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Published in:
International Journal of Agile Systems and Management

DOI:
10.1504/IJASM.2018.10015580

Published: 22/08/2018

Document Version
Peer reviewed version

Heuristic and Fuzzy Scheduling Synergy with Knowledge Acquisition of Resource Selection System Development for Home Healthcare Service

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Abstract: Home healthcare service provides daily medical services at patients' homes. The service aims to satisfy the patients' requirements which must be done by one or more qualified staff visiting them in right time. This paper proposes a new framework integrating the heuristic search and fuzzy logic with knowledge acquisition to develop reliable and effective decision to match qualified staff to offer homecare services with the minimum cost and better preference consideration under feasible time-slots. The framework is designed based on a hierarchical approach which divides the staff selection system into two layers: high and low level. The high level is responsible for retrieving information, such as patients' locations, service

distance and operation cost as well as dealing with constraints such as patients' requirement and working time-slots. This information is passed to the lower level which is employed with fuzzy logic to estimate a set of the level of staff selection before returning results back to the higher layer to create the service plan.

Our empirical study shows that the proposed framework has a potential to provide improved solutions with minimized operating cost and improved patient's satisfaction. The case study for the experiment comprises of 40 medical tasks with 8 service routes and 8 carers under time-slot windows.

Keywords: *Resource selection, Homecare service, Fuzzy logic, Heuristic search, Knowledge engineering*

1. Introduction

The World Health Organization reports that the proportion of older people in Europe and the United States will rise constantly in the coming decades *(Tarricone and Tsouros, 2008)*. This trend is seen in many countries around the world and is caused by factors such as decreasing birth rates and rising life expectancies. Asia is predicted to have the uppermost number of elders owing to the increasing population in China and India. In particular area such as Thailand, a new demographic turning point has been extended and from the year 2000 to 2030, the entire elder population of Thailand is projected to increase 303.9%, from 5.8 million to 17.7 million (*National Economic and Social Development Board, 2012).*

As the population of elders is expected to increase worldwide, Technologies are enable to generate systems of health and long-standing carefulness that alleviates the economic *(Institute, 2009)*. Artificial Intelligence (AI) is also one of technologies which has been applied to support increasing of elders. In general, AI is served from various disciplines which include philosophy that is logic, reasoning method, mind as physical system, basics of learning, language and reason. Various applications based on AI are employed for homecare service, i.e., AI chatbot developed by *Cera (Techcrunch, 2017)* that is being developed to provide personalized care advice.

Homecare service plays a fundamental and essential role in everyday living. This service begins with patients' requirements which must be assessed by qualified staff members. These members have to acquire accurate skills and experiences for the assigned task, for instance, the language skills, license to administer medications, etc. In general, the homecare staff members, referred to as nurses or carers, are usually equipped with private vehicles, bicycles or public transportation to travel to patients' homes from the homecare office during particular time ranges, typically between 8:00 am to 16:30 pm. Therefore, an effective scheduling system is crucial for the homecare service. In working homecare service, schedule is normally produced by the planner to arrange service plan. This problem is referred to here as "Homecare Staff Scheduling Problem (HSSP)", relating to a large number of resources such as staff members, competency, preference, cost under specified time and capacity constraints.

As the routing and scheduling problem, HSSP has grown significant interest over the past several years such as shift scheduling problem *(Gutiérrez and Vidal, 2013)*. Recently, researchers proposed a hierarchy problem-solving procedure to divide the problem into smaller diverse domains in order to extend the search space and find the global optimal solution for solving larger HSSP *(Yalçındağ et al., 2016)*. A two-stage procedure based on integer linear stochastic programming collaborating with historical data is proposed *(Rodriguez et al., 2015)*. The first step creates possible demand service scenarios while the second stage estimates the optimal number of staff members offering the service. In our previous works, the experimental results *(Sinthamrongruk, 2016),(Sinthamrongruk and Dahal, 2017)* indicated that hybrid approach based on Genetic Algorithm (GA) provided the optimal service route.

Concerning to scheduling based on preference and satisfaction, several techniques have been proposed such as mathematical, heuristics and meta-heuristics for the HSSP. As part of mathematical programming methods, *Felici and Gentile(2004)* presented an integer programming model that maximizes the total satisfaction of the nursing staff. *Bard and Purnomo (2005)* adopted the column generation scheme to solve the problem in terms of minimising the nursing staff members' violating preferences. Fuzzy theory was applied to HSSP in order to determine the changeable factors that influence nurse satisfaction *(Topaloglu and Selim, 2010)*. For application related to matching qualified resource for scheduling, the closest approach was proposed by *Remde et al.(2007)*. The selection system creates a set of potential resources for the selected task subjected to precedence constraints.

In this research, a step-scheduling technique has been proposed. The highlight of the technique is to solve the problem in different domains by dividing entire HSSP into sub-domain problems and then finding solutions with three-step scheduling framework for *route scheduling*, *resource selection* and *local improvement*. Route scheduling focuses on how to arrange effective routes for staff with minimum distance travel time and travel cost. Resource selection points to match qualified staff to each route with the minimum cost and the satisfaction by the scheduler and also a customer representative under feasible time constraint. Local improvement fixes output solution generated by the resource selection in some cases which are cancelled based on the cost function.

This paper aims at proposing a new framework integrating the heuristic search and fuzzy logic with knowledge acquisition to develop and improve the reliability on *resource selection* which is the second step of the three-step scheduling for matching qualified carer to medical service tasks. In addition, the knowledge acquisition through targeted work based on transfer roles derived from scheduler expert knowledge and past experience has been employed in the framework to improve reliability decision and satisfaction to patients with right skill and performance of carers.

2. Research Methodology

Figure 1 illustrates a general overview of HSSP where there are eight people, from *Patient-A* to *Patient-H*, who require home homecare service. Firstly, all of patients have to register and inform their intention at the homecare office. Then, scheduler or planner consider patients' details such as type of services and patient profile based on their experience before assigning homecare staff members to offer medical services at patient's home in each service route. **Figure 1(B)** demonstrates that two carers are assigned to visit patients' homes. Even though this service seems easy to create schedule manually, it is a complicated problem in the real situation as the aging population has expanded dramatically, demanding an automatic scheduling system to handle with the HSSP, for example, *Patient-D*, an overweight patient requires two carers for service at the same time where each carer is operating service in different routes. A question is how to plan service schedule for carers offering the service at *Patient-D*'s location at the same time in uncertain environment under limited time, limited resources and caretakers' and customers' preferences.

