Designing Green Routing and Scheduling for Home Health Care

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Abstract. Nowadays, Home health care (HHC) procurement has become a hot topic of research in recent years due to the importance of HHC services for the care of the elderly. With the growth of the percentage of elderly people in different cases, we are witnessing concerns about providing health services to these people in the community. With getting older, the demand for Home Health Care increases. HHC includes a wide range of medical, paramedical and social services that can be provided at home and can be an alternative to receiving these services in a location other than the hospital. Also, due to the possibility of conflict in different countries in the future, with the spread of diseases such as Covid-19 and turning all the facilities and medical and health potential of countries to these epidemics, the need for medical services and home care for the elderly and sick people increases. In this research, a green routing problem is designed for the Home Health care network for the elderly. The network is structured in such a way that the medical service provider with services teams provides services to a group of patients located in a geographical area. The problem is presented as a multi-period mixed integer mathematical model. The purpose of the model is to maximize profits under carbon dioxide emission limits. In this model, an attempt has been made to address the environmental aspects as well. Finally, the mathematical model is solved in GAMS software with numerical examples and its results and performance are presented.

Keywords: Home Health Care (HHC) · Green routing problem · Scheduling problem · COVID-19 epidemic

1 Introduction

Different types of disasters, such as the spread of infectious diseases, can threaten human lives along with natural disasters. History has shown that pandemics can cause extraordinary suffering and death [1, 2]. COVID-19 is a highly transmissible and pathogenic viral infectious disease that caused a global epidemic and resulted in the loss of many lives worldwide [3]. As of July 22, 2020, more than 15 million cases of COVID-19 have

A. Abraham et al. (Eds.): IBICA 2021, LNNS 419, pp. 491–504, 2022.
https://doi.org/10.1007/978-3-030-96299-9_47

been reported worldwide, with nearly 618,000 deaths [4]. Hospital readiness is crucial in organizing national and local responses to infectious disease epidemics. However, it soon became clear that hospitals were under pressure [5]. Even a conservative estimate shows that the health needs of the coronavirus epidemic far exceed the capacity of USA's hospitals [6]. In older communities where an increasing number of people with illness and disability live longer, monitoring the quality of home health care delivery is important for sustainable health and social care [7].

Health systems and payers are increasingly recognizing a subset of functionally deficient adults who have difficulty accessing the health care system. To optimize their care, home adults need coordinated medical care at home [8, 9]. Like other older communities, the Czech Republic needs to improve the quality of home care. Currently, about 7% of the elderly covered by health care use home care [10]. Home Medical Care (HBMC) refers to clinical practices that provide physician or nurse-led interdisciplinary care for adults living at home, with functional impairments, and serious illnesses that make it difficult to access traditional primary care. Offers. This includes primary home care and home palliative care [11]. Home health care, i.e. meeting and nursing patients in their homes, is a growing part of the medical services business [2, 12].

The purpose of home care services is to help people with functional limitations to live in their own homes. Home care is considered as a possible strategy to reduce hospital use among the elderly [13]. Home care leads to a significant improvement in patients' quality of life, as they continue to live in a familiar environment at home. On the other hand, this leads to significant cost savings in the health care system, as it avoids the costs of hospitalization [14]. A wide range of skills among home care nurses can prevent unnecessary hospitalization and emergency care [15]. In home services, to serve a range of customers spread across a wide geographical area, a service team starts at the origin (General Service Provider) and visits each dedicated customer before returning to the origin [16].

The rest of the article is described below. In the next section, a summary of the research background of the subject is collected. Section 3 describes the definition of the problem and its assumptions. Also, in Sect. 4, the formulation of the mathematical model of the problem is described. In Sect. 5, the solution method and the results of implementing the mathematical model in the software are presented. Finally, Sect. 6 summarizes the present study and ideas for future research.

