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A Multi-Objective Optimization Model for Home Health Care Routing and Scheduling with a Case Study

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Abstract: Home health care (HHC) is a health service provided by a hospital so that patients can be taken care of at their homes. Assigning multiple caregivers to serve patients during working hours is one of the main issues of HHC planning. In this study, a multi-objective mixed-integer nonlinear programming was formulated for HHC daily planning. The model aims to simultaneously minimize total service time, total traveled distance, total cost comprising the opportunity loss from unvisited patients and penalty cost due to the violation of gender preference, and total carbon emissions generated by the caregiver's vehicle. Using real data from Dr. Moewardi Hospital, a case study was provided in order to show the applicability of the model. The model can be utilized to help the HHC coordinator in the determination of the optimal schedule and routing of the HHC visits.

Keywords: Home health care, routing and scheduling, multi-objective optimization.

Introduction

Home health care (HHC) is health services provided by a hospital with the aim of taking care of patients at their homes [1]. The concept of HHC was introduced in 1958 and is still being developed and enhanced until now [2]. The HHC was considered to be cheaper and more convenient but as effective as services in a hospital. In the last decades, there has been an increase in the number of organizations that provide HHC services [3]. To tackle the HHC problems, a mathematical programming approach has been employed extensively. HHC is the extension of vehicle routing problem (VRP) with the addition of some unusual side constraints relevant to the HHC context [4].

HHC planning comprises scheduling and determining the routing of patient visits by caregivers. Due to the constantly increasing demand for HHC, manual HHC planning will take more time and effort, leading to inefficiency [5]. HHC planning is a complex problem and makes it interesting to solve using operation research techniques [6,7]. Some researchers solved the model using exact programming, and some of them solved the model heuristically including the use of several metaheuristic techniques. For instance, Liu et al. [8] used the branch and price method to solve the model. Riazi et al. [8] and Naderi et al. [9] respectively employed column generation-based gossip and SP-timed logic-based benders decomposition algorithms to determine the solution of the model. In more recent research, several researchers utilized and compared the performance of metaheuristics on VRP problems [10, 11, 12]. These researchers solved VRP problems using a genetic algorithm with cluster-first route-second, neighborhood structures in local search, and the Camel algorithm (CA). The performance of two neighborhood structures was compared in Kenaka and Suprayogi [11], namely, tour- and permutation-based neighborhood search, and concluded that the latter structure was better than the former one. However, in Utama et al. [12], the CA was compared with particle swarm optimization (PSO) and ant colony optimization (ACO). The research showed that CA resulted in better performance compared to PSO and ACO. Labadie et al. [13] provided more details of metaheuristic techniques application in vehicle routing problems.

Several studies on the routing and scheduling of HHC have been carried out. For instance, to support the short-term human resource planning of HHC, an optimization model has been developed by Borsani et al. [14]. The objective of the model is to identify the optimal decision of the patient visit using either the company's own resources or outsourcing to the vendor. The objective function of the model is to minimize the total cost which comprises several penalty costs and outsourcing costs. To solve the routing deliveries of drugs in a French home care with the objective function of minimizing the traveled distance, another optimization model was developed by Bachouch et al. [15]. Four strategies were proposed in the research. The strategies dealt with starting the deliveries after some achievements of a specified number of deliveries, distance, deliveries per carrier, and fixed hours. The authors concluded that each strategy has its advantages and disadvantages. The right strategy to be taken will depend on the given situation. To determine the optimal visit schedule and study the trade-off between cost and patients' inconvenience, Braekers et al. [16] developed a bi-objective model. The proposed model considered several aspects including working regulations and overtime costs of the nurses, transportation costs, and client preferences on visit times and nurses. The model was solved via a metaheuristic algorithm.

Di Mascolo et al. [17] focused on the daily planning of HHC by emphasizing patient satisfaction in terms of service time and caregiver's gender. A mixed-integer linear programming (MILP) model was developed in the research to solve the problem. The model was also tested using hypothetical data to study the model behaviors, and it was found that a problem of 30 patients could be solved within 5 min of computer time. Fathollahi-Fard et al. [18] developed a bi-objective optimization model of HHC aiming to simultaneously minimize both travel distance and carbon emission. The model tackled the routing problem of nurses in visiting patients. A hybrid metaheuristic of simulated annealing and salp swarm algorithm was employed to solve the problem more efficiently. Liu et al. [19] developed a MILP model for medium-term HHC planning problems. The objective function of the model is to minimize total costs comprised of penalty costs of unvisited patients, the wages of caregivers, oil costs, and car charges. According to Di Mascolo et al. [20], the future research topics on HHC planning issues are patient preferences, sustainability aspects such as minimization of gas emissions or environmentally friendly means of transportation, and multi-objective approach.