HSSP has received intensive attention since the pioneering work in the UK in 1974 *(Fernandez et al., 1974)*. From then on, several methods have been investigated for solving HSSP in different regions and problem domains. The majority of published papers emphasize on single-optimization problems, such as preference *(Lin et al., 2015)* and shift scheduling problem *(Gutiérrez and Vidal, 2013)*; these do not cover all issues of HSSP. To concern multi-issue of HSSP, a step-scheduling technique has been proposed to solve HSSP. With minimising operation cost, preferences, double staff unit requirement, modes of transportation, and accurate data for scheduling, i.e., travel distance and time have been taken into account to a model for the experiment as shown in **Figure 2**. The highlight of this technique is to solve the problem in hierarchical perspective by dividing the problem into sub-problems using route scheduling, resource selection, and local improvement steps. *Routes scheduling* focuses on how to arrange effective routes for staff with minimum distance travel time and travel cost. GA-based approach is widely used for modelling such as *(Dahal et al., 2007)* and *(Choudhury et al., 2008).* This approach has been employed for generating service route. *Resource selection* points to match qualified staff to each route with the minimum cost and the preferences by the scheduler and also a customer representative under feasible time, qualification requirement constraint and modes of transportation. *Local Improvement* enhances the output solution generated by the resource selection using swapping task based on the cost function.

In this paper, we focus on an improved scheduling algorithm for solving HSSP on *resource selection* which is the second step in the three step-scheduling. The proposed algorithm will be applicable for real-life situations based on heuristic and fuzzy logic approaches to generate an effective schedule for the homecare service.

Figure 1. Overview of Homecare Staff Scheduling Problem (HSSP)

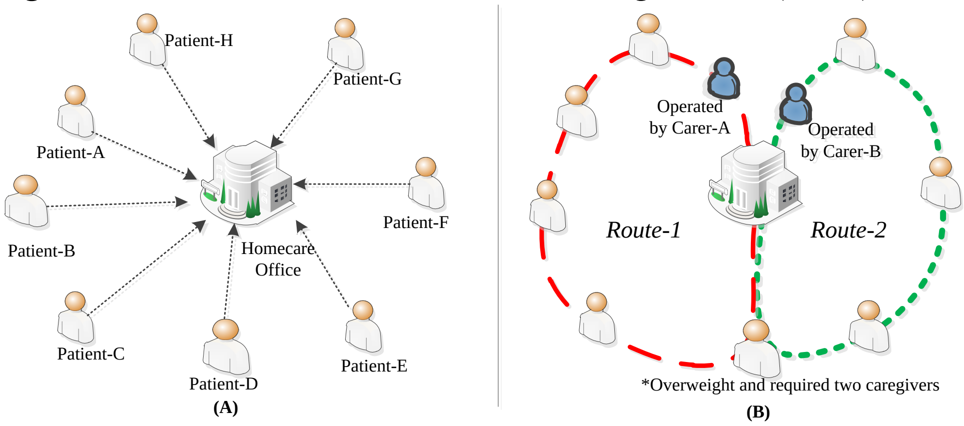
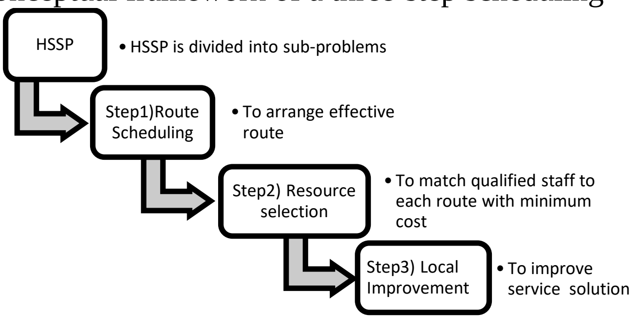


Figure 2. Conceptual framework of a three-step scheduling



2.1.Design of cFuzzy for resource selection

In general, the basis of fuzzy logic is based on human communication that is stated to be a mapping method of the stream of information from an input area to an output area, for achieving this is a list of if-then declarations named rule *(Ross, 2009)*. Briefly, fuzzy logic reflects how people think which might be uncertainties. This technique attempts to model our sense of words, our decision-making and our common sense. As a result, it is leading to new, more human-like, intelligent systems. In terms of application based on uncertainty and fuzzy logic. *Vadiee and Jamshidi (1994)* proposed a typical system for coping with uncertain knowledge. In research of *(Bowles and Pelaez, 1995)* they contributed systems which employed fuzzy logic to satisfy the requirements of humans.

In this paper, the *cFuzzy* has been proposed based on hierarchical approach which incorporates fuzzy logic and heuristic algorithm.

