COMPROMISED TIME AND ENERGY REQUIRED IN WORK TEAM-ROUTE ASSIGNMENT FOR DAILY HOSPITAL FOOD DELIVERY

BY

MR. NUTPAKORN THONGARUNESAENG

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)

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ABSTRACT

This paper focuses, is mainly focus on workforce scheduling and routing problem, denoted that multi-period regard to dependent tasks. In this problem, hospital wards are demanding food trolley pushers to complete the delivery tasks which executed independently on different routes in shift, and each delivery service is composed of dependent task meaning that team is paired up, and the team can visit the same route along the shift period until the end of the day. The objective number one is trying to minimize max time consumption whose contribution apply the balance on time consumption for the set of teams. The objective number two is that we want to minimize the energy expenditure of the max energy capacitate team, so that the rest of the team can bare the equivalent amount of work. In order to solve this problem, Fuzzy Multi-Objective Linear Programming will be used based on the fact that energy capacity, time consumption and energy expenditure could vary day by day, and to defuzzification to solve the multiple-objective with the fuzziness, and the techniques to conduct on solving fuzziness of the model is Minimizing the Satisfaction Standard Deviation. Computational model results show that it could solve 150 variables consists of 5 teams, 5 routes and 6 shifts. In most case, Fuzzy Multiple-Objective is very practical in term of solving the fuzziness that the objectives can vary and was able to find the most compromise solution of each scenario (Pessimistic, Most Likely, Optimistic). For the best scenario from the applied technique is maximize weighted average approach which shows the subtle solution between two goals.

Keyword: Work Forces Scheduling, Optimization, Linear Programming, Goal Programming, Fuzzy Multi-Objective Linear Programming, Energy Expenditure, Time Utilization, Planning Horizon, Bio-mechanic, Ergonomics Bio-mechanic, Ergonomics, Material Handlings, Food Trolley

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Mr. Nutpakorn Thongarunesaeng

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CHAPTER 1
INTRODUCTION

1.1 Introduction

In industrial standard, the firm only focuses on how to utilize the current work forces that are in the pool. The particular goal is to determine whether energy expenditure has a significant impact on correct ergonomic posture and awkward biomechanics movement or not. As the industrial standard is all about to settle everything as a standard. In order to keep everything safe and up to standard in order to improve the quality and standard to the workplace. For this paper, we will use scheduling enhanced ergonomics and biomechanics that workforces have to face in everyday life. This is because unbalance of work distribution will cause them to be extremely exhausted.

This paper considers a daily food delivery problem in hospitals. A day is divided into multiple periods. In each period, hospital wards need foods which are supplied by food trolleys. The food trays are carried by a food trolley from a kitchen to visit a number of wards, and bring empty food trays of previous period back to the kitchen for cleaning. A round trip of food trolley from the kitchen to wards, and back to the kitchen is called a route. Multiple routes are pre-defined in each period. Routes have different distances, travelling times, and food weights. An energy required to carry a trolley in each route is dependent on total weight of foods and a trolley, distance, and travelling time. The food trolley is carried by a work team of two persons. Multiple work teams of two members are pre-defined. Work teams have different strength of bodies so they have different daily energy capacity. When the total energy required by all routes in all periods exceeds the energy capacity of the work team, workers will feel too tired.

The food delivery problem in hospitals can be solved by a linear assignment problem where multiple work teams are assigned to multiple routes in each period. Normally, the number of work teams and routes are equal. Therefore, a work team is assigned to a route in each period. Currently, a hospital under consideration assigns work teams to routes under two constraints, namely, time and energy constraints. First, total time of all routes in all periods of each work team must not be longer than the available time (8 hours). Second, total energy required of all routes in all periods of each work team must not be more than the energy capacity of that work team. Note that the energy capacities of work teams are different. This hospital tries to manually determine feasible assignment to satisfy both constraints.