In this research, to determine the optimal routing of patient visits by the available caregivers, we develop a multi-objective optimization model. The objective function of the model is to simultaneously minimize total service time, total traveled distance, total cost comprised of the opportunity loss from unvisited patients and penalty costs due to the violation of gender preference, and total carbon emissions generated by the caregiver's vehicle.

Methods

System Description

Figure 1 depicts the system under consideration. A hospital faces the problem of determining the optimal routes of patient visits. Each patient will be visited by a caregiver on a certain route. Each caregiver's visit will produce a different amount of carbon emission since it uses different vehicles in the visit. The patients should be visited by the caregivers within their time window. The caregivers start to work from the hospital, visit the patients within the time window, serve the patients, and finally return to the hospital. The problem considered in this paper is the daily planning of the caregivers. The patients have their gender preference of the caregivers. Once the visited caregiver does not match the gender preference of the patient, a penalty cost is applied. We assume that the caregivers will start the work from the hospital and will end the work at the hospital. The duration of visits is assumed to be known in advance and deterministic.

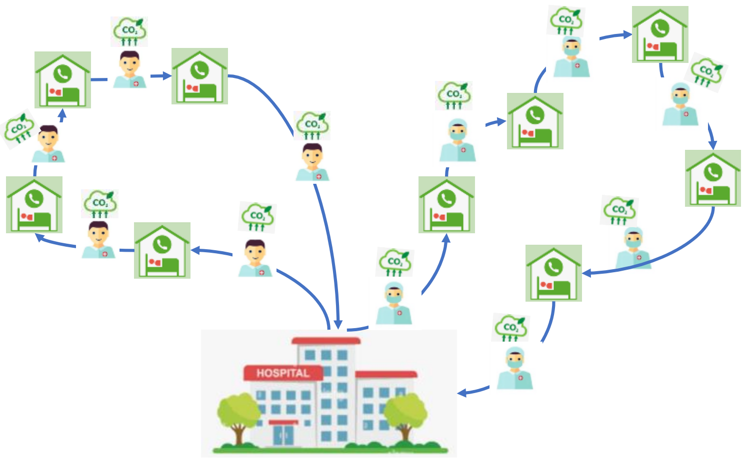

Figure 1. System description

Notations

The following notations are employed in the model of this research:

Indices

G : Index for origin location
j : Index for destination location
k : Caregiver index
P : Set of locations

Parameters

W : Total service time
S : Total traveled distance
TC : Total cost
TE : Total carbon emission
St_j : Service duration of patient at location j
Tt_{gj} : Travel time from location g to location j
D_{gj} : Travel distance from location g to location j
PG_j : Preference of caregiver's gender for the patient at location j (0 for female, 1 for male, and -1 if the patient does not specify the gender preference)
G_k : The gender of caregiver k (0 for female and 1 for male)
tS_k : Starting time of caregiver k at the hospital
tF_k : Finishing time of caregiver k at the hospital
tM_k : Maximum working duration per day for caregiver k
PL_j : Lower bound of the time window of patient j
PU_j : Upper bound of the time window of patient j
F : Opportunity loss from unvisited patient
PC_i : Penalty cost whenever the preference of patient j concerning caregiver gender is not respected
CE_k : Carbon emission rate per unit distance for caregiver k
y : Total number of patients

Decision Variables

X_{gjk} : Binary variable equals 1 if location j is visited after location g by caregiver k; 0, otherwise
C_{jk} : Binary variable equals 1 if location j is visited by caregiver k; 0, otherwise
NR_j : Binary variable equals 1 if the preference of patient j concerning caregiver's gender is not respected; 0, otherwise
U : The number of patients who cannot be served in HHC planning
A_{kj} : The time point when caregiver k arrives at location j
E_{kj} : The time point when caregiver k finishes the service at location j
B_k : The time point of caregiver k arrived at the hospital after visiting the patients
F_k : The finish time point of the caregiver k to work
TA_k : Total time home health care services by caregiver k

Model Formulation

The objective functions of the model are formulated in Equations (1)–(4).

$$Min\ W = \sum_{k\in K} TA_k \quad (1)$$
$$Min\ S = \sum_{g\in P}\sum_{j\in P}\sum_{k\in K} X_{gjk}\, D_{gj} \quad (2)$$
$$Min\ TC = FU + \sum_{j\in P} C_{jk}\, NR_j \quad (3)$$
$$Min\ TE = \sum_{g\in P}\sum_{j\in P}\sum_{k\in K} CE_k\, D_{gj} X_{gjk} \quad (4)$$

The first objective function is to minimize the total time home health care services. The second objective function is to minimize the total traveled distance of the caregivers. The third objective function is to minimize a total cost consisting of opportunity loss due to unserved patients and the penalty costs due to the gender preference of the patient not being respected. The fourth objective function is to minimize the amount of CO_2 emission of the caregiver's vehicle.