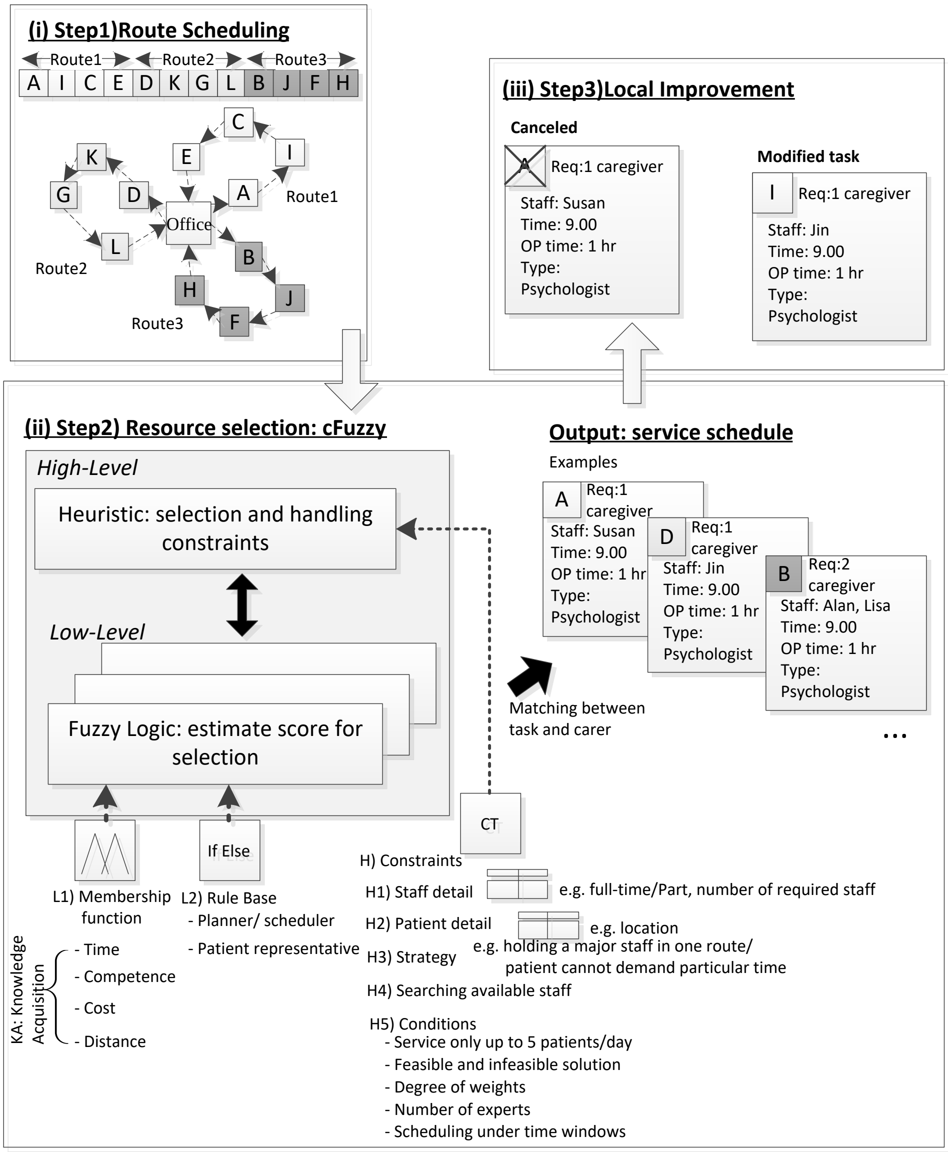
Figure 3 illustrates the structure of resource selection or *"cFuzzy"* which is the second step of the three-step scheduling proposing a framework for matching qualified staff members to medical tasks in each route with the minimum cost concerning to the preferences by scheduler and a customer representative under feasible time constraint.

The hierarchy framework of the *cFuzzy* is designed by separating the system into high and low level. The high level employs the concept of heuristic approach while the low level uses fuzzy logic

The *cFuzzy* begins at the high level by receiving the optimal routing plan generated by the first step of the three-step scheduling in terms of multiple travelling salesman problems (MTSP) as shown in **Figure 3 (i)** before using seeking essential data, parameters, scheduling constraints consisting of (H1) Staff detail involving in type of service, competence, cost and operating time of the carers, (H2) Patient detail considering about patients information such as service type, location and bodyweight, (H3) Strategy for scheduling : an attempt to hold a major carer offering at the same route, (H4) Finding available carers focusing on exploring available carer for matching task in specific time windows, and (H5) Other conditions such as the maximum service task per carer per day. These factors are filtered and then transferred to the low level to estimate a set of the level of selection.

In the process of designing the low level, fuzzy logic has been employed to contribute to the level of selection. After observation and discussion with the scheduler using knowledge acquisition technique (KA), four influencing factors/parameters(L1): day-time, competence: performance for service of each carer, cost: service cost per hour of each carer, and distance: length between current carer's locations and patient's homes are used to create membership function in the fuzzy system.
Lastly, the high level will choose the best solution of the set of the level of selection to create an optimal service plan. With this hierarchy framework, the high-level can activate the low level more than one process at the same time. The advantage of this feature is to select or consider outputs of Fuzzy logic.

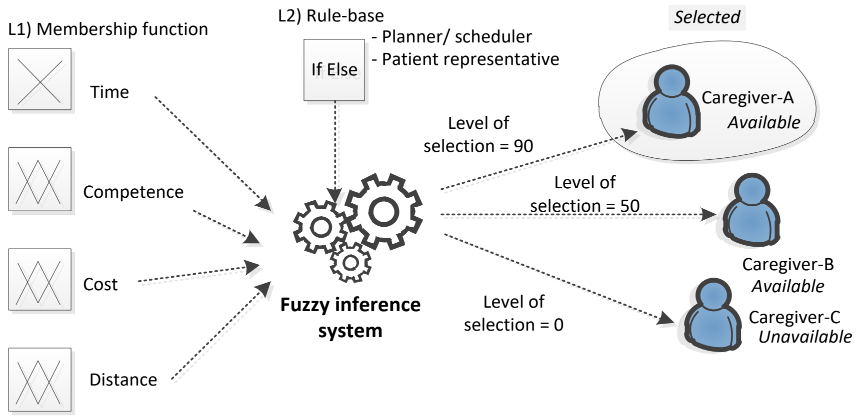
Figure 3. The structure of resource selection or "*cFuzzy*"



2.2. Fuzzy reasoning structure

Figure 4 shows the system structure with the use of the low-level of the framework. Three factors including competence, cost and distance have been fuzzified with three linguistic variables using linear triangular membership function while day-time has been fuzzified with two linguistic variables. Rule-bases (L2) of the fuzzy inference system were derived from the experience of the scheduler and the patient representative to compromise the preferences of two groups related to the homecare service. An example of fuzzy rule-base includes: if 'day-time' is 'low', 'distance' is 'near', 'competence' is 'excellent' and 'cost' is 'normal', then the 'level of selection' is 'high'. A defuzzification method is employed to explore a crisp output of the level of selection using the standard Centre of Area method or COG to determine the estimated centre of gravity of the distribution for the fuzzy set.

Figure 4. Structure of the low level of the *cFuzzy*



2.3.Knowledge engineering and knowledge acquisition

Knowledge engineering is a process to elicit knowledge from experts. It can be referred to as encompassing processes for knowledge acquisition *(Schreiber, 2000).* Meeting to obtain the requirements of the expert is done by knowledge engineer *(Thesen et al., 1987).* The majority of acquisition approach includes manual, automatic or semi-automatic approach *(Reyes et al., 2015)*. For the manual approach, experts are interviewed through particular knowledge acquisition terms to define how they solve problems. The automatic method consists in eliciting knowledge from data sets, for example, machine-learning *(García-Galán et al., 2012).* In terms of application, the knowledge-based system was originally applied in artificial intelligence for comprehending human knowledge *(Liao, 2003)*.

In this paper, this stage involved knowledge acquisition manually by interviewing a scheduler expert, reviewing, eliciting and collecting existing knowledge from a scheduler expert using knowledge engineering methodology. Additionally, all repositories and instructions, previous work procedures from a scheduler expert which are presently available on the health care foundation website and homecare service workplace, will also be gathered and reviewed prior to acquiring and organising. Repositories are probable to include instructions, previous work procedures, documents and research publications. Scheduling problem and all attributes for resource selection knowledge from a scheduler expert will be acquired, elicited, organised through a framework based on heuristic based reasoning and fuzzy logic, then formulised for the case study.