The feasible assignment of work teams to routes in each period receives unsatisfactory feedback from work teams since some work teams complain that they have no rest time while other work teams have some rest time. There are also complaints that some days their work is not so heavy but some days they are too tired. After investigation, they feel too tired because total energy required by all routes are very closed to their energy capacity.

An interview survey of work teams is conducted to determine what performance measures should be used for evaluating the optimal assignment. Firstly, the work teams respond that the free times (later called leftover time in this paper) of all work teams should be equal. Therefore, the first performance measure should be the standard deviation of the percentage of leftover time per total available time of all teams. Secondly, the team with stronger physical body (with higher energy capacity) should have higher total energy required by all assigned routes. Technically, the percentage of leftover energy per energy capacity of all teams should be equal. Thus, the second performance measure is the standard deviation of percentage of leftover energy per energy capacity of all teams. These performance measures will be mathematically represented in section 3.

The daily food delivery problem in hospitals is complicated because of three reasons. First, the performance measures are conflicting since they cannot be the best at the same time. A compromised solution from bi-objective problem should be determined. Second, the performance measures are related to the standard deviation measure which is a non-linear function. To directly optimize the non-linear performance measure is inefficient. Therefore, other linear objective functions must be developed to indirectly optimize the performance measures. Third, the input parameters (travelling time and energy required) of each route cannot be easily estimated as constants. However, they can be estimated using triangular fuzzy numbers (TFNs). Note that the TFNs are applied since it is the simplest type of fuzzy number that has only three parameters (low, medium, and high values).

To overcome complications of the daily food delivery problem in hospitals, this paper has objectives as follows:

1. To develop a fuzzy multiple objective linear programming (FMOLP) model to assign worker teams to routes in all periods of a day.
2. To develop methods to defuzzify the model and handle two conflicting objectives to determine compromised solutions.
3. To compare the proposed performance measures of the compromised solutions from the proposed models and the solutions from single objective models.

1.2 Solution Approach

Fuzzy Multiple-Objective Linear Programming is the optimization technique which can deal with uncertainty parameters in the uncertain condition and it is capable of solving two objectives at a time. This technique should be able to work well in this problem since there are uncertainties to the model. The applied techniques to defuzzify uncertainty in objective are maximize weighted average and maximize minimum satisfaction. For the defuzzification of uncertainty in constrains, we will be using ranking method.

1.3 Application

This studying should enhance the workforce scheduling in the area of industrial and workforce application. In industrial, the focuses are on how to improve biomechanics movement with the reduction of awkward ergonomic posture when energy expenditure being depleted. As in workforce application, we consider on how workforce will be beneficial from improving biomechanical movement by reducing energy expenditure and unnecessary movement during the working period.

1.3.1 Industrial Application

There are many applications for industrial application, but ergonomic is still not widespread among the industrial research. The hazard would arise when improper scheduling plan is taken into account which can result in serious injuries or paralysis. In hospital industry, typically, the work distribution is not slightly equal. Since the work distribution would be a provision for fairness. The work distribution should cope with the fact that all food trolley pushers does not have the same endurances and physical body which can result in one employee who is the weakiest among the team confront with the toughest job, while the most endurance one finds that the job is not so intensive. This is the prime example of unbalance work distribution.

For this case, energy expenditure will be the key indicator to dictate on how the workforce scheduling should be in place and how to arrange the proper plan to improve the work life balance in the work place. Biomechanics related problem is a typical hazard that repetitive work is involved with. Since it requires repetitive movement and should be a pain on that spot. This kind of hazard can be reduced when equivalent work distribution. Considered that in any industry should be up to industrial standard. There should be the additional criterial to provide a safe working environment.

1.3.2 Workforce Application

Workforce application is related to how to improve the work life balance for workforce. Reduction in time and energy expenditure should provide them the maximum satisfaction in the work place. Since workforces are required to work for the rest of the day. Key indicators like time and energy expenditure should be dictated on how workforces can attain work life balance in the friendly working environment. Hence, job satisfaction enhanced scheduling will keep the workforces safe during the working period.

