Homecare Staff Scheduling with Three-step Algorithm

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***Abstract*— This paper introduces a three-step algorithm, an efficient framework for solving a homecare staff scheduling problem (HSSP) service schedule, a multi-objective problem requiring a combination of the VRP and the staff scheduling problem. The proposed scheduling technique takes account of the design of optimal daily service routes and the dispatch of caregivers to visit patients under time and capacity constraints. The framework consists of three major stages: Step 1) Route scheduling creates effective routes for homecare caregivers to service patients at different task locations with the shortest path. Step 2) Resource selection seeks to match qualified staff to each route with the minimum cost and preferences under possible time, qualification requirement constraints, and modes of transportation. Step 3) Local improvement enhances the output solution generated by the resource selection by swapping tasks based on the cost function. Our empirical study reveals that the proposed scheduling technique can explore the improved service plan for an adapted case study with the minimum service cost and highest efficiency for arranging service tasks compared to the manual procedure.**

Keywords—homecare, scheduling, routing, staff scheduling, multi-objective

I. INTRODUCTION

Providing a quality healthcare service is becoming challenging as the number of retired older people continues to rise. Home healthcare services offer a fundamental and essential role in daily life for older people. The service starts with each patient's requirement and doctor's recommendation, which qualified staff must do. The staff members should possess appropriate skills and qualifications for the given task, for example, the languages spoken, license to administer medicines, and medical expertise. Technically, the staff members, referred to as caregivers, are typically equipped with private cars and bikes or use public transport to visit the patients' homes from the homecare office[1] under specific time windows, usually between 08:00 to 16:30. Hence, effective scheduling of the healthcare service is indispensable for the service.

Traditionally, a service schedule is manually planned by an administrator, with the task referred to as the "Healthcare Staff Scheduling Problem (HSSP)." HSSP is a notoriously difficult Home Health Care (HHC) problem, requiring a combination of the VRP and the staff scheduling problem. In addition, HSSP is also associated with resource limitations such as staff members, individual preferences, unexpected accidents, and costs under specified time and capacity constraints.

HHC and HSSP have received intensive attention since the pioneering work began in the UK in 1974[2]. After that, many researchers have investigated HSSP. Several methods, such as routing and scheduling, have been used for solving HSSP in different regions and problem domains. However, many of these studies focus on more than one specific perspective and avoid the other.

Due to the increase of older people in areas already steering towards an aging society, HHC service providers face increasing operational costs. Therefore, effective scheduling of the homecare service is essential to provide healthcare with minimum cost. In general, experienced senior caregivers manually plan the less optimal schedules.

II. A THREE-STEP SCHEDULING

A. Concepts of the three-step scheduling

In light of the rapid development of computing science, various content of the homecare service has been presented and discussed. There are many scenarios in which caregivers must carry out tasks at patients' locations, hence requiring some form of routing, scheduling, problem management, as transportation. Regarding techniques and procedures for optimization, over the years, many methods have been introduced and presented on aspects of scheduling for healthcare. In earlier times, Fries [3] introduced service scheduling procedures created by a personal manager or senior caregiver working in a healthcare institute. Next, Sitompul and Randhawa [4] proposed a model of nurse scheduling concerning operational cost. Stochastic demands, supplies and constraints were included in the optimization model providing stages in the scheduling consisting of: 1) Determine a set of feasible solutions under the constraints, 2) Select the best solution, 3) Fine tune to accommodate change and 4) Make specific assignments. Bradley and Martin [5] proposed a model of nurse scheduling considering full-time and part-time employees to be sufficient of service capabilities in practical situations i.e., holiday periods (annual leave). The stages in the scheduling are still employed in this model. Siferd and Benton [6] presented a review of the factors influencing hospital staff scheduling in the United States. This also revealed that manual scheduling was the most common approach performed. However, the early research has applied a simple or single method for addressing workforce scheduling problems. A single meta-heuristic method cannot tackle the dynamic and uncertain nature of modern problems [7].

