Novel Routing-Scheduling Problem for Home Health Care Network

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Abstract

In today 's competitive world, one of the most important goals for home health care companies (HHCCs) is responding to the patient's demand, immediately and being on time for it. On the basis of feedbacks from Home Health Care Networks (HHCCs), caregivers and nurses should encounter some ambiguities when performing a specific plan for visiting patients. In this study, we presented a model for a Home Health Care Routing and Scheduling Problem (HHCRSP) with considering time window with using some meta-heuristic algorithms. Three meta-heuristic algorithms include Tabu search, variable neighborhood search, and particle swarm optimization are used to solve the model. Finally, we added the constraint of working hours of nurses to the model as innovation and linearized it to improve the model.

Keywords: Home health care network, scheduling and routing problems, Meta-heuristic algorithms

1 Introduction

Home health care is actually the medical care given at the patient 's home. home health care can include intensive care, for example: intensive care, physical therapy, occupational therapy and speech therapy, that each one presented by the relevant specialist [1, 2]. It can also include non-medical care, such as social services or aid to day-to-day life using a qualified home health assistant. Also, HHC is unique as a therapeutic environment, because not only care is offered at home, but it is usually cheaper, easier and accurate just as careful in hospital with nursing facilities. HHC has attracted widespread attention in the past decade, and most of the work done in this regard is related to medical skills, medical equipment, ethics and operation management and HHCRSP has also been the most attractive research topic in the field of operations management in the past five years. Increasing hope of life, especially in the last three decades, has aroused the need for domestic health services. So, the number of organizations that provide home health care services is increasing in nowadays. However, these organizations are struggling with the ongoing increase in demanding for domestic healthcare. Thus, it is necessary to optimize the operation of such these organizations that have limited resources for their job. In the following of this paper, a new mathematical model is proposed to optimize the routing and schedule of HHC under uncertainty conditions with robust optimization approach. First, a summary of the assumptions of the studied problem is presented. In the next section, MIP deterministic model is proposed to describe the HHCRSP with skill requirements. Then, we develop the constraints of the time interval and uncertainty service time. Finally, the robust optimization model is suggested for HHCRSP with respect to the skill requirements and the time interval and uncertainty time. in the second part, the literature related to routing and scheduling of the HHC and main subject is reviewed. in the third part, the problem and the model will be discussed and the development constraint section will also be presented. finally, in the last part the general results and suggestions for future work are presented.

2 Literature Review

In this section, the studies related to the research are considered. In recent years, various articles have been presented regarding the routing and daily planning of nurses in charge of home care. The common characteristics of these studies include instances of minimizing the distance traveled by nurses on a day or planning and optimal scheduling to perform their services at the patient 's home which are mentioned below:

Begur et al. [3] were among the first to deal with HHCRSP. In their study, they presented a decision support system to schedule nursing in HHC and to the following their way. Mankowska et al. [4] fulfilled daily planning HHC services. planning that considers: individual service needs of patients, personal competencies of staff and dependence between different service operations. they considered HHCRSP as two parts. In the first section, they consider HHCRSPs that they following a weekly optimal schedule. In the second part, in practical they use a major application of registered operational changes. Mascolo et al. [5] summarized that most studies related to routing problems and planning are closely related to the vehicle routing problem (VRP), which is a fundamental problem in transportation planning and logistics. Hence, in the literature review section, some of the recent works related to VRP are addressed. then deterministic HHCRSP studied and then non-deterministic models for HHCRSP are studied. Yu et al.[6] proposed an improved branch and price to accurately solve the heterogeneous routing problem of green vehicles with time windows. Sun et al. [7] designed the first accurate algorithm to solve a variable of heterogeneous GVRP. The accurate algorithm is based on a partitioned model and its main features are its optimal solution. Lai et al.[8] developed a Tabu search meta-heuristic algorithm that effectively employed parallel bows to solve the routing problem of a heterogeneous machine with limited time, in a multi-graph model. They proposed an adaptive large neighborhood search algorithm for the vehicle routing problem with random demands and weight-related costs. Also they addressed the generalized vehicle routing problem, which is formulated by a mixed integer linear programming model (MILP). Decerle et al.[9] studied the multi-objective HHC problem considering the usability of the planning application. And to solve the proposed problem, they are using a memetic algorithm based on the constraints of the developed model. Fikar and Hirsch [10], provided a comprehensive overview of the studies related to home health care planning and routing. They share home health care planning and routing problems into two main categories, one periodical, and a number of rounds, each with different consequences. Most research papers focus on single-time optimization problems. Further studies are divided into categories in terms of goals, limitations, and methods of solution. The constraints of single-time models include time windows, skill requirements, work time constraints, and resolution methods used in this type of issues include variable neighborhood search methods, branch and bound algorithm, simulated memetic algorithm, and particle swarm optimization. Recently, Fathollahi-Fard et al. [1] considered the patient's satisfaction as an objective function under uncertainty. To make this problem more practical, this study proposes a bi-objective optimization methodology to model a multi-period and multi-depot home healthcare routing and scheduling problem in a fuzzy environment.