There are 29 constraints imposed in the model as shown in Equations (5)–(29).

$$\sum_{j\in P} X_{gjk} = 1, \forall k, j, g = 1 \quad (5)$$
$$\sum_{g\in P} X_{gjk} = 1, \forall k, j = 1 \quad (6)$$
$$\sum_{k\in K}\sum_{g\in P} X_{gjk} = 1, \forall k,\ j \neq 1 \quad (7)$$
$$\sum_{k\in K}\sum_{j\in P} X_{gjk} = 1, \forall k,\ g \neq 1 \quad (8)$$
$$\sum_{a\in P, l\neq a} X_{glk} - \sum_{i\in P, l\neq i} X_{ljk} = 0, \forall l, k \quad (9)$$
$$X_{gjk} = 0, \forall, j, k, g = j \quad (10)$$
$$U = y - \sum_{g,j\in P, j\neq 1}\sum_{k\in K} X_{gjk} \quad (11)$$
$$tA_k = \sum_{g,j\in P} X_{gjk}\left(Tt_{gj} + St_j\right), \forall k \quad (12)$$
$$tA_k \leq tM, \forall k \quad (13)$$
$$F_k = tS_k + TA_k \quad (14)$$
$$E_k \leq tF_k \quad (15)$$
$$E_g = tS + St_g, \forall g \in P, g = 1 \quad (16)$$
$$A_{kj} \geq \left(E_{kj} + Tt_{gjk}\right)X_{gjk}, \forall g, j \in P, g \neq j, j > 1 \quad (17)$$
$$E_j = A_j + St_j \quad (18)$$
$$B_k = \sum_{g,j\in P}\left(E_{gk} + Tt_{gjk}\right) X_{gjk}, \forall g, k, j \in P, j \neq 1, j = 1 \quad (19)$$
$$B_k \leq F_k \quad (20)$$
$$PL_j \leq A_{kj}, \forall g, k, j \in P, g \geq 1, j \geq 1 \quad (21)$$
$$A_{kj} + St_j \leq PU_j, \forall g, k, j \in P, g \geq 1, j \geq 1 \quad (22)$$
$$A_{kj} \geq 0, \forall g, k, j \in P, g \neq 1, j \neq 1 \quad (23)$$
$$PL_j \leq A_{kj} \leq PU_j, \forall j, k, j \neq 1 \quad (24)$$
$$\sum_{g\in P. g\neq j} X_{gjk} = \sum_{j\in P}\sum_{k\in K} C_{jk}, \forall k \quad (25)$$
$$\sum_{k\in K} C_{jk} = 1, \forall j \in P, j \neq 1 \quad (26)$$
$$\sum_{k\in K} C_{jk} PG_j = NR_j, \forall j, PG = 0 \quad (27)$$
$$\sum_{k\in K} C_{jk}(1 - G_k) = NR_j, \forall j, G = 1 \quad (28)$$
$$X_{gjk}, C_{jk} \in \{0,1\} \quad (29)$$

Equations (5) and (6) guarantee that each caregiver must start and finish their work at the hospital. Equations (7) and (8) ensure that each patient is exactly visited only once. Equation (9) is formulated to denote the caregiver visits and then leaves the patient. Equation (10) is required to ensure that the caregiver is not moving from and to the same patient. Equation (11) determines the number of unserved patients. Equation (12) defines the total time of home health care service provided by the hospital. Equation (13) guarantees that the working time of the caregivers on each day must be less than the maximum daily working hours. Equations (14) and (15) indicate the end of the caregiver's working time. Equations (16), (17), and (18) determine the starting and finishing time point of a caregiver at location *j*. Equations (19) and (20) define the time point of the caregiver at the last location (hospital). Equations (21), (22), (23), and (24) are to ensure the feasibility of each visit based on the patient's time window. Equations (25) and (26) respectively determine the routing of the caregiver and define the location *j* visited by the caregiver. Constraints (27) and (28) define that if the gender preference of the patient at location *j* is not respected, then the decision variable corresponding to the not respected preference will equal to 1. Equation (29) defines the binary of the decision variables.

