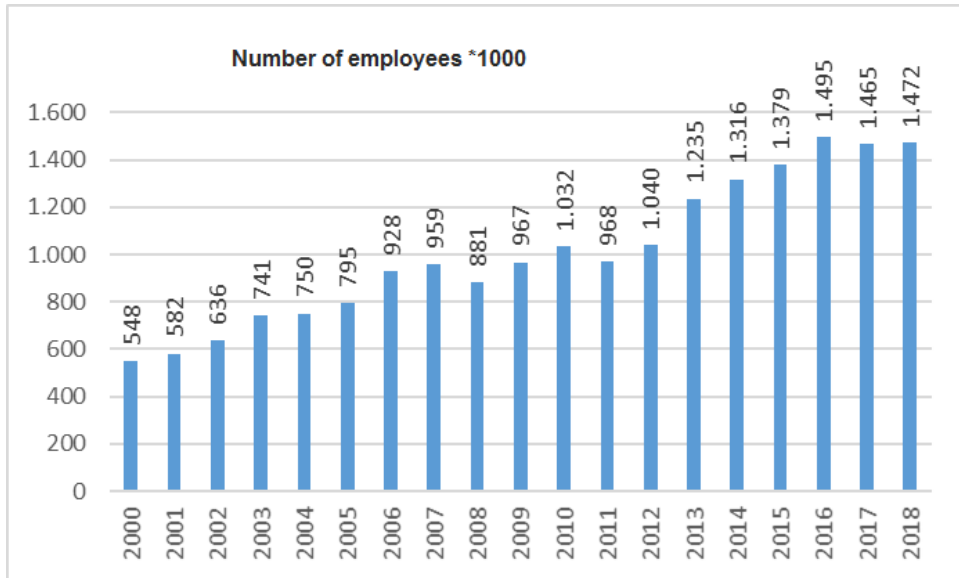
Figure 0.1 Number of employees working in USA in home health
care sector between 2006-2017 (Https://www.statista.co)

As it can be seen in Figure 1.1, there have been significant increases
in the number of staff who provides services to patients at home. This
increase in the number of personnel in the sector is proportional to the
increase in the number of patients. For many personnel and patients, this
has created difficult to solve problems such as planning, routing and
appointing appropriate personnel to the appropriate patient (Redjem &
Marcon, 2016).

In Turkey, home health care service was initiated with the Regulation
on the Delivery of Home Health Care Services published in the official
gazette No. 25751, which entered into force in 2005. In line with the
directive of the Ministry of Health on the Procedures and Principles of
Home health care Services dated 1 February 2010 and numbered 3895, 407
Home healthcare Units were established under 34 roaming teams and
hospitals, which were established under the supervision of Health
Directorates of 81 provinces (Altuntaş, Yilmazer, Güçlü & Öngel, 2010).
Home health care services in Turkey are carried out in three ways
(http:www.saglik.gov.tr; Altuntaş et al. 2010)
  a)   The health clinic
  b)   Through the units established within the hospitals

c)   Through the mobile teams established under the health directorate for citizens in the rural areas,

The units established in hospitals and health directorate have to plan patient visits according to the received requests and they must also plan which patients will be visited first, in which order visits will be performed, and how to reach patients. In Turkey, depending on the status of the patient, different occupational groups such as physicians, nurses, social workers, psychologists, physical therapists, speech therapists, occupational therapists, home economists, and pharmacists can be benefited from through the home care service (Işık, Kandemir, Erişen, & Fidan, 2016).

In this study, it is shown how daily routing of all these teams can be solved by modeling like capacity limited vehicle routing problem.