2 Literature Review

In recent years, optimization of home health care routing has attracted a lot of attention instead of home health care planning. This is because logistics costs of home care are a major concern in organizing home health care [17]. Kergoshen et al. presented a mathematical model of correct linear programming to solve the problem of vehicle-specific routing and the collection of laboratory samples of patients in the province of Quebec. Also, to solve the mathematical model, two methods of forbidden search and neighborhood search have been used [18]. Goodarzian et al. examined the multi-objective multi-product and Multi-period drug supply chain network along with the production of purchase, distribution, inventory order and holding-allocation-routing problem under uncertainty. Their model type is MINLP and they have used meta-heuristic methods to solve the model [19].

Nahli et al. presented a multi-objective approach based on linear integer programming for human resource allocation and home health care routing. Numerical results obtained from solving the model show that using the proposed method, a good balance can be established between the preferences of patients and caregivers and travel costs [20]. In Breckers et al. A dual-objective model of routing and scheduling home health care is presented. The objectives of the model include minimizing operating costs while increasing the level of service provided to customers by taking into account their preferences [21]. Goodarzian et al. designed a network of green drug supply chains in the state of uncertainty. Their mathematical model type is fuzzy dual-purpose MILP. The purpose of this network is to consider the environmental impacts of establishing pharmacies and hospitals and to reduce the greenhouse effects and control of pollutants. Several meta-heuristic algorithms and two new hybrid algorithms have been used to solve the model. Experimental data were obtained through simulation [22, 23].

Ferfita et al. conducted a study in the field of vehicle routing by considering the time window. The purpose of this study is to optimize the appointment of home nurses and the order of visits [24]. Dasserl et al. provided an integrated mixed-time programming formulation for the multifunctional home health care problem. The objectives of the proposed model are to minimize the total working time of caregivers, optimize the quality of services and minimize the difference in working time between nurses and nursing assistants. A memetic algorithm has also been proposed to solve the mathematical model of multi-objective optimization [25]. Shiri et al. used a mixed integer programming model for home health care network design is presented. In this research, the interactive method and robust optimization approach for the problem of multi-purpose home network under uncertainty have been used. The computational results showed the competencies of the proposed powerful model in an uncertain environment and the superiority of the Nimbus method as a new interactive method [26].

Fathollahi-Fard et al. presented a mixed integer linear programming (MILP) model for optimizing multi-stage and multi-period health care. This article is able to solve the problem of optimizing home health care with total cost and patient satisfaction as complex goals and constraints such as patients performing pharmacy tasks, scheduling and routing constraints, delivery time, balancing travel time travel constraints using a two-objective optimization approach [17]. Jean and Van addressed the issue of vehicle routing and appointment scheduling by assigning the team to home care services. To solve it, an innovative algorithm based on Tabu search (TS) was used [27]. Demirblick et al. addressed the issue of home nurse planning. The goal of their model is to maximize the average number of daily appointments for a nurse. Their main new assumption was that patients arrive dynamically in each time period [28].

Manukuska et al. provided a model for day-to-day planning of health care services. The objectives of the model include optimizing the total distance traveled by all caregivers, general service delays starting beyond time windows, and maximum overall operation delays [29]. Environmental pollution is one of the biggest challenges of the present century [30]. Over the past few decades, great strides have been made to incorporate ethical and environmental responsibilities into the core culture of today's business world. With more emphasis on such responsibilities, an increasing number of companies have opted for "green" (environmentally friendly) designs as competitive strategic weapons [31]. Considering environmental considerations and considering the amount of greenhouse gas emissions from nearly a decade ago, in the literature on individual supply chain issues had begun [2, 32, 33]. Goodarzian et al. developed an optimization approach for the drug supply chain network by considering delivery time and usability with multi-purpose transportation. Innovative method was used to solve the model and two proposed meta-heuristic algorithms improved social engineering optimization (ISEO) and a hybrid of firefly and simulated annealing algorithm (HFFA-SA) were developed for validation [34]. Luo et al. introduced a mixed-integer programming model, addresses the issue of green routing and scheduling in home health care (HHC) with limited simultaneous visits and carbon emissions. The aim of this study is to design a rational logistics route while reducing the impact of the home health care network on the environment. The solution method includes an innovative approach based on two precise methods using Grubi solution method and dynamic programming method (DM) [35].