Results and Discussions

A Case Study

The case study in this research was taken from Dr. Moewardi Hospital and was utilized to present the implementation of the proposed model. Dr. Moewardi Hospital is one of the big hospitals in Surakarta that provides HHC. The HHC services provided daily were from Monday to Friday at the working hours of 07:30 AM to 03:30 PM. The HHC team conducted the HHC services using the vehicles available at the hospital, such as ambulances and motorcycles. The vehicles will emit compounds such as CO (carbon monoxide), THC (total hydrocarbon), TSP (dust), NOx (nitrogen oxide), SOx (sulfur oxide), and CO_2 (carbon dioxide). These emissions are the main source of pollution in many big cities in Indonesia [23]. Thus, it is necessary to control pollution, which otherwise will increase the risk of disease and greenhouse gas emissions, and hence, in this study, carbon emissions are considered to be among the objective functions of the model.

Presently, routing and scheduling HHC at Dr. Moewardi Hospital are carried out by the HHC coordinator manually. Routing and scheduling with a manual system have a high risk of errors, low efficiency, and reduced job satisfaction. Thus, to enhance the efficiency of routing and scheduling HHC as a decision-making tool, quantitative methods with mathematical models are required. Therefore, the model is tested using real data from Dr. Moewardi Hospital. Ten patients must be served at home. Each patient has a time window and caregiver's gender preference. We assume that there are two available caregivers (one male and one female). The male caregiver uses a motorcycle, and the female caregiver uses an ambulance.

The opportunity loss is applied when the patients cannot be served by the available caregivers. The unit cost of opportunity loss comes from the cost that must be paid by a HHC patient, which is worth IDR 131,000. A patient may request to be served by a caregiver based on their gender preference. A penalty cost will be applied when the caregiver's gender is different from the one that the patient requested. Based on the interview with the person responsible for the HHC scheduling, the penalty cost due to the mismatch preference of the gender is IDR 50,000. The emitted carbon emission is based on a study by Nurdjanah [21]. Based on the research, the ambulance fuel consumption is 0.1160 L/km, whereas motorcycle fuel consumption is 0.0266 L/km. According to Sihotang and Assomadi [22], the carbon emission factor of gasoline is 2597.86 g/L. Therefore, the emitted carbon from the motorcycle and ambulance is 301.35 and 69.10 g/km, respectively.

Tables 1–3 show the parameters needed in the case study. Table 1 lists the patients and their respective locations including the hospital as the start and end destination. The table also shows gender preference, service time, and the lower and upper bound (LB and UB) of the time window of each patient. Tables 2 and 3 show respectively the travel time between patient locations and their respective travel distance.

Table 1. Patient data

Patient Index	Address	Gender Preference	Service Time (Min.)	Time Window LB	Time Window UB
J1	RSUD Dr Moewardi. Jl. Kolonel Sutarto Jebres	−1	0	-	-
J2	Jl. Veteran No.15. Tipes. Serengan. Surakarta	1	15	07.30	08.40
J3	Bayan. Kadipiro. Kec. Banjarsari. Surakarta	1	20	08.30	09.30
J4	Fajar Indah. Baturan. Colomadu. Karanganyar	0	15	08.00	09.00
J5	Kepatihan Kulon. Jebres. Surakarta	0	20	07.30	12.00
J6	Jl. Manggis VI. Jajar. Laweyan. Surakarta	1	20	07.30	15.30
J7	Jebres. Jebres. Surakarta	0	15	08.00	15.00
J8	Gedangan. Grogol. Sukoharjo	1	25	07.30	15.00
J9	Jl. Veteran No.15. Tipes. Serengan. Surakarta	0	30	07.30	15.30
J10	Jl. Baturan Raya No.8. Colomadu. Karanganyar	0	20	07.30	15.30
J11	Jl. Siwalan No.12. Kerten. Laweyan. Surakarta	0	15	07.30	15.30

Table 2. Travel time between locations (minutes)