Considering the rapid development of soft-computing algorithms, many more complex and hybrid optimisation methods have been proposed for solving the scheduling problem. In this chapter, we propose to consider these concepts to develop a three-step scheduling. Cheang et al. [8] presented a survey of mathematical constraint programming methods and metaheuristics for solving the nurse rostering problem. Felici and Gentile [9] introduced an integer programming model that maximizes the total satisfaction of the nursing staff. Integer Linear Programming models have been proposed based on the concept of patterns, i.e. a priori scheduling profiles, to combine the diverse decision levels [10]. In addition, most articles in our review show that metaheuristics are popular to employ for solving the HHC service and the HSSP.

Regarding the subjects of the research of the HSSP, the most updated review paper for homecare routing and scheduling is published by C. Fikar in 2017 [11]. A visualisation of the selected author's use of keywords in the reviewed papers illustrates that the HHC and the HSSP have a strong relationship with 1) routing, 2) scheduling, 3) metaheuristics, 4) local search, 5) optimisation 6) staff planning and time-windows. Most of the reviewed articles are formed as an extension of the VRP focusing on travel. The total service distance remains as the main objective concerned. Travel cost and travel time are often considered. The travel cost significantly varies the total service distance. Maximum working time such as time-slot windows or the total distance or duration for each caregiver's route are also often considered to endorse that caregivers and nurses can be scheduled. Thus, travel time has become a more crucial factor for planning. A symmetric OD-matrix calculated by Euclidean distance [1, 12, 13] is often used for estimating travel time and distance, which cannot address the asymmetric distance issue and actual shape of roads, leading to a poor real world solution; especially in areas prone to severe traffic conditions where it is difficult to estimate actual travel times due to temporary road closures for resurfacing works, or parades. A stochastic travel programming model is integrated into the HHC routing problem for addressing this issue of uncertain travel time[14]. Even though a stochastic model has more efficiency than the deterministic model; it lacks real-time data that has unexpectedly changed. Based on the basic principles of data analysis, the quality of a solution strongly depends on the quality of the input data.

Although the HSSP is a crew scheduling problem with strong ties to vehicle routing with time windows, many complicating issues differentiate the problem from a traditional vehicle routing problem. One complication is multi-objective optimization, which is naturally important to minimise operational costs. Another important criterion is the maximization of the service level or preferences that can be provided [15]. Most articles related to the HSSP have employed an aggregate object model or weighted sum method [16] to incorporate different objectives to create a single objective function. However, it is widely known that the drawback of the weighted sum method is how to declare the appropriate weight of each objective due to each objective having different problem domains and value units. Hence, multi-objective solution procedures deriving a set of Pareto optimal solutions are sometimes applied to the HSSP. The greatest advantage of Pareto optimal approaches, such as NSGA-II [17] and SPEA2 [18], is not requesting each objective's weight. This approach calculates the optimal solutions in the objective space by fitting a parallel curve in each generation of searching [19]. However, using the Pareto optimal approach might not address the HHC and the HSSP in practical terms due to an infeasible solution may rise unexpectedly during optimising objectives in parallel. This issue relates to the reduction of search space. So, the search system cannot explore the optimal solution, and setting parameters for the initial searching point is difficult. For example, f**ig.1 (a)** shows a wide feasible region of the multi-objective for a single constraint, and **(b)** a globally optimal solution can be found easily. In contrast, **fig.2** illustrates an infeasible region with problems relating to numerous hard constraints. This figure illustrates the difficulty of initialisation in searching for the solution. On the one hand, the searching algorithm might explore the global optimal and the local solution in **Fig. 2 (a)** and **(b)**. On the other hand, the search algorithm might not explore any optimal solution because an initial search line started outside of the feasible region, as shown in **Fig. 2 (c)**.