3. Research Result

3.1. Knowledge Acquisition

The resource selection intensive-task knowledge is acquired and modelled by interviewing, reviewing existing knowledge from a scheduler expert, using knowledge engineering methodology. The input attributes as resource selection inference-knowledge consist of time, distance, staff competence and labour cost. Additionally, effective ontology knowledge was semantic annotated from scheduling expert's knowledge transcript which were low and high: time; near, average and far: distance; low, average and excellent staff: competency; save, average and high: cost as shown in **Figure 5**. The competency ontologies and domain knowledge were acquired and elicited from homecare medical expert using homecare source staff assessment to measure carer competency as shown in **Figure 6**.

The competency scales and staff attributes have been identified as important factors which contribute to successful carer performance *(American Hospital Association, 2014)*. Score in the "low" range is 1-2.5 that indicates a lack of carers's competency and skills. Then semantic annotation this score "low" range is equal to 0 score to staff input attribute for *cFuzzy* development as shown in **Table 1**.

Figure 5. The knowledge model of attributes input for resource selection knowledge using knowledge acquisition

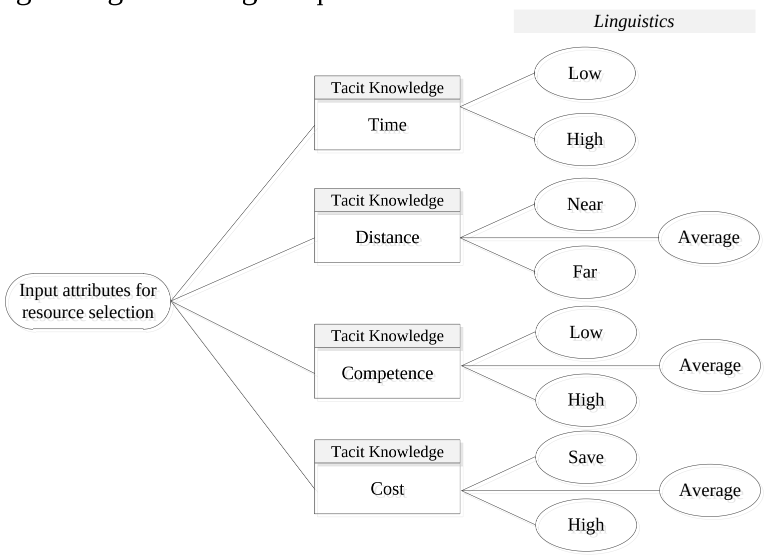
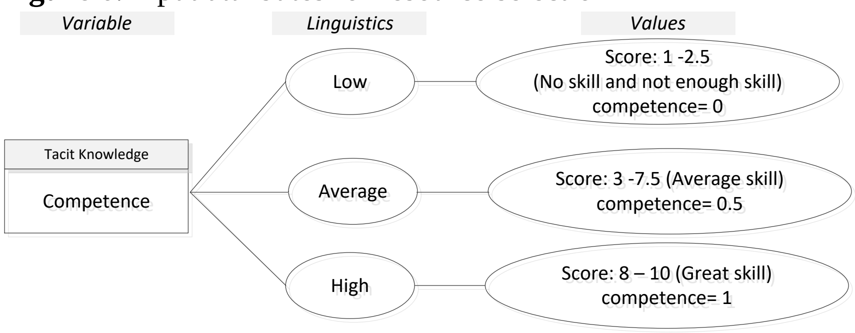


Figure 6. Input attributes for resource selection



In addition, the problem constraints of this research are given as follows:

- Staff members are recommended to service only up to 5 patients every working day as higher number of patients may lead to fatigue and exertion on the staff members.
- Each job has the same priority. Patients cannot demand specified service time because it is free service from a local hospital.
- Each carer starts from the homecare office at 8:00 and is expected to finish the service at 16:30.

- The location of patient homes is defined by Geolocation (Latitude and Longitude coordination).
- In this paper, mode of transportation is private car.

The model of the framework can take a form as:

$$\text{Min}_{travel\ cost} \quad \sum_{d=1}^{n_{day}} \sum_{r=1}^{n_{route}} \sum_{j=1}^{n_{job}} P_{office,j}^{r,d} \cdot c_{office,j}^{r,d} \cdot d_{office,j}^{r,d} \tag{1}$$

$$+ \sum_{d=1}^{n_{day}} \sum_{r=1}^{n_{route}} \sum_{i,j \in \mathrm{I}}^{n_{job}} P_{i,j}^{r,d} \cdot c_{i,j}^{r,d} \cdot d_{i,j}^{r,d}$$

$$+ \sum_{d=1}^{n_{day}} \sum_{r=1}^{n_{route}} \sum_{j=1}^{n_{job}} P_{j,office}^{r,d} \cdot c_{j,office}^{r,d} \cdot d_{j,office}^{r,d}$$

Note that $d_{i,j}^{r,d}$ *may be different from* $d_{j,i}^{r,d}$

$$Where \quad P_j = \begin{cases} 1, if\ a\ journey\ is\ made\ from\ location_s\ to\ location_k \\ 0, otherwise \end{cases}$$

$c_{ij} = cost\ of\ travel\ between\ location_s to\ location_k\ depending\ on\ modes\ of\ transportation$

$j \neq i\ and\ j > i$

$d_{i,j}^{r,d} = distance\ between\ location_i\ to\ location_i\ in\ route_r\ on\ day_d$