1.4 Problem statement

1.4.1 Industrial Application

The problem arises when the industrial would like to utilize the workforce's capabilities and time available to the fullest of usage, without considering the well-beings of others. In this paper, we will focus on hospital industry in the sense that the scheduler only aims to maximize the utilization of workforces. In engineering sense, utilization is certainly not a main objective. Despite from that firm only aims to maximize their profit, consider that each worker has different in body condition and shape which will result in inequal of energy capacity which can be calculated based on their body height and weight and congenital disease. As the result of maximizing of workers' utilization, the hazards are likely to occur. For instance, the lowest energy capacity worker has the toughest job during the work day. It is likely to that worker to cause injuries or awkward movement, which leads to serious condition such as chronic pain and the worst case might cause them paralyzed due to biomechanics risk by doing repetitive job. The fact that energy expenditure exceeds energy capacity of that worker. Hence, the problem can be solved by sharing the equivalent of work among the work team to serve all the demands which is occurred in each ward. The treys will be carried by food trolley in order to serve the patients in each ward.

In summary, the goal has to be separated in order to generate a compromise solution between the two whose are hospital and workforces.

1) In the hospital sense, the time consumption should be the key indicator whether the scheduling be able to cope with the minimum working hours or not. Most importantly, time consumption could be the potential key indicator to measure the amount of work distribution.
2) In engineering sense, the objective that is needed to take into accounts is that we consider energy expenditure is compulsory in order to maintain workforces' health. In order to create an appropriate job rotation, welfare and work life balance must be going along with the goal of worker utilization.

1.4.2 Workforce Application (job satisfaction enhanced scheduling)

Since turnover rate has been rapidly increased in the recent year due to the fact that repetitive task or routine job cannot settle a provision for leisure period or decrement in work life balance. The highly satisfied workers are tended to do the better performance than those workers who are dissatisfied from the job, and those who are highly satisfied from a work place will have a better life physically and mentally (Rahman et al., 1987). Hence, this has been proven that job dissatisfaction from work place is likely to lead workforces to resign from the work, because the work life balance is unequal.

First of all, the result generated by the model should give the be subtle in term of compromise solution between workforces and the hospital. As the work distribution is equivalent, the satisfaction should be rising along with the goal setting. Considered that the job scheduling must generate the schedule that enhances job satisfaction. The scheduling must meet the specific criterial where using the energy expenditure is the key indicator to dictate how biomechanics hazard and hectic ergonomic can be mitigated by drawing a conclusion based on job rotation enhanced through energy expenditure. Once, work distribution can be equivalent. It has the high potential that biomechanics movement and work-factor ergonomics have a significant impact on how to develop workforce scheduling enhanced with job satisfaction to the food trolley pusher.

As the fairness of work will consider as the importance to reduce the risk, considering, energy residual does not only indicate that fairness of work distribution, but still indicate that scheduling improves on work life balances in the repetitive task and routine work as well which will lead to less turnover rate.

1.5 Scope of this research

The main objective for this research is to develop optimization model in order to find the optimal solution for work scheduling problem and primarily focus on fuzzy multiple-objectives linear programming in order to cope with the uncertainty. Hence, the scope will be covered as follows:

1.5.1 Industrial application

- Job Distribution: The first thing that can be done is the scheduling can mitigate unfair work distribution. Using time as a key measurement can cope with how team possess to finish their job according to time specifies.
- Job Fulfillment: No matter what another objective is whether it will help work teams to achieve the job satisfaction in the work place. The scheduling must manage every team to finish the task for the entire shifts on that day.
- Enhance Biomechanics Movement: The scheduling is designated to complete with correct ergonomic posture in order to increase efficiency while teams moving their material handlings.

- <u>Promote Work Life Balance</u>: The aim of industrial application is to reduce biomechanical hazard that occurs by work-factor ergonomic which often incurs by awkward posture when the team pulls their limit or work in repetitive task in workforce environment.