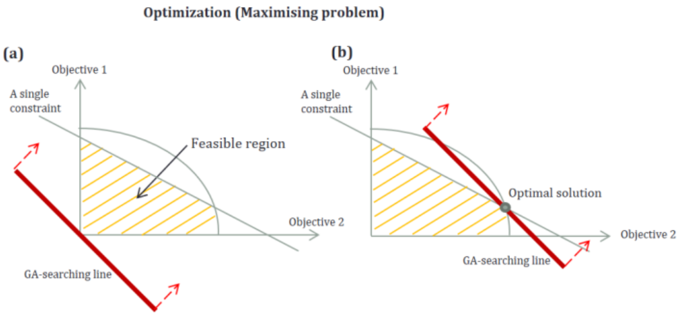

Fig.1 Feasible region and a searching line with a single constraint of the multi-objective optimisation

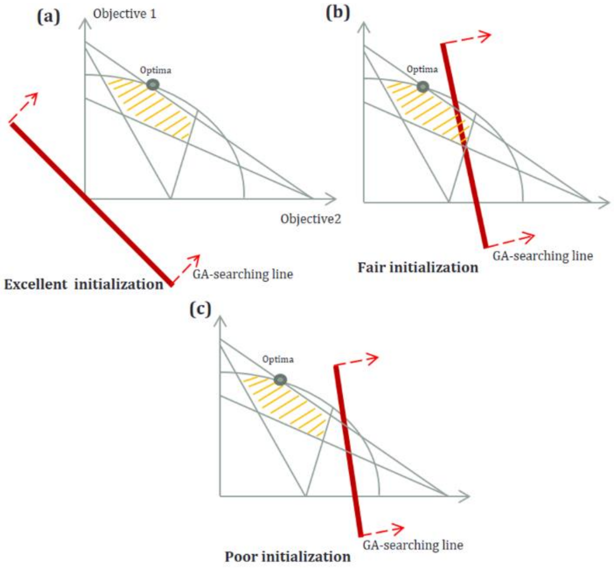

Fig.2 Limited feasible region and a searching line with a lot of hard constraints of the multi-objective optimisation