$i, j = index\ of\ locations$

$n_{job} = number\ of\ jobs$

$n_{route} = number\ of\ routes$

$n_{day} = number\ of\ days\ for\ scheduling$

$$\text{Min}_{operation\ cost} \quad \sum_{d=1}^{n_{day}} \sum_{r=1}^{n_{route}} \sum_{j=1}^{n_{job}} O_j^{r,d} . Operation_{time,j}^{r,d} . cost_j^{r,d} \tag{2}$$

$$Where \quad O_j^{r,d} = \begin{cases} 1, if\ a\ job\ is\ operated\ by\ caregiver \\ 0, otherwise \end{cases}$$

$$Operation_{time,j}^{r,d} = Finished_{time,j}^{r,d} - Starting_{time,j}^{r,d}$$

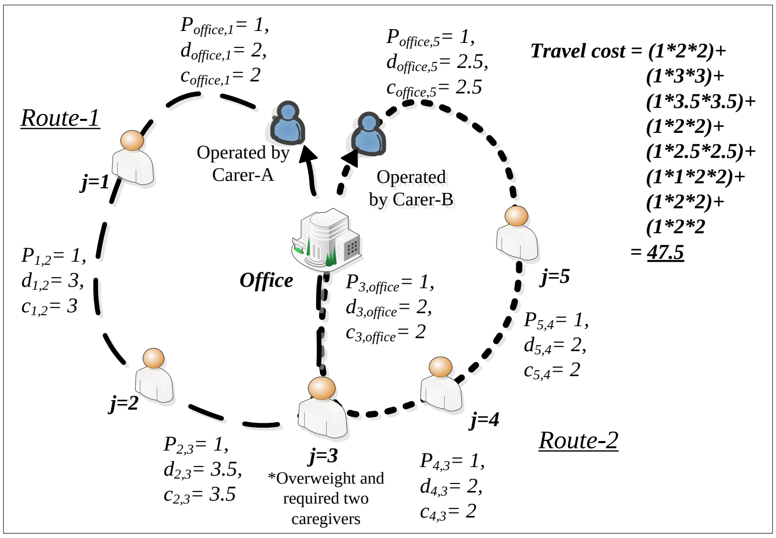
$$cost_j^{r,d} = \sum_{v=1}^{n_{carer_{req_j}}} O_j^{r,d} . wage_j^{r,d}$$

$$cost_j^{r,d} = \begin{cases} O_j^{r,d} . wage_j^{carer_{major}}, if\ job_j\ requires\ a\ single\ staff\ unit \\ O_j^{r,d} . \left(wage_j^{carer_{major}} + wage_j^{carer_{minor}} \right), if\ job_j\ requires\ two\ carers \end{cases}$$

$$Cost\ function = (1) + (2) \tag{3}$$

Figure 7 shows an example of parameters and indices for better understanding of mathematical expression.

Figure 7. Illustration of parameters and indices used in mathematical expression.



3.2. cFuzzy

The case study of this research, the fuzzy output, is called “The level of selection” which range is between 0 – 100 units (the higher level of selection is better than lower level). The system performs selections for five time slots (first round – fifth round) based on office hour between 8:00 am.-16:30 pm. and three part-time slots after 16:30 pm. (part-time; first round – part-time; third round). Additionally, alternative concept of the *cFuzzy* is heuristic algorithm which endeavors to keep a staff of each route doing in the same route that is called “a major staff” for one staff requirement.

In a task require two staff, the major staff in the desirable route is firstly selected for offer the service, and then a staff who has the second highest fuzzy value will be chosen to be the minor staff for the task.

3.2.1. Input attributes for cFuzzy development

1) Staff: Members and names

There are eight staff colleagues in the case study that include 1) *Susan*, 2) *Jin*, 3) *Ala*n, 4) *Jordan*, 5) *Lisa*, 6) *Emma*, 7) *Peterson*, and 8) *Memphis*. For available time of all staff colleagues, it is available from 8:00 am. -16:30 pm except *Memphis* who has available time after 12:00 pm. Each staff colleague has different competences of each skill which means they have different performance in particular homecare skill. **Table 1** provides skills in this study including nursing, cleaning, and therapy. Carers' compensation are also included.

Table 1 Resource details

Resources								
staffID	*name*	*nr*	*nr_cost*	*nc*	*nc_cost*	*tp*	*tp_cost*	*Type*
1	Susan	1	1	0	0	1	1	Full-time
2	Jin	1	1	1	0.5	0	0	Full-time
3	Alan	1	1	1	1	0	0	Full-time
4	Jordan	1	1	1	0.5	1	1	Full-time
5	Lisa	1	1	0	0	1	0.5	Full-time
6	Emma	1	1	0	0	1	1	Full-time
7	Peterson	1	1	1	1	1	1	Full-time
8	Memphis	1	1	1	0.5	1	0.5	Part-time

* *nr:competence in nursing*
nc:competence in cleaning
pt:competence in therapy skill

As shown in **Table 1**, *Susan* has Staff ID = 1 which has nurse skill, therapy skill with the maximum cost, i.e., nr_cost and pt_cost = 1 unit/hour score but she has no skill of cleaning skill task as shown in nc_competence(nc) that is equal to 0 score. In terms of competence, although all staff colleagues have the same homecare skill but each staff has different competence which depended on his/her experiences, for example, both *Jin* and *Alan* have cleaning task skill but *Alan* can complete any task faster than *Jin* at around 50 percentages which was acquired from scheduler’s expert. Cost attribute is the same as competence attribute that labour cost of all staff colleagues is different, for example, *Jin* and *Alan*, they can do cleaning task but labour cost of Alan is higher than *Jin* at 50 percentages.

2) Task details

All of patient homes which is called "Location" are generated in terms of x and y- coordination between 1 and 16 units as shown in **Table 2**.

Table 2 Task scheduling details

Task scheduling						
	Number	**x**	**y**	**operating time**	**staff requirement**	**Type**
Route1	1	7	7	1	1	Patient
	2	6	8	1	1	Patient
	3	4	8	1	2	Patient
	4	2	7	1	1	Patient
	5	1	6	1	2	Patient
Route2	6	3	5	1	1	Patient
	7	3	6	1	1	Patient
	8	4	5	1	1	Patient
	9	5	4	1	2	Patient
	10	7	3	1	1	Patient
Route3	11	8	3	1	2	Patient
	12	13.8	7.5	1	1	Patient
	13	11	3	1	2	Patient
	14	9	4	1	1	Patient
	15	11	5	1	2	Patient
Route4	16	13	5	1	1	Patient
	17	15	4	1	2	Patient
	18	16	6	1	1	Patient
	19	14	8	1	1	Patient
	20	11	8	1	2	Patient
Route5	21	10	7	1	1	Patient
	22	9	8	1	2	Patient
	23	7	6	1	1	Patient
	24	5.5	6	1	1	Patient
	25	9	12	1	1	Patient
Route6	26	10	12	1	1	Patient
	27	1.5	2.5	1	1	Patient
	28	2.5	3.5	1	1	Patient
	29	3.5	1.5	1	1	Patient
	30	4.5	4.5	1	2	Patient
Route7	31	5.5	6.5	1	1	Patient
	32	6.5	7.5	1	1	Patient
	33	7.5	4.5	1	1	Patient
	34	8.5	2.5	1	1	Patient
	35	9.5	3.5	1	1	Patient
Route8	36	10.5	4.5	1	1	Patient
	37	11.5	9.5	1	2	Patient
	38	12.5	8.5	1	1	Patient
	39	4.5	5.5	1	1	Patient
	40	5.5	6.5	1	1	Patient
	0	8	6	0.5	0	Office

- *Staff requirements (1-2 staff requirements),* for example, on lifting task, some patients are very heavy so only single staff could not service them effectively. Then, the patients who have heavy weight required homecare staff assistants to carry on the task.