3 Problem definition and mathematical formulation

The present paper proposes a new modeling approach to solve the routing problems and home health care routing. As described earlier, the real-world services are often subject to uncertainty. thus, deterministic HHCRSP that ignoring uncertainty in the data, may not be a good choice. But a robust optimization model with consideration of the uncertainty quantification is more appropriate for decision-making. Under the guidance of robust optimization technique proposed by Ben-Tal et al., [11], a robust version of HHCRSP is considered with uncertainty as the distance travelled and the time of services is considered. To effectively represent uncertain parameters, robust optimization requires precise and clear definition of uncertain sets. In the following, the mathematical model is brought together with the details used. First, a set of assumptions are given below:

3.1 Assumptions of Mathematical model

1. Every nurse begins her route from the nurse's station and reaches the lab at end.
2. Nurses and caregivers have different levels of skills and abilities.
3. The time interval between each two points is unknown.
4. Each nurse can have a limited number of patients on his/her list of tasks.
5. Service time is uncertain for each patient.

3.2 Notations

This section contains the description of all the sets, parameters and decision variables used in the mathematical model.

Sets and Parameters:

V: The collection of all vehicles.
C: set of all patients.
K: number of available devices in set V.
N: The collection of all the patients which means $N = C \cup \{0\} \cup \{n+1\}$
$[ai, bi]$: interval time for patients.
Q: maximum number of patients can be visited by each nurse.
c_{fk}: The fixed cost for the kth nurse.
c_{ij}: transportation cost between patients i and patients j.
σ: Weight to balance the fixed cost of nurses and transportation cost.

t_{ij}: time interval between patients i and j for a single trip.
d_i: The level of service for the patient i.
t_i: service time to the patients.
M: set of all nurses which they are working.
m: a nurse from the set of M.
p_m: The total time that is available to nurse m in a working day.
D_k: The level of skill for the kth nurse.
Decision variables:

$$X_{ijk} = \begin{cases} 1, \text{ If the vehicle k moves from point } i \text{ to point } j \text{ which } i \neq j \\ 0, \text{ otherwise} \end{cases}$$

$$y_{im} = \begin{cases} 1, \text{ If the patient } i \text{ visited by nurse m .} \\ 0, \text{ otherwise} \end{cases}$$

S_{ik}: service beginning time, for patient i.

3.3 Proposed mathematical model

In this section, mathematical model is presented and at the end of this part, we define objectives and constraints individually.

$$\min \sigma . \sum_{k \in V} cf_k \sum_{j \in C} x_{0jk} + \sum_{k \in V} \sum_{i \in N} \sum_{j \in N} c_{ij} \, x_{ijk} \quad (1)$$

$$\sum_{k \in V} \sum_{j \in N} x_{ijk} = 1, \ \forall i \in C \ , \quad (2)$$

$$\sum_{i \in N} x_{ihk} - \sum_{j \in N} x_{hjk} = 0, \ \forall h \in C \ ; k \in V \ , \quad (3)$$

$$\sum_{j \in C} x_{0jk} \leq 1 \ , \ \forall \ k \in V \ , \quad (4)$$

$$\sum_{j \in C} x_{j(n+1)k} \leq 1 \ , \ \forall \ k \in V \ , \quad (5)$$

$$\sum_{i \in N} \sum_{j \in N} x_{ijk} \leq Q \ , \ \forall \ k \in V \ , \quad (6)$$

$$d_i \sum_{j \in N} x_{ijk} \leq D_k \ , \ \forall \ k \in V \ , \ i \in C \ , \quad (7)$$