2. Literature Review

VRP was first described by Dantzig and Ramster (1959), who defined VRP as the shortest distance from one or more depots to more than one cus-tomer, or the route required to provide services in the shortest time Dantzig & Ramser, 1959; Ercan Cömert, Yazgan, Sertvuran, & Şengül, 2018). Although it is possible to solve all probabilities of VRP with definite methods, it is classified under NP-difficult problems in the literature due to the required processing times. Other than definite solutions, heuristic solutions were also suggested for VRP. In 1964, Clarke and Wright proposed the savings algorithm, which is a heuristic approach to solving the problem (Clarke & Wright, 1964). In this study, the savings algorithm suggested for classical VRP will be used to solve the problem of Home healthcare Service Service Routing (HHC-VRP). As with VRP, there are both precise methods and heuristic methods present in the literature for HHC-VRP. Precise methods produce results for fewer patients and caregivers, while heuristic methods achieve near-optimal solutions for a much larger data set at an acceptable time. In their study, Kergosien, Lenté & Billaut (2009) considered the home health care service routing problem as a part of the VRP problem and attempted to resolve it through integer linear programming method. After considering the time constraint for the patients, they have stated that the problem had become complex as the number of points to be visited increased and due to this reason, the problem could not be solved through integer programming. Again in 2011, Redjem, Kharraja, Xie and Marcon tried to solve the problem by using two-based mixed coefficient linear programming model. Like Kergosien et al., Redjem et al. found that the model is very dependent on the size of the problem and

mentioned that heuristics methods should be employed to solve this problem. Lanzarone and Matta (2012) considered the problem of home services as a resource assignment problem and attempted to solve this problem by assigning resources through mathematical programming models to ensure the sustainability of home health care services and as a result of their experiments, they achieved a mathematical method that can provide the obligatory limits. Braekers, Hartl, Parragh and Tricoire (2016) examined the home health care service routing problems from the perspective of patient satisfaction and expenses such as wages of the workers and their transport expenses to bilaterally solve the problem from a standpoint which included both the expenses and the patients. Their study showed that a bilateral solution would be complex. They also suggested that a heuristic method should be used when the data regarding the problem grows in magnitude. In their study, Du, Liang and Sun (2017) compared integer programming, Genetic Algorithm and Hybrid Genetic Algorithm in terms of the speed of solving the problem to solve the problem that existed in Shanghai, China and observed that GA and Hybrid genetic algorithm have provided better results in comparison to integer programming when number of addresses to visit was increased. In their research, they reported that Cplx software solved integer programming took 1.2 units of time for visiting 30 points, while the Genetic Algorithm took 0.8 units and Hybrid Genetic Algorithm took 0.7 units. Similarly, the study conducted by Frifit, Masmoudi and Euchi (2017) examined the solution to the problem from the standpoint of temporal complexity and attempted to use variable neighborhood search algorithm for solving the problem for the first time. They stated that the neighborhood search algorithm they had used in their studies provided good results in terms of temporal complexity. Shi, Boudouh and Grunder (2017) also tried to solve the time limited home health care problem, but they attempted to do so while taking into account the amount of medication to be given to patients. In their study, they considered the problem as a general time constrained vehicle routing problem. They developed a hybrid genetic algorithm to solve this stage of the problem. They then used fuzzy logic to find out the amount of medication patients might need. Thus, they were able to decide whether to go to the next patient or to the warehouse based on the amount of medication in the vehicle. As a result of these studies, the total circulation time was reduced.

3. Material and Method

In this study, a model for planning home health care services which would deal with assigning teams to patients and allow these teams to visit their patients with the shortest distance possible was suggested. Since actual patient addresses are personal data, 20 randomly generated patient addresses were used instead of actual patient addresses. Patient addresses were expressed as a point in the x.y coordinate system, and the distances between the addresses were taken as Euclidean distances. The care times required for the patients were also generated as random values. In this way, the problem can be solved as Capacity Restricted Vehicle Routing Problem (C-VRP). Table 3.1 displays the HHC-VRP parameters with their C-VRP correspondents.