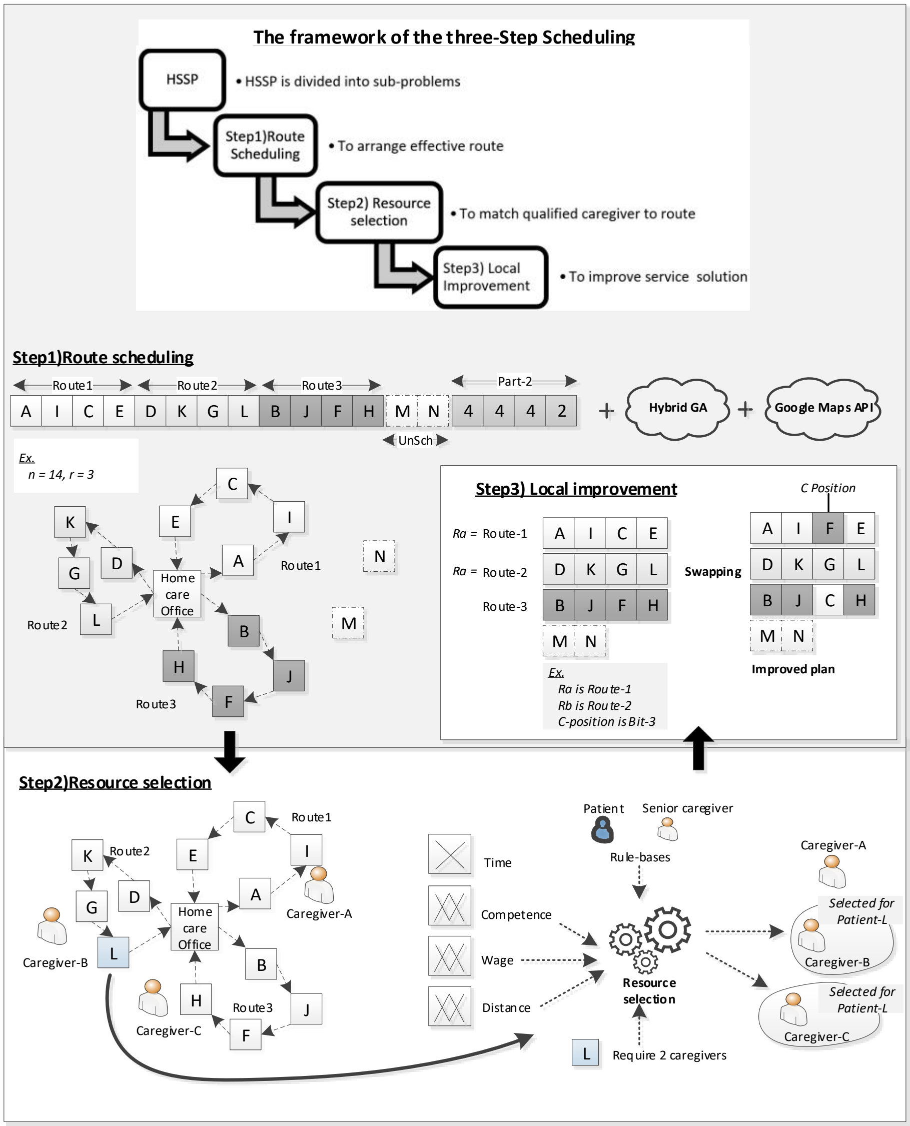

Fig.3 Limited feasible region and a searching line with a lot of hard constraints of the multi-objective optimisation

Due to the reasons mentioned previously, we introduce three-step scheduling, a general scheduling framework which takes advantage of single and multi-objective optimisation techniques, and incorporates with heuristics, a fuzzy inference system and geographic information system technology to solve the practical HSSP. This proposed framework is designed by considering the three main aspects of the HSSP including:

(1) Hierarchical optimisation — The multi-objectives of the HSSP is defined and solved in different priorities. Travel factors including transportation cost and travel time are considered first; with subordinate factors such as staff competence and the preference and satisfaction of people involved in the home care service considered afterward;

(2) Covering the whole of HSSP — Most important criteria and constraints i.e., travel time, lunch time, workload balance and parking time are taken into account to cover the entirety of the HSSP for both practical and academic purposes.

(3) Flexibility — The proposed scheduling framework is designed as a generic system, applicable to all practical HSSP instances. This framework can be modified flexibly because each problem domain is designed to be solved separately. Unexpected conditions such as variable travel times are provided by the high-quality transportation data provided by Google MAP APIs.

B. *The structure of the three-step scheduling*

The structure of the three-step scheduling is designed with the notion that the quality of the travel distance is the most important priority; significantly contributing to the quality of the service plan and operational cost. The whole problem is hierarchically divided into sub-problems based on the VRP and the scheduling problem, and then the problem is solved in three steps: *Step1)* Route scheduling, *Step2)* Resource selection, and Step3) Local improvement. So too, one of the advantages of three-step scheduling is that this framework extracts explicitly the sub-problems that are of practical importance for each problem to allow additional constraints as shown in **Fig.3**. This scheduling framework integrates a component of a highly reliable travel distance between locations obtained from GIS for optimising the travel distance in real-world scenarios. Further details of each will be described in the following section.

Step1) Route scheduling

This step focuses on how to arrange the solution of the service route while minimising the total of distances travelled for r routes containing n tasks' locations, taking both the limitation of workers and constraints of time windows into consideration. The sub-problem is defined as a MTSP employing a hybrid GA-based algorithm – a metaheuristic approach to optimise the model and achieve an optimal service route. We select a GA to integrate into the model for two reasons: 1) GAs can explore the optimal global solution with a high probability of success. 2) GAs have been applied to large-scale optimisation problems and 3) GAs are convenient for problem representation with a high speed of computation. GA encoding of chromosomes is widely accepted as it is flexible and convenient and allows additional components, i.e., MTSP. There are also several articles relating to GAs on the development of chromosome representations to support more complicated problems.