$$s_{ik} + t_i + t_{ij} - M \ (1 - x_{ijk}) \leq s_{jk} \ , \ i, j \in N \ ; k \in V \ , \quad (8)$$

$$a_i \leq s_{ik} \leq b_i \ , \ i \in N \ ; \ k \in V \ , \quad (9)$$

$$\sum_{i\in N} t_i \times y_{im} + \sum_{k\in V}\sum_{i\in N}\sum_{j\in N} t_{ij} \times x_{ijk} \times y_{jm} \le p_m \quad \forall m \in M \tag{10}$$

$$x_{ijk} \in \{0,1\},\ y_{ij} \ge 0,\ z_{ij} \ge 0,\ i,j \in N,\ k \in V, \tag{11}$$

The first objective function is proposed to minimize the travel cost and fixed cost of nurses. constraint (2) states that each patient is visited only once. constraint (3) states that a nurse leaves the patient after visiting him/her. Constraints (4) and (5) indicate that each nurse starts him/her journey from HHC station, visits several patients and reaches the lab at the end. Constraint (6) indicates that the total number of patients who meet by a nurse cannot be more than a fixed value. Constraint (7) describes the skills required for strategy. Constraints (8) and (9) show that the service interval cannot exceed from time window constraints. Constraint (10) indicates the limitation of nurse working hours, per day and constraint (11) means that decision variables are binary.

3.4 Linearization of the nonlinear constraint

According to the proposed model, the constraint (10) makes our mathematical model nonlinear. So, we linearize it with the following formula:

$$x_{ijk} \times y_{jm} = F_{k,m}^{i,j} \tag{12}$$

$$\Downarrow$$

$$\sum_{i\in N} t_i \times y_{im} + \sum_{k\in V}\sum_{i\in N}\sum_{j\in N} F_{k,m}^{i,j} \times t_{ij} \le p_m \quad \forall m \in M \tag{13}$$

$$\Downarrow$$

$$x_{ijk} + y_{jm} - 1 \le F_{k,m}^{i,j} \le \frac{1}{2}\left(y_{jm} + x_{ijk}\right),\ F_{k,m}^{i,j} \in \{0,1\},\ \forall\, i,j,k,m \tag{14}$$

By adding constraint (14) to the original model, we transform constraint (10) to linear constraint. Eventually, the original model is converted to a simpler mixed integer linear programming model.

4 Solution Methodology

In this study, A Bi-level mixed integer linear programming model is developed. The patient also includes nurses in the model.

To solve the problem in the small dimensions the Gams software, has good performance but in large dimensions, due to the complexity of the model and being a NP-hard problem we used some meta-heuristic methods such as Tabu search (TS), variable neighborhood search (VNS) and particle swarm optimization (PSO) algorithm [12-20].

as mentioned, the model is partitioned into small and large sizes that the parameters used for each algorithm are shown in Tables 1 and 2.

Table1. The size of the problem instances

Problem	Number of the sample	Size of the problem
Small	S1	2×2
	S2	2×3
	S3	3×6
	S4	4×5
	S5	6×4
Large	L1	6×5
	L2	7×8
	L3	7×9
	L4	9×11
	L5	10×11

Table2. Tuned parameter levels for tuning the TS, VNS, PSO algorithms.

Algorithms	**Factors**	**levels**			
		1	**2**	**3**	**4**
TS	A: Max Iteration	1000	2000	4000	7000
	B: Tabu List	30	50	80	100
VNS	A: Max Iteration	3000	5000	7000	8000
	B: Number of neighborhood approaches	1	2	3	4
PSO	A: Max Iteration	300	500	800	-
	B: Population size	100	200	300	-
	C: Weight inertia	0.65	0.8	0.9	-
	D: Acceleration coefficient (C_1)	1.2	1.5	2	-
	E: Acceleration coefficient (C_2)	1.2	1.5	2	-

The meta-heuristic algorithms are all coded in MATLAB version R2020b and run in a computer with Intel Core i7 5GHz. The proposed meta-heuristic algorithms are implemented for the sample problem and their results are presented in Table 3 and Fig.1 shows that the small size problems, with branch and bound method have much better result in GAMS. Fig.1 also indicates that the large size problems with the Tabu search algorithm have better result than other algorithms. Table 4 indicates the computational times required by the small and large size problems. in the following, Fig.2 shows computational times which TS, VNS and PSO algorithm needs to run.