Increased trade, logistics and transportation have led to increased emissions of harmful gases into the Earth's atmosphere and pollution [36]. Vehicle Routing Problem (VRP) is a combined optimization and programming problem that finds the optimal set of routes that the fleet of vehicles must pass to reach a specific set of customers [37].

The Green Vehicle Routing (GVRP) problem is a recent alternative to standard traditional vehicle routing models [34, 38].

Transportation plays an important role in the sustainable management of logistics. Traditionally, the main purpose of solving the problem of vehicle routing was to minimize the cost of distance traveled. Today, economic benefits cannot be the only driver of achieving sustainability, and environmental issues must also be considered [39]. In their own research, Michael et al. examined a vehicle routing issue with economic and environmental aspects simultaneously in order to achieve a sustainable vehicle routing decision. Also, firefly algorithm has been used to solve the problem of vehicle routing and TOPSIS technique has been used to integrate economic and environmental factors [39]. Foroutan et al. In this paper, have examined the issue of routing and planning of green vehicles with a heterogeneous transportation vehicles, including reverse logistics in the form of collecting returned goods with early and late costs. Their goal is to minimize operating and environmental costs and create a balance between them [40].

Goodarzian et al. Examined a multi-objective, multi-level, multi-product, and multi-period issue for a sustainable medical supply chain network, as well as the distribution of drugs related to Covid-19 patients and drug production and delivery periods due to the perishability of some drugs [41].

Gupta, P., et al. presented an Iot-based health monitoring system for emergency medical services that flexibly demonstrates the collection, integration, and operation of Iot data that is capable of supporting ICU services.The proposed result of this project is to provide appropriate and efficient medical services to patients by connecting and collecting information through health status monitors [42]. Pasquadibisceglie and et al., proposed a new solution for evaluating critical indicators using a non-invasive monitoring. The proposed system is a smart device consisting of a mirror to a camera that captures a person's face and uses photo plethysmography to instantly estimate heart rate and heart rate saturation, and can be easily used at home [43].

In the event of epidemics such as Covid-19 that all the capacity of the health care system is used to deal with it. Also, for reasons such as the decline in the quality of response to the elderly in epidemic conditions, the dangerous presence of the elderly in centers such as hospitals due to the spread of the disease and the refusal of the elderly to attend these centers, the existence of home medical care centers are more needed. Based on previous studies in the field of home medical care, this article attempts to provide a new model for the issue of green routing of home medical services for the elderly. The objectives of the proposed model include increasing profits and reducing costs for the home health care network. This model also deals with the environmental aspects and the effects of the home medical care transportation network on the environment.

3 Problem Definition

The green routing of elderly Home Health Care is a multi-period Mixed integer linear programming and defined on a graph $G = (N_0, A)$ consisting of nodes and arcs that $N_0 = N \cup \{0\}$ represents a set of nodes containing a set of points $N = \{1, 2, ..., n\}$ as a set of patients in Different geographical areas and $\{0\}$ as a center providing medical services with a set of different medical service teams. We also show the set of arcs with A and thus $A = \{(i, j) : i, j \in N_0 \text{ , i} \neq \text{j}\}$ indicate the relationship between different points of the model network. The $T = \{1, ..., \tau\}$ set represents time periods. It is assumed that the medical service center has only three services:

1) Laboratory affairs, injections and bandage.
2) Home Visit Doctors and check-up.
3) Performs physiotherapy and massage therapy.