In addition, the system is designed to support practical modern scheduling problems. High accuracy data such as precise transportation times and distances in different modes of transportation are used in the proposed model through integration of Google Maps–the most popular GIS technology. The daily uncertain conditions/constraints for scheduling, e.g. traffic jams, a particular time to limit vehicle speed, or a schedule for swapping between a two-way and a one-way road is obtained from the Google Maps API to create an origin-destination (OD) matrix instead of using a conventional method for evaluating the distance and travel time before the hybrid GA starts.

Step2) Resource selection

Resource selection aims to match workers to each service route and job. The designed structure integrates the heuristic search and fuzzy logic to develop a reliable and practical decision to match each qualified worker to each operation. The resource selection system is firstly responsible for handling all information and data, such as retrieving the planned route from the hybrid GA in *step1*, customers' and workers' profiles; and then matching between the correct workers and customer tasks. The operational cost is subsequently minimised, considering preference and possible time windows. Then, the system employs fuzzy logic with rule-bases acquired from both customers and the planner team to create a fuzzy inference system (FIS) to estimate a set of scores for all workers in each task. One of the advantages of the resource selection step is that the system is designed to address a particular case requirement for multiple engineers by using a decision from the fuzzy inference system. **Fig. 4** illustrates the structure of a FIS with four input variables, which are defined as the membership function, and consisting of 1) *Time*: low and high, 2) *Distance*: near, average, and far, 3) *Competence*: low, average, high, and 4) *Cost*: low, average and high.

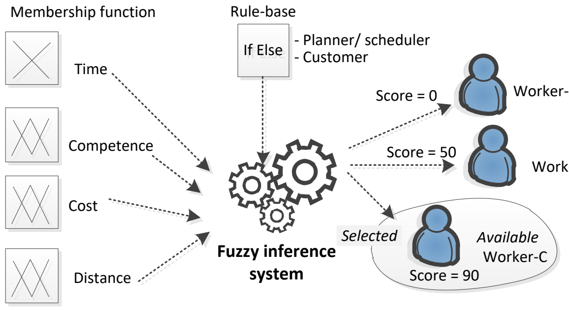

Fig.4 FIS to match caregivers to service routes with the requirement of multiple caregivers.

Step3) Local improvement

Local improvement repairs the service plan generated by the previous steps using the swapping procedure. In addition, it also re-checks the service plan generated by the previous steps. This step interchanges activities between two caregivers' routes. Given each route has a set of the sequence of service activities, the process starts by selecting a pair of two routes R_a and R_b and swapping the service activities at position c along the chosen pair. The service plan after re-arrangement is recalculated with the objective function evaluation only.

III. PROBLEM DETAILS AND MODEL

A. Assumptions

- The patient is an outpatient or follow-up patient in the phase of recovering. And the caregiver specifies the date to check on the patient's progress since his or her last appointment or hospital discharge.
- Caregivers are recommended to service between 4 to 6 patients every working day as a higher number of patients may lead to fatigue and exertion of the staff members; (Normally, each can serve between 4 to 5, or exceptionally 6, patients a day.)
- All the patients have the same priority, and the service does not require specified time.
- Each caregiver starts from the homecare office at 8:00 and expects to end the service at a regular time of 16:30.
- The assigned tasks must be completed within time windows. In case the service needs extra time after regular hours, the healthcare office is responsible for additional expenses. Note that the service policy is not permitted to pay extra costs for any caregivers if the service ends after 17:00.
- The patients' locations are defined by geolocation (latitude and longitude coordination).
- Operating time is set to a default of 60 minutes.
- Lunch breaks are also considered. Half an hour is allocated, starting after the completion of two tasks between 11:00 -12:30 each day. The start of lunchtime varies depending on the service activities of each route.

- Caregivers can define available and unavailable times for daily work.
- A subset of caregivers offers healthcare services for psychological counselling, hygiene, and medicine advice.
- Travelling time between tasks automatically includes 15 minutes for finding a car park.