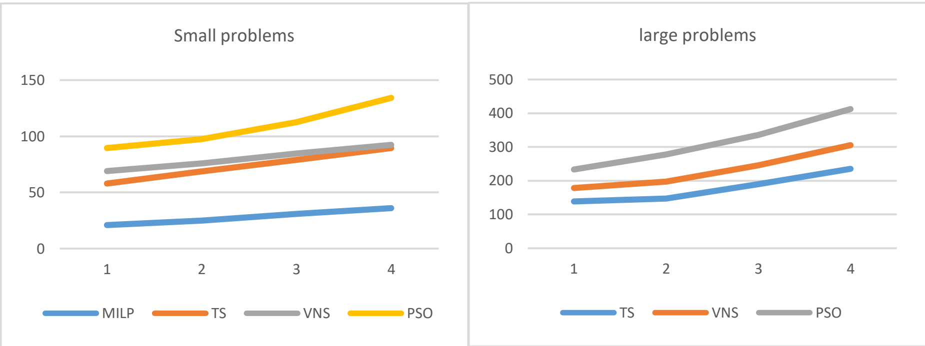

Fig.1. The results of the proposed algorithms in small and large size problems

Table 3. The results of the proposed algorithms

Problem size	MILP	TS	VNS	PSO
S1	12	40.261	41.800	67.068
S2	21	57.943	68.899	89.500
S3	25	68.766	75.809	97.566
S4	31	78.944	84.544	112.433
S5	36	89.405	92.322	134.203
L1	-	115.405	145.455	187.399
L2	-	138.899	178.677	233.390
L3	-	147.402	196.899	278.277
L4	-	189.388	245.567	335.466
L5	-	235.506	305.688	412.677

Table 4. CPU times of each sample problem

Problem size	CPU time MILP	CPU time TS	CPU time VNS	CPU time PSO
S1	0.17	0.23	0.34	0.56
S2	0.37	0.41	0.57	0.77
S3	0.45	0.58	0.79	0.9
S4	0.55	0.71	0.89	1.02
S5	0.67	0.88	1.12	1.37
L1	-	1.04	1.35	1.78
L2	-	1.58	1.89	2.32
L3	-	1.87	2.56	3.23
L4	-	2.02	2.91	3.56
L5	-	2.67	3.67	4.04

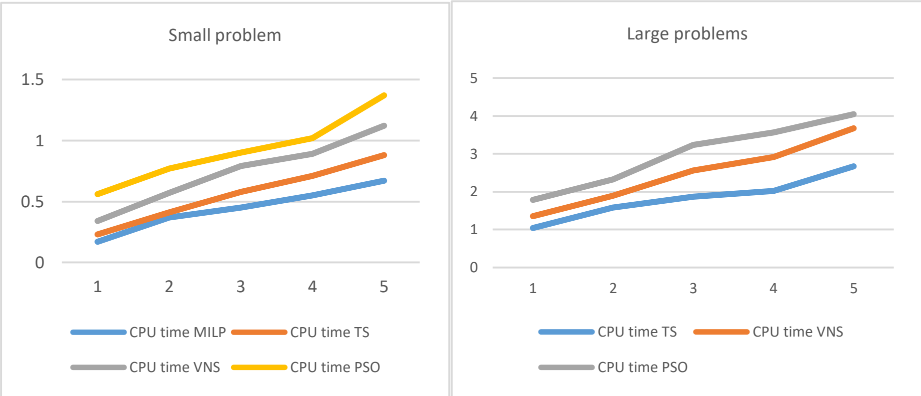

Fig.2. computational times in small and large size problems

5 Conclusion and future works

In this paper, we have developed a MILP model for a HHCRS problem and the main goal was to minimize the total costs at different levels of the chain. The model is solved in different sizes. in small sizes, branch and bound method has a good accountability. however, due to the complexity of the model and being NP-hard and also increasing the time of solving, Tabu search algorithms, variable neighborhood search and particle swarm optimization have been used. implementation of these algorithms resulted that the Tabu search algorithm has less computational time for solving the model.

Besides the proposed meta-heuristic algorithms, other algorithms, such as neural networks, colony optimization, whale optimization, imperial competitive optimization algorithms, etc. could be used for comparison in PSCN optimization. Also, there are many problems such as sustainability, pricing, and regulations, etc. or other uncertainty approaches such as stochastic, probability, etc. that can be incorporated to improve the model and solution methodologies in future studies.

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