Travel Time	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11
G1	0	15	11	15	4	14	6	19	15	15	13
G2	14	0	18	13	12	11	19	11	0	13	10
G3	12	19	0	12	12	15	16	26	19	13	14
G4	15	15	12	0	15	6	22	27	15	4	8
G5	5	11	12	15	0	15	12	17	11	16	13
G6	16	15	14	5	16	0	22	24	15	5	4
G7	4	15	13	16	7	17	0	22	15	17	24
G8	23	11	30	24	20	22	29	0	11	26	22
G9	14	0	18	13	12	11	19	11	0	13	10
G10	18	17	13	4	17	5	23	29	17	0	8
G11	16	11	13	7	13	3	21	20	11	6	0

In this research, owing to the different units of the objective functions, a function was required in order to transform all the objective functions into one dimensionless objective. Since the four objectives employed in the study have varying units (minimizing total service time, traveled distance, cost, and carbon emission), we cannot determine the sum of these four objectives. Hence, the objective functions must be transformed into a dimensionless function. Based on Marler and Arora [23], the most robust function in the multi-objective optimization problems is the transformation function as shown in Equation (30). The model was then solved using LINGO 18.0 software to find the optimal schedule and the routing of the visits. The optimal result of the multi-objective function was 0.106344 with a total traveled distance of 65.4 km. The total time for home health care was 349 min, there was no opportunity loss and gender preference penalty cost, and the total carbon emission was 10,998.92 g. The results of the optimization are shown in Tables 4 and 5, for the decision variables and objective function, respectively.

Table 3. Distance between locations (km)

Distance (km)	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11
G1	0	6	5.1	7.1	1.6	6.8	2.8	8.7	6	7.4	6.5
G2	4.9	0	8.4	5.7	4.6	5.4	8.4	4.3	0	6.3	5
G3	5.1	6.8	0	5.3	4.9	7.4	7.8	11.6	6.8	5.5	5.7
G4	6.8	6.6	5.3	0	6.5	1.8	9.4	11.8	6.6	1.3	3
G5	1.6	4.5	5.3	6.7	0	6	4.3	7.5	4.5	6.6	5.7
G6	6.9	6	6.2	1.5	6.7	0	9.6	10.3	6	1.5	1.2
G7	1.5	7.1	6.5	7.9	3	8.3	0	9.7	7.1	8.8	7.8
G8	8.3	4.3	11.1	9.3	7.3	9.1	11	0	4.3	10	8.6
G9	4.9	0	8.4	5.7	4.6	5.4	8.4	4.3	0	6.3	5
G10	7.4	7.2	5.5	1	7.2	1.4	10.1	12.4	7.2	0	3.6
G11	6.4	4.8	5.7	1.9	5.3	1.2	9.1	9.1	4.8	2.4	0

$$F_i^{trans} = \frac{F_i(x) - F_i^0}{F_i^{max} - F_i^0} \tag{30}$$

In Table 4, the male caregiver served more patients than the female one for individual objective function in terms of total service time, total traveled distance, and total carbon emission. Minimizing the total carbon emission cost became the least number of served patients by the female caregiver compared to the other objective functions. This result makes sense since the male caregiver's vehicle emits less carbon than the one used by the female caregiver. For the multi-objective function, number of served patients was relatively balanced between both caregivers since the objective function balances all the individual objective functions. Table 5 shows that the total service time is equal for three objective functions (minimize total service time, minimize total carbon emissions, and multi-objective function). For minimizing total traveled distance and multi-objective function, the traveled distance is equal, as well as the total cost.

Table 4. Optimal results of the decision variables

Objective function	Optimal routing	
	Female caregiver	Male caregiver
Minimize total service time	1-2-5-1	1-10-6-4-3-7-11-9-8-1
Minimize total traveled distance	1-2-4-10-1	1-5-9-3-6-11-8-7-1
Minimize total cost	1-5-11-4-7-9-10-1	1-2-8-3-6-1
Minimize total carbon emissions	1-5-1	1-2-4-6-3-7-11-10-9-8-1
Multi-objective optimization	1-5-4-10-11-9-7-1	1-2-6-3-8-1

Table 5. Result summary of the objective function

Objective Function	W (min)	S (km)	TC (IDR)	CE (g)
Minimize total service time	349	60.8	270,000	7,034.73
Minimize the total traveled distance	350	65.1	220,000	9,236.31
Minimize total cost	374	72.9	0	14,861.57
Minimize total carbon emissions	349	60.7	250,000	4,937.57
Multi-objective optimization	349	65.4	0	10,998.92

Sensitivity Analysis

To determine the effect of some changes in the value of several parameters on the objective function and decision variables, sensitivity analysis is an analysis carried out. In this research, sensitivity analysis is conducted on the following parameters: opportunity loss, gender preference penalty costs, the working duration for caregivers, the number of patients, and the duration of care for each patient. Tables 6 and 7 respectively show the effect of changing of those parameters on the objective function and decision variables.