And depending on the needs of patients and in order to respond to it, one of the teams that has expertise related to these three categories of services is sent. Also, according to the type of service, the number of service team members and the equipment they need, K-type heterogeneous vehicles are used for transportation. Each service team starts its journey from the origin node and returns to the origin node after visiting the patients. According to the explanations, Fig. 1 shows a schematic view of the flow of Home Health Care services for the elderly. Which includes a medical care center and several patients in different geographical locations that these patients receive by medical care teams in different periods of service. The proposed model is a green routing problem that in addition to meeting the needs of patients pursues environmentally friendly goals. The purpose of the proposed mathematical model is to maximize profits under carbon dioxide emission limits, which are obtained by subtracting costs from revenue from service delivery. Model network costs include: cost of travel between points, cost of service team, cost of carbon dioxide emissions by vehicles, and cost of non-response to customers.

The total service time of medical service teams to patients is limited and fixed. It is also assumed that all costs are clear and precise in the planning horizon. Another

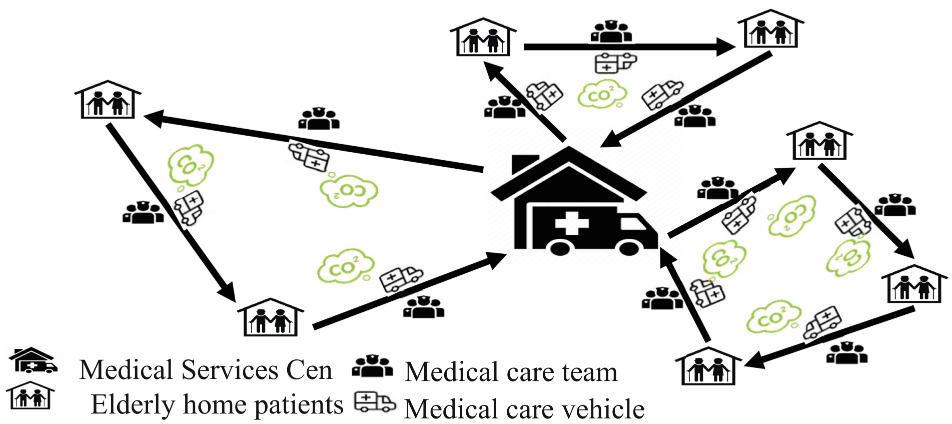

Fig. 1. Schematic view of the green routing problem model of home medical services

assumption is that, in order to minimize the number of customers who are not served. For each unit of customers who suffered from non-response, a penalty was considered and we try to be able to reduce the costs of non-response to customers as much as possible by considering this section.

4 Mathematical Formulation

4.1 Indices, Parameters and Decision Variables

In this section, the indices used to introduce the indices, parameters and variables of the model are defined.

Indices:

i, j Total points index, $i, j \in N_0$
o Medical Center Index, $0 \in N_0$
i, j Patient Index, $i, j \in N$
s Medical Service Index, $s \in S$
k Vehicle index, $k \in K$
t Period index, $t \in T$

Parameters

dis_{ij} The distance between points i and j
co_{ijk} Cost of travel between i and j points by vehicle k
$\alpha 1_k$ Carbon dioxide emissions for the vehicle k
φ^* Estimated average cost of carbon emissions
cf_s Fixed cost of hiring medical team s
cv_k Fixed cost of using the vehicle k
pic_{is} The cost of a fine for each patient i who has not received medical care s
mco_{is} Income from each patient i who has received medical care s
$\theta 1_{ijk}$ Time required to cross arc(i,j) by vehicle k

$\theta 2_{is}$ Time required to provide team service s to the patient i
ψ Maximum service time

Decision variables:

Z_{ijskt} The binary variable takes the value (1) if the medical team j crosses the arc (i,j) with the vehicle k in period t. Otherwise (0).
V_{ist} The binary variable takes the value (1) if the medical team s is assigned to the patient i in period t. Otherwise (0).