B. *Objectives and mathematic models*

$$\text{Min}_{\text{travel cost}} \sum_{d\in D}\sum_{r\in R}\sum_{i,j\in N} P_{i,j}^{r,d} \cdot C_{i,j}^{r,d} \,.\, d_{i,j}^{r,d} \qquad \text{(Eq.1)}$$

$$P_{i,j}^{r,d} = \begin{cases} 1, \text{if a journey is made from } location_i \text{ to } location_j \\ 0, \text{otherwise} \end{cases} \qquad \text{(Eq.2)}$$

$$\text{Min}_{operating\ cost} \sum_{d\in D}\sum_{r\in R}\sum_{j\in N} P_j^{r,d} \,.\, Operating_{time,j}^{r,d} \,.\, cost_j^{r,d} \qquad \text{(Eq.3)}$$

$$Operating_{time,j}^{r,d} = Finished_{time,j}^{r,d} - Starting_{time,j}^{r,d} \qquad \text{(Eq.4)}$$

(Eq.5)

Service cost = *Travel cost* (Eq. 1) + *Operating cost* (Eq.3) + *Penalty cost*

Note that ${d}_{i,j}^{r,d}$ may be different from ${d}_{j,i}^{r,d}$. Penalty cost is cost for re-schedule if an appointment is delayed or cancelled.

The objective function (Eq.1) minimises the total of the travel cost, which includes the total of distances travelled by caregivers, and the total travel cost varies in different modes of transportation. Constraints (Eq. 2) are the binary constraints for variable $P_{i,j}^{r,d}$. It can be seen from the data that (Eq.3) and (Eq.1) are quite similar but (Eq.3) focuses on the operating cost, calculated using the wages of caregivers, according to service conditions, including staff competence and task constraints while (Eq.1) points to the travel cost. Finally, the service cost can be formulation as shown in (Eq.5).

C. *A case study*

A real case study from a hospital with 44 task-locations. Patients' information (such as name, address, and types of disorders) have been anonymised in the report. The Google Map is used to obtain information consisting of travel distance and travel time.

IV. EXPERIMENTAL RESULTS

Performance of the proposed framework for the HSSP was measured using Eq. (5) in GBP.

A. *Manual scheduling technique*

As this method is informed by interview with the HHC senior planner who manually generates the plan, it benefits from a combination of a common sense for scheduling, which can be referred to as a first-come, first-serve (FCFS) approach; along with the incorporation of a heuristic search, to create a final service schedule.

B. *A comparison of the three-step scheduling and the manual technique*

The experimental results of three-step scheduling are described with 15 comparative criteria:

(1) **Number of service tasks** – All tasks/patients of each dataset;
(2) **Number of caregivers** – the number of active caregivers offering the HHC service;
(3) **Actual daily service tasks** – the number of tasks that can be operated by caregivers;
(4) **Expected daily service tasks** – the expected tasks that can be completed by the service schedule. For the manual, the expected daily service tasks = (the number of full-time caregivers *4) + (the number of part-time caregivers*2). There are two types for part-time: morning or afternoon time; and we can thus assign two tasks to a part-time caregiver. For example, the number of full-time caregivers = 7 and part-time =1, the expected daily service tasks = (7 full-time × 4 tasks) + (1 part-time × 2 tasks) = 30 tasks;
(5) **Efficiency ratio** = The ratio of actual daily service tasks (3) to expected daily service tasks (4**)**;
(6) **Number of tasks requiring a multi-caregiver** – the number of tasks requiring a multi-caregiver for operating in (3) actual daily service tasks;
(7) **Operating cost** – the total operating cost calculated using Eq. (6.1);
(8) **Travel cost** (Eq. 1) – the total of distance travelled by caregivers * petrol cost/km.;
(9) **Penalty cost** – the total extra rescheduling cost in the case of a caregiver unable to complete their expected tasks within time-slots. The remaining tasks are rescheduled for the coming days. This cost is calculated from the penalty cost of each task, combined with the wages of caregivers for each remaining task;
(10) Service cost (Eq. 5) = The sum of 3 criteria listed above: (7) + (8) + (9);
(11) Cost/Unit = (10) / ((3) + (6) – (1));
(12) Average overtime (min.) – the sum of overtime for all caregivers in minutes;
(13) Computation time(sec.) – CPU time for execution for *Step2)* and *Step3)*;
(14) %Efficiency Improvement (EI) – the efficiency improvement, calculated from the efficiency of each technique, relative to that of the manual technique;
(15) %Efficiency Cost per unit (EU) – the cost improvement, calculated from the total cost of each technique, relative to the total cost of the manual technique.