- *Operating time (default: 1 hour),* the standard of operating time is set for 1 hour.

- *Location's types (Home care office and patient home),* there are two kinds of location types which include patient homes and the Home Care Office.

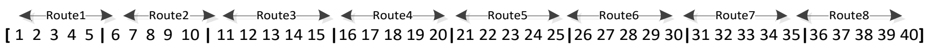
In this study, each task is located in x and y-coordination and the number of required staff is between 1 to 2.

3) Sequence, routes, and tasks

Figure 7 provides a sequence of service task for eight routes.

- *Route 1* contains *$Task_1$, $Task_2$, $Task_3$, $Task_4$ and $Task_5$*, respectively.
- *Route 2* contains *$Task_6$, $Task_7$, $Task_8$, $Task_9$ and $Task_{10}$*, respectively.
- *Route 3* contains *$Task_{11}$, $Task_{12}$, $Task_{13}$, $Task_{14}$ and $Task_{15}$*, respectively.
- *Route 4* contains *$Task_{16}$, $Task_{17}$, $Task_{18}$, $Task_{19}$ and $Task_{20}$*, respectively.
- *Route 5* contains *$Task_{21}$, $Task_{22}$, $Task_{23}$, $Task_{24}$ and $Task_{25}$*, respectively.
- *Route 6* contains *$Task_{26}$, $Task_{27}$, $Task_{28}$, $Task_{29}$, and $Task_{30}$*, respectively.
- *Route 7* contains *$Task_{31}$, $Task_{32}$, $Task_{33}$, $Task_{34}$, and $Task_{35}$*, respectively.
- *Route 8* contains *$Task_{36}$, $Task_{37}$, $Task_{38}$, $Task_{39}$, and $Task_{40}$*, respectively.

Figure 7 Service sequence generated by the route scheduling



4) Service times

There are five different kinds of times consisting of *i) Available time*: any staff is ready to offer medical service, *ii) Not available time* or busy time: carer is operating service, *iii) Idle time*, *iv) Travel time*: time to travel from $location_i$ to $location_j$, and *v) Meeting time* for staff discussion and sharing about problems and assigning new tasks for them.

3.3. Resource selection process

3.3.1. Vertical selection

The beginning step of resource selection is task selection, e.g., the first task of the $route_1$ is $task_1$, then $task_1$ will be filled up to first round as shown in **Figure 9.**

Figure 9 *cFuzzy* starts to selection of a qualified a carer for $Task_1$ of $route_1$

	Route1					Route2					Route3					Route4					Route5					Route6					Route7					Route8				
Schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
First																																								
Second																																								
Third																																								
Fourth																																								
Fifth																																								
Office hour																																								

Subsequently, the *cFuzzy* will estimate fuzzy outputs that is using fuzzy logic combining two fuzzy output values by the scheduler and a representative staff based on weight (weight of the scheduler and a representative staff = 0.5) as shown in **Figure 10**.

Figure 10 Combined Fuzzy outputs to estimate the level of selection

```
Weight of Expert1 <- .5
Weight of Expert2 <- .5
[1] " outputFuzzy1= 75"
[1] " outputFuzzy2=18.125"
FZ>> Output =" 46.5625"    // The level of selection
(((0.5*75)+(0.5*18.125))/2)
```

All staff statuses are collected in an array named "*staffavailableArray*" which has a range equal to the number of staff that start from *Susan*, *Jin*, *Alan*, *Jordan*, *Lisa*, *Emma*, *Peterson* and *Memphis*. Staff candidates and decision support system are using Fuzzy logic as shown in **Figure 11 (A)** that the array is [1 1 1 1 1 1 1 0]. It can be seen that there are seven available members or seven candidates at the same time who are *Susan*, *Jin*, *Alan*, *Jordan*, *Lisa*, *Emma*, and *Peterson*, respectively while *Memphis* is not available.

Figure 11 (A) *cFuzzy* reports available carer and **(B)** the level of selection for all candidates

```
[1] " staffavailableArray"
[1] 1 1 1 1 1 1 1 0
/ / Available Staffs are members1-7.

[1] Member 1(Susan)
[1] " outputFuzzy1 75"
[1] " outputFuzzy2 18.125"
FZ>> Output =" 46.5625"

[1] Member 2(Jin)
[1] "Distance is 1.4142135623731"
[1] " outputFuzzy1 75"
[1] " outputFuzzy2 18.125"
FZ>> Output =" 46.5625"
...
…
[1] Member 7(Peterson)
[1] "Distance is 1.4142135623731"
[1] " outputFuzzy1 75"
[1] " outputFuzzy2 18.125"
FZ>> Output =" 46.5625"
```

```
fuzzyOutput (Higher is better)
(1)Susan              46.5625(Selected)
(2)Jin                46.5625
(3)Alan               46.5625
(4)Jordan             46.5625
(5)Lisa               46.5625
(6)Emma               46.5625
(7)Peterson           46.5625
(8)Memphis              0.0000
[1] " Task:: 1"
[1] " n of reqStaff :: 1"
[1] " SelectedStaffAtidx :: 1"

FZ>> Target job: 1 and the number of
        required staffs: "1"
FZ>> Selected staff to do job 1 is
        Susan.
```

Figure 11(B) illustrates that *Susan*, *Jin*, *Alan*, *Jordan*, *Lisa*, *Emma* and *Peterson* have the same fuzzy outputs at 46.5625 while Memphis has the fuzzy output at 0 because he is unavailable for *Task₁*. Next, *cFuzzy* will select *Susan* for *Task₁* due to the fact that she is the highest in top of the table. Afterward, the system will update *Task₁* into Susan slot as shown in **Figure 12**.