Table 0.1 Modeling HHC-VRP as C-VRP

Capacity Restricted Vehicle Routing Problem (C-VRP)	Home Health Care Routing Problem (HHC)
Depot	HHC center
Customer addresses for distribution	Patient addresses for home health care
Distance matrix	Distance matrix
Amount of goods to be delivered to addresses	Amount of time spent on patient care
Total number of vehicles	Number of teams offering HHC
Vehicle capacity	Daily working time of HHC workers
Exceeding vehicle capacity	Exceeding daily working time

In this study, HHC-VRP was modeled as seen in Table 3.1 and solved through the Savings Algorithm

3.1. Savings Algorithm

This is an algorithm developed by Clarke and Wright in 1964 and it is easy to implement it for solving VRP problems. The savings algorithm starts with the assumption that all points (patient addresses) will be visited starting with a central point (health center). Afterwards, the amount of savings that can be obtained by combining the points to be visited are calculated and routes are created by combining the points that provide the greatest amount of savings.

When the capacity for VRCP is exceeded, the process is repeated with the remaining points to create a new route. The operation of the algorithm was demonstrated in Figure 3.1.
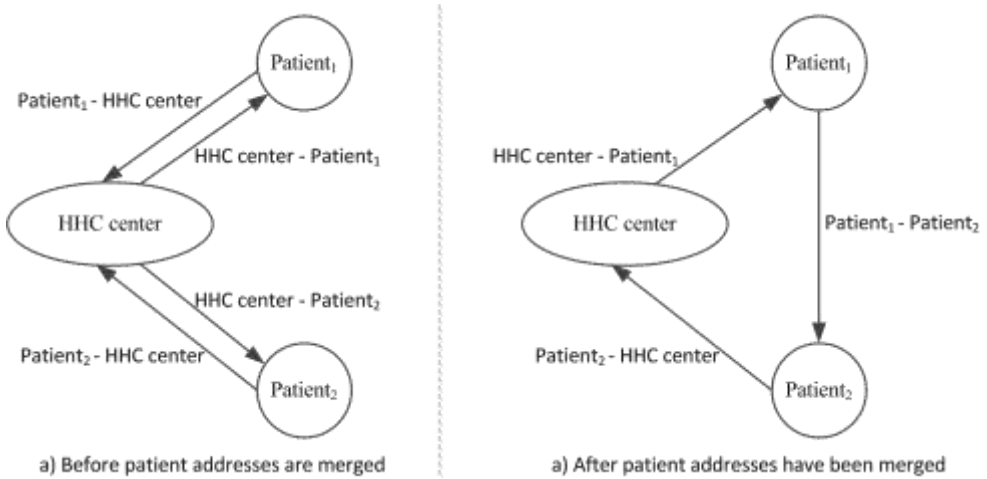
Figure 0.Operation of the savings algorithm

If Health Center noted on Figure 3.1 is defined as 0, address of the $Patient_1$ as i and address of the $Patient_2$ as j, the savings provided by the algorithm can be calculated by using following formula:

$$S_a = c_{0i} + c_{i0} + c_{0j} + c_{j0}$$
$$S_b = c_{0i} + c_{ij} + c_{j0}$$
$$S_a - S_b = c_{i0} + c_{0j} - c_{ij}$$

The steps of the saving algorithm are shown below.
In the algorithm, patient addresses are called points, and the connections between addresses are called the edges.

1. *Calculate savings for all patient addresses (i, j).*
    a. $S_{ij} = c_{0i} + c_{0j} - c_{ij}$
2. *Sort the resulting savings values from large to small.*
3. *Start creating route with first value of list (unless capacity constraint is exceeded)*
4. *Find the appropriate edge that can be added to the current route and add the point that is not on the route to the route (if the capacity constraint is not exceeded)*
5. *If the new point cannot be added to the route due to capacity constraint, select the first edge as a new route.*
6. *Repeat Steps 4 and 5 until there are no more points to add.*

4. Application

Since the aim of this study was to demonstrate that HHC-VRP can be solved by modeling it as C-VRP, tests were conducted with 20 randomly generated patient addresses and randomly generated patient care times.