C. *Experimental results*

TABLE I. EXPERIMENTAL RESULTS

Methods	*Manual*	*Three-step scheduling*
(1) Number of service tasks	42	
(2) Number of caregivers	8 caregivers (7 full time and 1 part-time)	
(3) Actual daily service tasks	26	35
(4) Expected daily service tasks	30	30
(5) Efficiency ratio	0.87	1.17
(6) Number of tasks requiring a multi-caregiver	2	2
(7) Operating cost (Eq.1)	40.98	54.15
(8) Travel cost (Eq.3)	53.89	65.69
(9) Penalty cost	18.97	0
(10) Total service cost (Eq.5) = (7) + (8) + (9)	113.84	119.84
(11) Cost/Unit = (10) / ((3) + (6) - 1))	4.22	3.33
(12) Average overtime (min.)	On time	On time
(13) Computational time (sec.)	-	7.66
(14) % Efficiency Improvement: EI	-	34.48
(15) % Efficiency Cost per unit: EU	-	21.05

*Please note,

1) Operating cost is the total of extra wages for caregivers (Not included in salary ≈1.5 GBP/hour or 66.91 THB/hour)
2) 1 GBP = 44.61 THB on 27th November 2023

As seen from TABLE I, the three-step scheduling technique can demonstrate a significant improvement in all comparative criteria. The efficiency ratio has risen to 1.17. In addition, three-step scheduling can offer a higher number of tasks which require multi-caregiver support, up from 2 tasks with the *manual* method, to 4 tasks. Regarding the **%EI** and **%EU**, *three-step scheduling* reach the highest number at 21.05% compared to the dataset.

V. CONCLUSION

A. Conclusion

The homecare staff scheduling problem (HSSP) presents a notable challenge for the HHC service, which includes a combination of the vehicle routing and the staff scheduling problems. The HPPS involves several restrictions such as patient demand, travel cost, staff skills and respecting preference, which must be done under specific time slot windows. This thesis presents a novel step-scheduling framework called "Three-step scheduling" for solving the HSSP by dividing the problem into sub-problems and then finding solutions with priority for route scheduling or vehicle routing problem (VRP) and staff scheduling problem. The overview of three-step schedule is depicted in **Fig.3**.

One of the advantages of three-step scheduling is that this framework extracts explicitly the sub-problems that are of practical importance for each particular problem to allow additional constraints. This scheduling framework integrates a component of a highly-reliable travel distance between locations obtained from GIS for optimising the travel distance in real-world scenarios.

In summary, the efficiency and the operating cost of service schedule generated by three-step scheduling is greater than the performance the manual technique required the experience of the senior scheduler. Compared to the manual technique, the efficiency of scheduling is improved up to 34.48% as well as the cost per unit is also reduced by 21.05% for the adapted real-world case study when three-step scheduling employed.

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REFERENCES

[1] D. S. Mankowska, F. Meisel, and C. Bierwirth, "The home health care routing and scheduling problem with interdependent services," *Health Care Management Science,* http://doi.org/10.1007/s10729-013-9243-1 vol. 17, no. 1, pp. 15-30, 2014.

[2] A. Fernandez, G. Gregory, A. Hindle, and A. Lee, "A model for community nursing in a rural county," *Journal of the Operational Research Society*, vol. 25, no. 2, pp. 231-239, 1974.