Figure 12 *Task₁* is updated into Susan time slot (T1@7,7 means Task1 at position (x, y) = (7,7))

All conditions		Office Time			First round			Second round	
	1	Susan			T1 @7,7				
	2	Jin	Meeting time	Travel time			Travel time		
	3	Alan							
	4	Jordan							
	5	Lisa							
	6	Emma							
	7	Peterson							
	8	Memphis							
			8.00	8.31	9.01	9.31	10.01	10.31	11.01
			8.30	9.00	9.30	10.00	10.30	11.00	11.30

After updating Susan for *Task₁*, *cFuzzy* will shift to the next route which is *Route₂*. The first task of *Route₂* is *Task₆* as shown in **Figure 13**.

Figure 13 *cFuzzy* is selecting carer for service *Task₆* of *Route₂*

	Route1					Route2					Route3					Route4					Route5					Route6					Route7					Route8				
Schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
First	1					6																																		
Second																																								
Third																																								
Fourth																																								
Fifth																																								
Service Plan	1					6																																		

The process of selection is repeated until time is over than 16:30 or no available carers for selection before returning a multiple dimensional array called "completedRouteTable" which contains whole scheduling data such as task number, operating time, travel mode of transportation, the major and minor staff and type of medical service to create the scheduling plan as shown in **Figure 14** and **Figure 15**.

Figure 14 A multiple dimensional array containing schedule planned

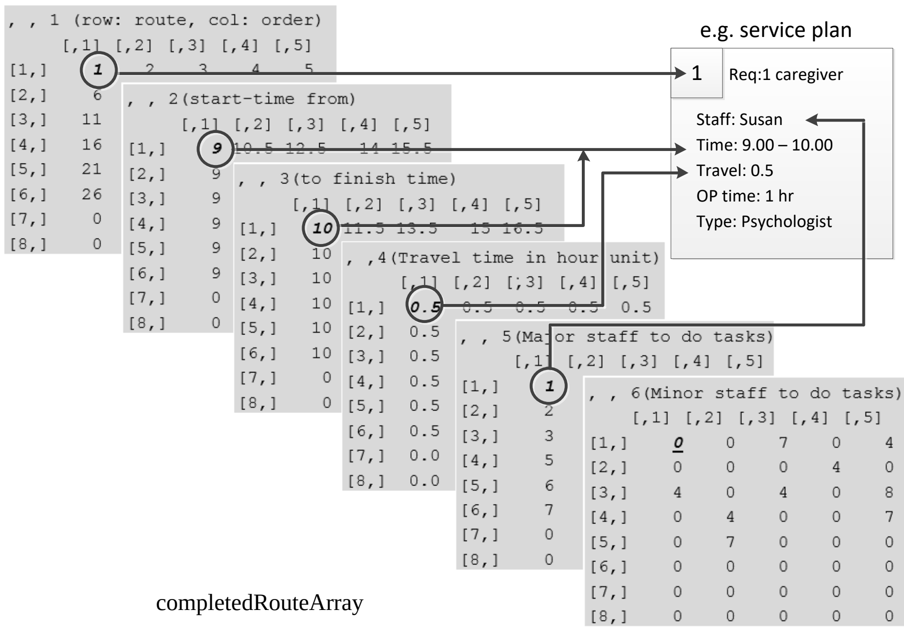


Figure 15 *cFuzzy* repeats selecting carers for service tasks

	Route1					Route2					Route3					Route4					Route5					Route6					Route7					Route8				
Schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
First	1					6					11					16					21					26														
Second		2					7					12					17					22																		
Third			3					8					13					18					23																	
Fourth				4					9					14					19					24			27				31									
Fifth					5					10					15					20					25															
Service Plan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27				31									

3.3.2. Fuzzy reasoning structure

1) Linguistic variables

Inputs variables: there are four variables including 1) ***Time***: Low and High (Type: Partition (0,100)), 2) ***Distance***: Near, Average, and Far (Near = trapezoid (-10, 0, 25, 50), Average = triangular (25, 50, 75), Far = trapezoid (50, 75,100, 110)), 3) ***Competence***: Low, Average and High (Low = trapezoid (-10, 0, 25, 50), Average= triangular (25, 50, 75), High = trapezoid (50, 75,100, 110)) and 4) ***Cost***: Save, Average and High (Save = trapezoid (-10, 0, 25, 50), Average = triangular (25, 50, 75), High= trapezoid (50, 75,100, 110)) as shown in **Figure 16**.

Output: Level of selection: low, average, and high. Low = trapezoid (-20, 0, 25, 50), Average = triangular (25, 50, 75), High = trapezoid (50, 75,100, 120).

Figure 16 Input linguistic variables and membership functions of Fuzzy reasoning structure

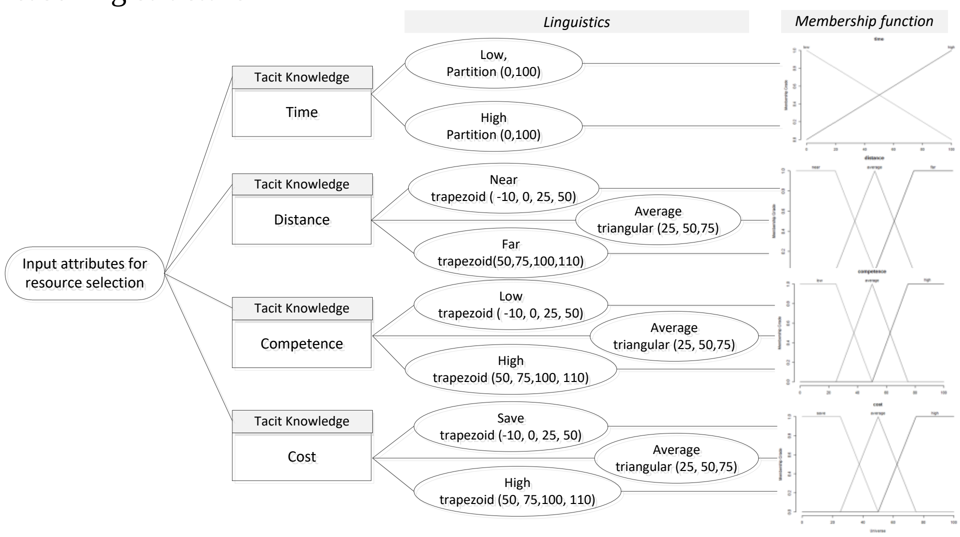
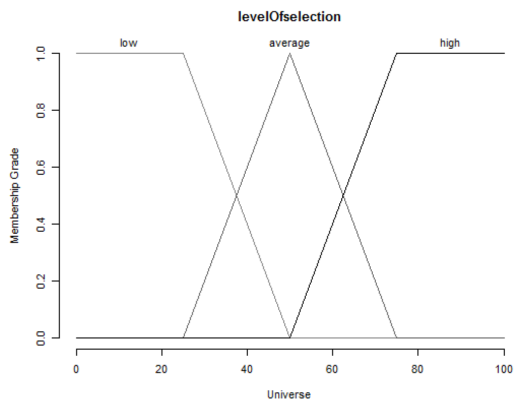