Table 0.1 Randomly generated patient addresses and care times

ID	Patient Address	x	y	HHC period
0	HHC center	40,75	30,78	0
1	p_1	42,74	31,72	20
2	p_2	38,5	29,4	30
3	p_3	39,74	32,7	20
4	p_4	42,84	31,89	25
5	p_5	45,6	33,8	40
6	p_6	41,4	28,15	15
7	p_7	44,21	25,4	10
8	p_8	41,8	32,1	25
9	p_9	47,56	38,4	30
10	p_{10}	42,5	32,3	25
11	p_{11}	43,23	33,33	35
12	p_{12}	46,4	32,05	30
13	p_{13}	41,41	23,2	25
14	p_{14}	39,35	35,6	20
15	p_{15}	38,16	33,17	25
16	p_{16}	40,99	28,25	15
17	p_{17}	43,1	32,5	25
18	p_{18}	44,65	28,7	35
19	p_{19}	41,5	25,8	30
20	p_{20}	38,2	29,8	25

The distance matrix between the points in Table 4.1 is shown in Table 4.2. The distance between patient addresses was calculated with Euclidean distance.

The maximum daily working time of health personnel who will be conducting patient visits will be taken as 240 periods at maximum.

Table 0.2 Distance matrix, Euclidean distance

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	2,2	2,6	2,2	2,4	5,7	2,7	6,4	1,7	10	2,3	3,6	5,8	7,6	5	3,5	2,5	2,9	4,4	5	2,7
1	2,2	0	4,8	3,2	0,2	3,5	3,8	6,5	1	8,2	0,6	1,7	3,7	8,6	5,2	4,8	3,9	0,9	3,6	6,1	4,9
2	2,6	4,8	0	3,5	5	8,4	3,2	7	4,3	13	4,9	6,2	8,3	6,9	6,3	3,8	2,7	5,6	6,2	4,7	0,5
3	2,2	3,2	3,5	0	3,2	6	4,8	8,6	2,2	9,7	2,8	3,6	6,7	9,7	2,9	1,7	4,6	3,4	6,3	7,1	3,3
4	2,4	0,2	5	3,2	0	3,4	4	6,6	1,1	8	0,5	1,5	3,6	8,8	5,1	4,9	4,1	0,7	3,7	6,2	5,1
5	5,7	3,5	8,4	6	3,4	0	7	8,5	4,2	5	3,4	2,4	1,9	11	6,5	7,5	7,2	2,8	5,2	9	8,4
6	2,7	3,8	3,2	4,8	4	7	0	3,9	4	12	4,3	5,5	6,3	5	7,7	6	0,4	4,7	3,3	2,4	3,6
7	6,4	6,5	7	8,6	6,6	8,5	3,9	0	7,1	13	7,1	8	7	3,6	11	9,9	4,3	7,2	3,3	2,7	7,5
8	1,7	1	4,3	2,2	1,1	4,2	4	7,1	0	8,5	0,7	1,9	4,6	8,9	4,3	3,8	3,9	1,4	4,4	6,3	4,3
9	10	8,2	13	9,7	8	5	12	13	8,5	0	7,9	6,7	6,5	16	8,7	11	12	7,4	10	14	13
10	2,3	0,6	4,9	2,8	0,5	3,4	4,3	7,1	0,7	7,9	0	1,3	3,9	9,2	4,6	4,4	4,3	0,6	4,2	6,6	5
11	3,6	1,7	6,2	3,6	1,5	2,4	5,5	8	1,9	6,7	1,3	0	3,4	10	4,5	5,1	5,6	0,8	4,8	7,7	6,2
12	5,8	3,7	8,3	6,7	3,6	1,9	6,3	7	4,6	6,5	3,9	3,4	0	10	7,9	8,3	6,6	3,3	3,8	7,9	8,5
13	7,6	8,6	6,9	9,7	8,8	11	5	3,6	8,9	16	9,2	10	10	0	13	11	5,1	9,5	6,4	2,6	7,3
14	5	5,2	6,3	2,9	5,1	6,5	7,7	11	4,3	8,7	4,6	4,5	7,9	13	0	2,7	7,5	4,9	8,7	10	5,9
15	3,5	4,8	3,8	1,7	4,9	7,5	6	9,9	3,8	11	4,4	5,1	8,3	11	2,7	0	5,7	5	7,9	8,1	3,4
16	2,5	3,9	2,7	4,6	4,1	7,2	0,4	4,3	3,9	12	4,3	5,6	6,6	5,1	7,5	5,7	0	4,7	3,7	2,5	3,2
17	2,9	0,9	5,6	3,4	0,7	2,8	4,7	7,2	1,4	7,4	0,6	0,8	3,3	9,5	4,9	5	4,7	0	4,1	6,9	5,6
18	4,4	3,6	6,2	6,3	3,7	5,2	3,3	3,3	4,4	10	4,2	4,8	3,8	6,4	8,7	7,9	3,7	4,1	0	4,3	6,5
19	5	6,1	4,7	7,1	6,2	9	2,4	2,7	6,3	14	6,6	7,7	7,9	2,6	10	8,1	2,5	6,9	4,3	0	5,2
20	2,7	4,9	0,5	3,3	5,1	8,4	3,6	7,5	4,3	13	5	6,2	8,5	7,3	5,9	3,4	3,2	5,6	6,5	5,2	0