Table 6. Result summary of decision variables of sensitivity analysis

Parameter	Changes Scenario	Objective Function	Routes for Female Caregiver	Routes for Male Caregiver
F	−50%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	-25%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	0%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	25%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	50%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
CG_j	−50%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	-25%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	0%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	25%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	50%	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
dM	−3	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	-2	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	0	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	2	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	3	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
St_j	-10	0.217171	1-5-9-11-10-4-7-1	1-2-8-6-3-1
	−5	0.169015	1-11-9-4-10-5-7-1	1-8-2-6-3-1
	0	0.106344	1-5-4-10-11-9-7-1	1-2-6-3-8-1
	5	0.209219	1-11-4-10-9-7-5-1	1-2-6-3-8-1
	15	0.664198	1-10-4-5-9-11-7-1	1-2-3-8-6-1

Table 7. Result summary of the objective value of sensitivity analysis

Parameter	Changes scenario	W (minutes)	S (km)	TC (Rupiah)	CE (Gram)
F	−50%	349	65.4	0 IDR	10998.92
	−25%	349	65.4	0 IDR	10998.92
	0%	349	65.4	0 IDR	10998.92
	25%	349	65.4	0 IDR	10998.92
	50%	349	65.4	0 IDR	10998.92
CG_j	−50%	349	65.4	0 IDR	10998.92
	−25%	349	65.4	0 IDR	10998.92
	0%	349	65.4	0 IDR	10998.92
	25%	349	65.4	0 IDR	10998.92
	50%	349	65.4	0 IDR	10998.92
dM	−3	349	65.4	0 IDR	10998.92
	−2	349	65.4	0 IDR	10998.92
	0	349	65.4	0 IDR	10998.92
	2	349	65.4	0 IDR	10998.92
	3	349	65.4	0 IDR	10998.92
St_j	-10	230	56.1	0 IDR	9775.660
	−5	286	61.0	0 IDR	11484.52
	0	349	65.4	0 IDR	10998.92
	5	406	67.4	0 IDR	11601.62
	15	522	77.0	0 IDR	13449.45

As shown in Table 6, all decision variables are relatively not sensitive to all parameters. The exception of the results emerges for service duration (St_j). We can see that the objective function is sensitive to this parameter.

A decrease of 10% of this parameter will make the objective function rise about twice, whereas increasing this parameter to 15% will raise the multi-objective function approximately six times. The detailed results of individual objective functions are shown in Table 7, which shows the same pattern as in Table 6. The most sensitive individual objective function is the minimize service time. Decreasing 10% of the duration time will decrease the total service time by approximately 30%, whereas an increase of this parameter to 15% will raise the total service time by approximately 50%. Hence, the hospital management should be aware of this parameter.

The model was also tested to determine the effect of the number of patients on the computation time. The computer specification for running the program has a processor of Intel Core i7, CPU of 2.70 GHz, and 8GR of RAM. For cases with 5–15 patients, the optimal solutions were found within 1 min and 20 s. For a case with 20 patients, the computation time increased to 4 h and 24 min. In that case, there were six unvisited patients due to the limitation of time constraints. Hence, for cases with above 15 patients, the use of metaheuristic techniques will be useful to determine the solutions in a shorter computation time. Several metaheuristic techniques can be employed such as nondominated sorting genetic algorithm (NSGA), ant colony, bee colony, or PSO.

Conclusions

Using a multi-objective optimization model, this research proposed a mathematical model for the HHC daily planning. The model was implemented in a case from Dr. Moewardi Hospital. The proposed model increased the efficiency of HHC planning and can be employed as a decision-making tool by the HHC planner. The optimization model resulted in a total distance of 65.4 km, 349 min of total time for home health care, IDR 0 for the opportunity cost, and 10,998.92 g of total carbon emission. The optimal routing for female and male caregivers is 1-5-4-10-11-9-7-1 and 1-2-6-3-8-1, respectively. The results of sensitivity analysis show that all decision variables were not sensitive to all parameters, whereas the objective function was sensitive to the service time. The model has several limitations, which include long computation time with more than 15 patients and the inability to cope with the problem of service time, which is usually uncertain. Therefore, further research can be directed to several directions including accommodation of the uncertainty of the service time, application of a metaheuristic technique to increase the efficiency of computation time, and development of a decision support system on the basis of the model.

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