4.2 Mathematical Model

According to the definition of Indices and the definition of the problem in the previous sections, the problem of responding to home care services for the elderly during the Covid-19 epidemic is modelled as a mixed integer linear programming as follows, taking into account environmental considerations.

$$Max\,TP = Q_1 - (Q_2 + Q_3 + Q_4 + Q_5 + Q_6) \tag{1}$$

$$Q_1 = \sum_{i \in N} \sum_{s \in S} \sum_{t \in T} mco_{is} \,.\, V_{ist} \tag{2}$$

$$Q_2 = \sum_{i \in N} \sum_{s \in S} \sum_{t \in T} cf_s \,.\, V_{ist} \tag{3}$$

$$Q_3 = \sum_{i \in N} \sum_{s \in S} \sum_{t \in T} pic_{is} \,.(1 - V_{ist}) \tag{4}$$

$$Q_4 = \sum_{i \in N_0} \sum_{j \in N_0} \sum_{s \in S} \sum_{k \in K} \sum_{t \in T} dis_{ij} \,.\, co_{ijk} \,.\, Z_{ijskt} \tag{5}$$

$$Q_5 = \sum_{i \in N_0} \sum_{j \in N_0} \sum_{s \in S} \sum_{k \in K} \sum_{t \in T} cv_k \,.\, Z_{ijskt} \tag{6}$$

$$Q_6 = \sum_{i \in N_0} \sum_{j \in N_0} \sum_{s \in S} \sum_{k \in K} \sum_{t \in T} \varphi^* . \,\alpha 1_k \,.\, dis_{ij} \,.\, Z_{ijskt} \tag{7}$$

Subject to:

$$\sum_{j \in N} Z_{0jskt} \le 1 \quad , \quad \forall \; s \in S, \; k \in K \, , \; t \in T \tag{8}$$

$$\sum_{i \in N} Z_{i0skt} \le 1 \quad , \quad \forall \; s \in S, \; k \in K \, , \; t \in T \tag{9}$$

$$\sum_{i \in N_0} Z_{ijskt} = \sum_{i \in N_0} Z_{jiskt} \quad , \quad \forall \; i \in N \, , \; s \in S, \; k \in K \, , \; t \in T \tag{10}$$

$$\sum_{s \in S} \sum_{t \in T} V_{ist} = 1 \quad , \; \forall \; i \in N \tag{11}$$

$$\sum_{j \in N_0} \sum_{k \in K} Z_{ijskt} \; = \; V_{ist} \quad , \; \forall \; i \in N, \; s \in S, \; t \in T \tag{12}$$

$$\sum_{i \in N} \theta 2_{is} \, . \, V_{ist} + \sum_{i \in N} \sum_{j \in N} \theta 1_{ijk} \, . Z_{ijskt} \le \psi \quad , \quad \forall k \in K \, , \; s \in S \, , \; t \in T \tag{13}$$

$$Z_{ijskt} \, , \;\; V_{ist} \;\in\; \{0, 1\} \quad , \quad \forall \; i \in N_0 \, , \; j \in N_0 \, , \;\; s \in S, \; k \in K \, , \; t \in T \tag{14}$$

Equation (1) represents the objective function of the problem that maximize the profit from patient care for the medical center and is obtained by deducting costs from revenues. Equation (2) shows the income from medical services for the elderly for the medical service center. Equation (3) shows the costs of using medical groups. Equation (4) shows the costs of fines for non-response to patients. Equation (5) calculates the cost of transportation or in other words the cost of travel between nodes. Equation (6) calculates the costs of using different vehicles to refer patients to medical care teams. Equation (7) shows the costs of carbon emissions by the transportation system. Equations (8) and (9) indicate that the origin and destination of all vehicles is the origin node. In this way, medical care teams start their travel from the medical service center and return to the medical service center after treating the patients. Equation (10) ensures the continuity of the route for medical service teams in such a way that if we enter a patient's node in a period, we must leave it in the same period with the same vehicle. Equation (11) indicates the limitation that only one medical care team should be assigned to each patient per period. Equation (12) ensures that when it is greater than 1, then the medical team should leave the node of the patient or medical service center, in fact showing the correlation of allocation and routing decisions. Equation (13) indicates that the total time of medical services for patients in the nodes as well as the time for medical teams to cross the routes by vehicles should not be more than time. Equation (14) also defines the decision variables of the mathematical model.