Figure 17 An output linguistic variables and membership functions of Fuzzy reasoning structure



2) Defuzzification

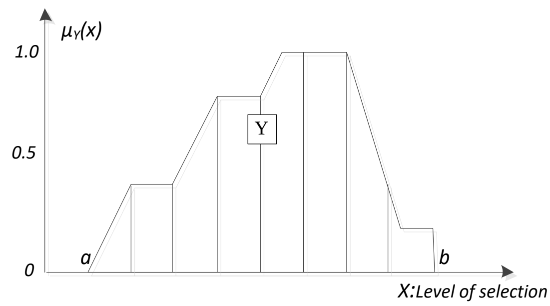
In this system prototype, there are several defuzzification approaches but the most popular one is centre of gravity (COG) or centroid technique which finds the point where a vertical line would slice the aggregate set into two equal masses. Mathematically, COG can be expressed as:

$$COG = \frac{\int_a^b \mu_Y(x) x \, dx}{\int_a^b \mu_Y(x) \, dx} \quad (4)$$

$$Where\ \mu_y\ is\ degree\ of\ membership\ function\ at\ intervals\ of\ a\ and\ b\ on\ X$$

$$Y\ is\ the\ area\ of\ output\ graph\ for\ defuzzification$$

Figure 18 Centre of gravity (COG) defuzzification method



3) Weights and combined fuzzy-output

[4,12,13,14] proposed improved algorithms for solving heath care service scheduling problem focusing on maximising the preferences of patients and carers. In this paper, the preferences are included as rule-bases of the *cFuzzy*. The weighted sum method is applied to acquire from differen (5) experts e.g. a scheduler and a patient. Hence, the final fuzzy output (the level of selection) is computed as follows:

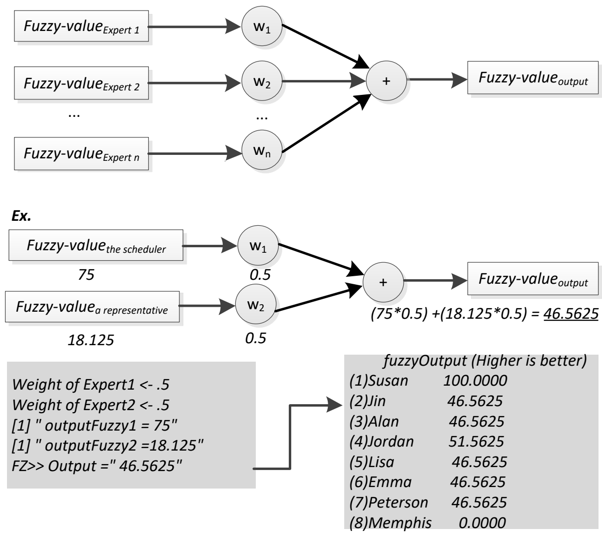
$$fuzzy - value = \sum_{expert_{i=1}}^{n} w_i f_i \quad (6)$$

$$\sum_{expert_{i=1}}^{n} w_i = 1$$

$$Where\ \ w_i\ is\ weight\ coefficient\ which\ defines\ the\ majority\ or\ importance\ of\ Expert_i$$

In **Figure 19**, *Jin* has 46.5625 of fuzzy output which is combined with fuzzy value of the scheduler and a representative customer with equal weights at 0.5. In this case, it means that both the scheduler and a representative patient have the same priority for resource selection. However, it always occurs in many cases. System user can adjust these weight-values later on for some situations such as setting scheduler weight is 0.75 and a customer weight is 0.25.

Figure 19 An example of weights and combined fuzzy-output



3.3. Comparative results

Performance of the proposed framework for the HSSP was measured by using cost function (see Eq. (3)) in THB (฿) unit. **Table 3** shows experimental results obtained for HSSP datasets run with different implementation approaches: manual planning and *cFuzzy*. With the manual planning approach, experimental results show estimated operation cost at around ฿4,680 (£107.59) or ฿180 (£4.14) per service task. In addition, resource selection with *cFuzzy* gives superior enhancement at ฿4,580 (£105.29) of the estimated operation cost or ฿143.13 (£3.29) per task. The results indicated that propose scheduling system with *cFuzzy* can conduct to the superior improvement at 20.49% compared to the manual planning.

Table 3 Experimental results

	Manual planning	*cFuzzy*
(1) Number of completed service tasks	26	32
(2) Sum of travel cost	฿3,000 (£68.97)	฿2,480 (£57.01)
(3) Sum of wage	฿1,680 (£38.62)	฿2100 (£48.28)
(4) Sum of operation cost	฿4,680 (£107.59)	฿4580 (£105.29)
(5) Average. overtime	On time	On time
(6) Average. cost per task = (4)/(1)	฿180 (£4.14)	฿143.13 (£3.29)
(7) % Comparison		+%20.49 (Improvement)

**Note that ฿ is Baht and ฿43.50 = £1*

4. Discussion and Conclusion

This research proposes a step-scheduling framework for solving HSSP by dividing entire whole problem into sub-problems and then finding solutions with priority for *route scheduling*, *resource selection* and *local improvement*.

In this paper, *cFuzzy* or Resource selection is proposed to match qualified staff to each route with the minimum cost and the preferences by experts consisting of the planner and a customer representative under feasible time, qualification requirement constraint and modes of transportation. The knowledge acquisition is used to acquire knowledge from the experts for designing rule-bases for the *cFuzzy*. The *cFuzzy* begins by obtaining a sequence of medical target task generated by *the route scheduling* before allocating available carers the sequence.

The case study comprising of 40 medical tasks with 8 service routes and 8 carers under time-slot windows starting from 8:00 am. to 16:30 pm was used to verity the proposed framework. The experimental results indicated that the proposed framework had a potential to provide improved solution compared to the original scheduling technique by hand.

In the context of contributions, the system finding features showed one or two qualified staff per task or job requirement, for examples, heavy patient and second finding feature can support full-time and part-time carers. The *cFuzzy* also addressed the problems of varying competence and skills of carers and compromise preferences between carer and patient side.

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