The distance matrix on Table 4.2 was calculated using Euclidean distance calculation and it was assumed that the distance between two points were symmetrical in both directions. This distance value for real points can be found by querying with map applications such as maps.google. For a route with 20*20 elements, 400-20 queries will be required.

Using the distance matrix shown in Table 4.3, the savings matrix was obtained. The savings matrix was calculated for all i, j values by the using the following formula.

$Savings(i,j)=c_{0i}+c_{0j}-c_{ij}$

In the above formula:

c_{0i}= Distance between Health center and i point
c_{0j}= Distance between Health center and j point
c_{ij}= Distance between patient address at point i and patient address at point j

Table 0.3 Savings matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	0,01	1,21	4,37	4,37	1,1	2,11	2,88	4,18	3,89	4,08	4,32	1,19	2,07	0,92	0,85	4,25	3,05	1,19	0
2	0,01	0	1,28	0,01	0	2,19	2,07	0,07	0,09	0,02	0,05	0,1	3,4	1,4	2,37	2,44	0	0,87	2,99	4,87
3	1,21	1,28	0	1,34	1,92	0,04	0,01	1,71	2,71	1,7	2,18	1,27	0,13	4,26	4,04	0,09	1,71	0,26	0,09	1,62
4	4,37	0,01	1,34	0	4,72	1,07	2,14	3	4,55	4,16	4,44	4,6	1,17	2,3	1,04	0,83	4,62	3,12	1,17	0,01
5	4,37	0	1,92	4,72	0	2,16	0,06	0,3	7,39	1,05	3,31	6,04	1,62	0,69	1,78	2,5	2,26	1,4	1,78	3,51
6	1,1	2,19	0,04	1,07	2,16	0	5,18	0,43	0,97	0,74	0,78	2,16	5,37	0	0,26	4,83	0,95	3,83	5,4	1,84
7	2,11	2,07	0,01	2,14	0,06	5,18	0	0,97	3,2	1,61	1,97	5,19	10,5	0,12	0,07	4,64	2,12	7,49	8,7	1,68
8	2,88	0,07	1,71	3	0,3	0,43	0,97	0	3,37	3,28	3,36	2,88	0,39	2,44	1,42	0,3	3,24	1,67	0,42	0,15
9	4,18	0,09	2,71	4,55	7,39	0,97	3,2	3,37	0	4,61	7,11	9,55	1,43	6,57	2,98	0,67	5,73	4,51	1,28	0,24
10	3,89	0,02	1,7	4,16	1,05	0,74	1,61	3,28	4,61	0	4,62	4,2	0,76	2,78	1,41	0,54	4,6	2,55	0,78	0,08
11	4,08	0,05	2,18	4,44	3,31	0,78	1,97	3,36	7,11	4,62	0	5,93	0,88	4,08	2,01	0,55	5,63	3,14	0,87	0,14
12	4,32	0,1	1,27	4,6	6,04	2,16	5,19	2,88	9,55	4,2	5,93	0	3,24	2,92	0,99	1,72	5,37	6,43	2,89	0,02
13	1,19	3,4	0,13	1,17	1,62	5,37	10,5	0,39	1,43	0,76	0,88	3,24	0	0,06	0,64	5,08	1,07	5,65	10,1	3
14	2,07	1,4	4,26	2,3	0,69	0	0,12	2,44	6,57	2,78	4,08	2,92	0,06	0	5,83	0,03	3,06	0,74	0,03	1,84
15	0,92	2,37	4,04	1,04	1,78	0,26	0,07	1,42	2,98	1,41	2,01	0,99	0,64	5,83	0	0,38	1,44	0,06	0,47	2,88
16	0,85	2,44	0,09	0,83	2,5	4,83	4,64	0,3	0,67	0,54	0,55	1,72	5,08	0,03	0,38	0	0,71	3,27	5,08	2,08
17	4,25	0	1,71	4,62	2,26	0,95	2,12	3,24	5,73	4,6	5,63	5,37	1,07	3,06	1,44	0,71	0	3,23	1,06	0,05
18	3,05	0,87	0,26	3,12	1,4	3,83	7,49	1,67	4,51	2,55	3,14	6,43	5,65	0,74	0,06	3,27	3,23	0	5,18	0,61
19	1,19	2,99	0,09	1,17	1,78	5,4	8,7	0,42	1,28	0,78	0,87	2,89	10,1	0,03	0,47	5,08	1,06	5,18	0	2,58
20	0	4,87	1,62	0,01	3,51	1,84	1,68	0,15	0,24	0,08	0,14	0,02	3	1,84	2,88	2,08	0,05	0,61	2,58	0