5 Solution Method and Numerical Results

Organizations' attention to environmental issues in supply chain-related decisions has led to environmental decisions as well as environmentally friendly decisions. In this paper, an mixed integer linear programming model is proposed to maximize profits while reducing carbon dioxide emission costs. This model seeks to provide home medical care for the elderly during and after Covid-19. In order to evaluate the performance of the proposed definitive model, five sample problems with small to large dimensions have been considered. The proposed mathematical model is then solved using GAMS software and Ciplex solver on a system with an Intel (R) Core (TM) i5-4200U CPU @ 1.60 GHz processor and 8 GB of RAM. The results of solving the model as well as the different dimensions of the sample problems are shown in Table 1. A uniform distribution is used to generate other parameters of the proposed model.

Table 1. The results obtained from solving the model with GAMS software

Sample	Dimensions of the problem					Objective value (total profit)	Cost of CO_2 emissions	Solving time (seconds)
	o	i	s	k	t			
1	1	3	3	2	2	361	128	00.262
2	1	10	3	3	5	1287	402	00.397
3	1	20	3	5	8	3856	498	00.746
4	1	35	3	8	15	6386	668	02.872
5	1	60	3	10	20	12065	849	10.079

The issue of providing medical services to the elderly at home seeks to meet the medical needs of the elderly. According to the 3 types of medical services defined for the medical service center, how to assign medical service teams to the elderly in different time periods for problem example (1) is shown in Table 2.

Table 2. How medical teams were assigned to patients in different periods

Patient	Medical team			Period	
	1	2	3	1	2
1		*		*	
2			*		*
3			*		*

In this section, the effect of changing the distance between nodes on supply chain performance in terms of total network profit, network costs and emission costs are investigated. For this purpose, in Fig. 2, the amount of changes in the profit target function, the cost of greenhouse gas emissions and the current costs of the home health care network for different percentages of increase in the distance between nodes parameter are shown in separate diagrams. The results show that the profit objective function shows different behavior in terms of greenhouse gas emission costs and current costs of the home health care network by changing different amounts of distance between nodes. In this way, increasing the distance, increases the emission costs of the greenhouse gases and the running costs of the system and on the other hand, reduces the profits of the centers that provide home health care services. To the extent that a 150% increase in distances brings negative benefits and losses for the service provider center. Therefore, Home Health Care service providers are only able to provide home care services within a certain range. To have a balance between costs and benefits at the same time, and this geographical area of service is determined by parameters such as distance, shipping cost, carbon emission cost, and time required to travel between nodes.

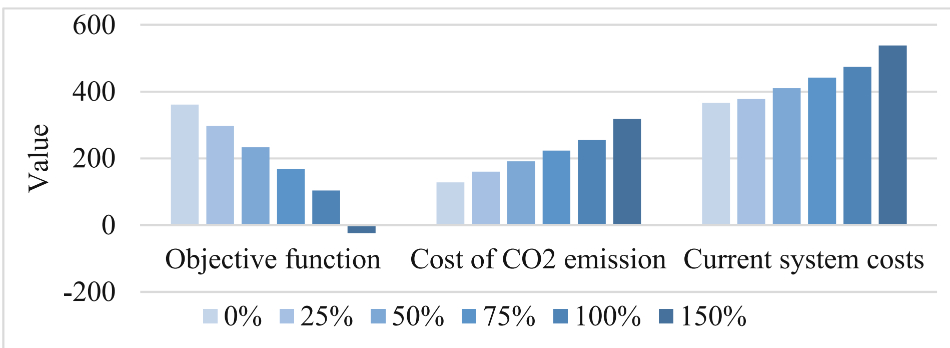

Fig. 2. Comparison of changes in the objective function and current system costs and the cost of greenhouse gas emissions relative to changes in distance between nodes