[3] B. E. Fries, "Bibliography of operations research in health-care systems," *Operations Research*, vol. 24, no. 5, pp. 801-814, 1976.

[4] D. Sitompul and S. Randhawa, "Nurse scheduling models: a state-of-the-art review," *Journal of the Society for Health Systems*, vol. 2, no. 1, pp. 62-72, 1990.

[5] D. Bradley and J. Martin, "Continuous personnel scheduling algorithms: a literature review," *Journal of the Society for Health Systems*, vol. 2, no. 2, pp. 8-23, 1991.

[6] S. P. Siferd and W. Benton, "Workforce staffing and scheduling: Hospital nursing specific models," *European Journal of Operational Research*, vol. 60, no. 3, pp. 233-246, 1992.

[7] E. K. Burke, P. De Causmaecker, G. V. Berghe, and H. Van Landeghem, "The state of the art of nurse rostering," *Journal of scheduling*, vol. 7, no. 6, pp. 441-499, 2004.

[8] B. Cheang, H. Li, A. Lim, and B. Rodrigues, "Nurse rostering problems—a bibliographic survey," *European Journal of Operational Research*, vol. 151, no. 3, pp. 447-460, 2003.

[9] G. Felici and C. Gentile, "A Polyhedral Approach for the Staff Rostering Problem," *Management Science*, vol. 50, no. 3, pp. 381-393, 2004, doi: doi:10.1287/mnsc.1030.0142.

[10] P. Cappanera and M. G. Scutellà, "Home Care optimization: impact of pattern generation policies on scheduling and routing decisions," *Electronic Notes in Discrete Mathematics*, vol. 41, pp. 53-60, 2013.

[11] C. Fikar and P. Hirsch, "Home health care routing and scheduling: A review," *Computers & Operations Research*, vol. 77, pp. 86-95, 1// 2017,

[12] C. Akjiratikarl, P. Yenradee, and P. R. Drake, "PSO-based algorithm for home care worker scheduling in the UK," *Computers & Industrial Engineering*, http://doi.org/10.1016/j.cie.2007.06.002 vol. 53, no. 4, pp. 559-583, 2007.

[13] B. Maenhout and M. Vanhoucke, "An electromagnetic meta-heuristic for the nurse scheduling problem," *Journal of Heuristics*, journal article vol. 13, no. 4, pp. 359-385, 2007, doi: 10.1007/s10732-007-9013-7.

[14] Y. Shi, T. Boudouh, and O. Grunder, "A Home Health Care Routing Problem with Stochastic Travel and Service Time," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 13987-13992, 2017.

[15] M. S. Rasmussen, T. Justesen, A. Dohn, and J. Larsen, "The Home Care Crew Scheduling Problem: Preference-based visit clustering and temporal dependencies," *European Journal of Operational Research*, http://doi.org/10.1016/j.ejor.2011.10.048 vol. 219, no. 3, pp. 598-610, 2012.

[16] C. M. Fonseca and P. J. Fleming, "Multiobjective optimization and multiple constraint handling with evolutionary algorithms. II. Application example," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 28, no. 1, pp. 38-47, 1998, doi: 10.1109/3468.650320.

[17] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," *IEEE Transactions on Evolutionary Computation*, http://doi.org/10.1109/4235.996017 vol. 6, no. 2, pp. 182-197, 2002.

[18] E. Zitzler, M. Laumanns, and L. Thiele, "SPEA2: Improving the Strength Pareto Evolutionary Algorithm," 2001.

[19] K. Braekers, R. F. Hartl, S. N. Parragh, and F. Tricoire, "A bi-objective home care scheduling problem: Analyzing the trade-off between costs and client inconvenience," *European Journal of Operational Research*, vol. 248, no. 2, pp. 428-443, 1/16/ 2016, doi: http://dx.doi.org/10.1016/j.ejor.2015.07.028.