After creating the savings matrix shown on Table 4.3 is created, the savings values obtained are sorted from large to small and routes are created by starting with the largest saving.

In the Table 4.3 the largest saving value is the value between points 7 and 13. The first route is created by combining these values. In this case, assuming that the route starts and ends at the health center, the route's configuration will be as 0-7-13-0. The cost in time is calculated by assuming that the travel time between two points is two times the cost between two

points. In this case, the cost of the first route was calculated as 70.2, which is found by combining the travel time between 0 and 7 (12.8), the care time at point 7 (10), the travel time between points 7 and 13 (7.2), the care time at point 13 (25) and the travel time between 13 and 0. Since this value is less than 240, which is the daily working value of health workers, the combination of these two points constitutes a feasible route. After the first combination of the route, the next highest saving value is achieved by combining points 13 and 19. Since the 13-19 combination can be added to the existing route, the new version of our route will take the form of 0-7-13-19-0. Since the cost is 100.2 with the new route configuration and this is less than the capacity, the new combination can be added to the route. 3. Since the next biggest savings value, 9-12, is not adjacent to our current route, these points are not added to our route. When a route is created by performing calculations for all combinations on the list, the configuration of 0-5-12-18-7-13-19-6-0 is formed, which has a cost of 237.2. Because the nodes in the first route are already visited when creating the route, the combinations for the nodes in the previous routes are ignored. The process is repeated until all nodes are assigned to a route.

Table 4.4 displays the routes created with savings algorithm, the total distance of the routes and total time necessary for completing the route.

Table 0.4 Routes created with the Savings algorithm

Route	Route path	Time	Distance
Route 1	0-5-12-18-7-13-19-6-0	237	26
Route 2	0-15-14-9-11-17-4-1-0	231	25,5
Route 3	0-8-10-16-2-20-3-0	176	15,4

5. Conclusion and Evaluation

In this study, it was demonstrated that Home health care Service Routing Problem (HHC-VRP) can be solved by modeling the problem in a manner similar to the Capacity Restricted Vehicle Routing Problem (C-VRP), which has many different solutions in the literature. Savings algorithm is often used for solving C-VRP since it is easy to implement and the application of the algorithm to our problem has created solutions for 20 randomly produced points. The obtained results show that appropriate routes can be created in a way that does not exceed the maximum daily working hours of health workers.

In future studies, studies on the solution of evolutionary algorithms can be made by considering patient time preferences.

Acknowledgment

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