This study presents a proposed green routing model for the problem of home Health services for the elderly. Another result of solving this model is to determine the optimal routes for teams to move towards patients and provide services to them and return to the medical service center. Figure 3 shows the optimal routes and how to allocate machines to medical care teams for example (1). (The indice t indicates the time period. The indice s indicates the type of medical service. And the indice k indicates the type of vehicle).

In this paper, a proposed model of green routing of Home Health services for the elderly during Covid-19 was presented. Then the proposed mathematical model in different dimensions was solved using GAMS software and the results were expressed. Based on the obtained results, it can be confirmed that the proposed model can be useful and practical to decision makers in designing a green network to meet the medical needs of the elderly during the Covid-19 epidemic and beyond. The proposed model also seeks to reduce the costs of emitting carbon dioxide from its heterogeneous vehicle fleet.

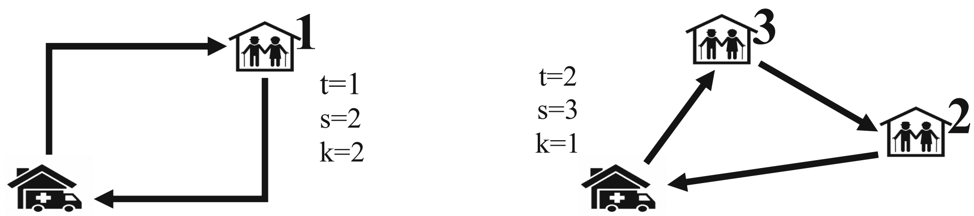

Fig. 3. Schematic view of the optimal paths for the sample problem (1)

6 Conclusions

Hospitals and medical centers are at the forefront of epidemic diseases. The experience of countries at the time of the outbreak of infectious diseases showed that these centers and the health care system are easily under pressure and the level of quality of medical services and care for ordinary patients is reduced. These centers also become high-risk places for patients. This situation is clearly visible now that the world is involved in the Covid-19 pandemic.

These experiences show that today and even in the future, Home Health Care and home medicine can be an auxiliary arm for the health care system in the event of an epidemic. To receive medical and care services in safer and healthier environments for patients and high-risk groups such as the elderly. Also, as time goes on and the demand for home care services increases, planning to achieve an efficient program to meet the needs of patients becomes more difficult and complex and new challenges are faced every day. Therefore, in this article, we have tried to provide an integer planning model for the green routing problem of home health care services. In this network, medical service centers are served by teams of patients who are scattered in a specific geographical area and return to the medical service center.

The purpose of the model is to maximize the benefits of providing services to patients for the medical center. Also, in this model, attention has been paid to the environmental aspects and reduction of carbon dioxide emissions caused by the network transportation system. The proposed model was implemented for simulated data in different dimensions in GAMS software. Problem solving in different dimensions and the results obtained from it confirm that the proposed model can help decision makers in designing and planning a home medical care network for the elderly.

As a basis for future research, the proposed model of Home Health Care can be implemented in a case study and the model can be evaluated for better performance. Some parameters of the problem can be considered indefinitely. Also, solving the model in larger dimensions with meta-heuristic algorithms is another issue that can be considered. In future work, the model can be planned several times with goals such as increasing the level of service to patients and addressing the sustainability aspects of the model. Patients' opinions, such as receiving service from a specific caregiver, can also be incorporated into the future model to be more similar to real-world situations.

Acknowledgement. This research has been financially supported by The Analytical Center for the Government of the Russian Federation (Agreement No. 70-2021-00143 dd. 01.11.2021, IGK 000000D730321P5Q0002).

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