1.5.2 Workforce application (Job satisfaction enhancement scheduling)

- <u>Planning Horizon</u>: This research focuses on a daily scheduling. The job rotation will be changed day by day based on energy expenditure and energy capacity on the day that teams operate their jobs.
- <u>Energy Expenditure</u>: The result obtain from mathematical model is simply quantitative, it must be looking into how those numerical values of energy expenditure corelated to time consumption.
- <u>Best Routing Strategy</u>: When multiple-objectives are being solved, the scheduling will produce the plan that two objectives will be settles which means a compromise must be produced during the optimization.

1.6 Research objective

To develop mathematical models for planning horizon for work force scheduling problem, which considered that energy expenditure and time consumption are multi-objectives goal. In order to achieve the satisfaction between two sides which are hospital and workforces. Energy consumption is needed to be taken into account. The optimization considers goals as follows:

1) Minimize max residual (energy capacity) leftover
2) Minimize max time leftover

1.7 Overview of this research

WSP for this problem will be focused on job satisfaction scheduling along with the hospital goal. Since hospital only provides 24 hours and 7 days a week for working day. The problem of work life balances become enormous for workers. A provision for this study would enhance job rotation in the sense that work-factor ergonomic would be measuring by energy residual and to cope with the hospital demand time requirement to complete the task have to be subtle.

CHAPTER 2
LITERATURE REVIEW

This section will firstly be introduction to workforce scheduling and the application that this paper will apply to. The optimization techniques will be using as the tool to solve this kind of problem. The application will focus on industrial applications in which considers to reduce ergonomic hazard and biomechanics risk. The other application is workforce application, will be looking into how reduction in energy expenditure can have an impact in satisfied workplace.

2.1 Workforce scheduling problem

Workforce scheduling problem is booming nowadays in allocation of human resources. It is the establishing of the schedules in the proper manner in the sense that many industries seek to minimize necessary personnel to cope with the standard. Typically, one of the most unarguably goal is to improve business process in order to minimize the cost and achieve cost effective on current labors that the firms own (Sauer, et al., 2007). WSP is the problem that assigns work to do the task at the same time but different route of execution in different location (Castillo et al., 2012). Workforce scheduling has gained more reputation to represent the right number of inputs for the right tasks, also must ensure every shift along the day is well staffed and appropriately be in the line. Appropriate design of scheduling should consider in satisfying both side which are the firm itself and workforces. Consider that cost effectiveness is the ultimate goal for firms but in order to attain enhanced scheduling, the objective must be subtle for workforces as well as firms are being considerate about their goal.

In industrial application, WPS usually aim to determine and manage how workforces will accomplish and cope with their task given within a day. Many previous studies considered about cost effective such as minimizing labor cost (Özgüven, et al., 2013). This research the balancing the number of workforces to be scheduling for the tasks demanding on the planning horizon. The cost-oriented objective could be found in minimization of labor cost (Guastaroba el at., 2020*)*. The paper mainly considered on the distribution of the work and execution of tasks in different location. What is also commonly found is nursing scheduling which the objective considered minimization of the deviations from the preferred number of nurses. The paper considers the coverage of nurses' requests along with the shift that needs to be compliance.

In workforce application, WPS does not only concern about the utilization of workers. On the other hands, consideration of satisfaction must be taken into account as well as the goal of cost efficiency. The satisfaction could be taken into account by considering another factor along with industrial application. Since many industrial applications mainly focuses on achieving cost effective and time efficient in the workforce scheduling. There will be an additional criterion to justify and enhance scheduling to satisfy the workforce's side. Therefore, an additional criterion will be added to increase the job satisfaction to worker in order to improve work life balances for workforces. There are a few previous papers that only considered on job satisfaction enhanced scheduling. The paper that is found to be a potential one is the author sets the objective to maximize employees' satisfaction (Florez el at., (2013). The paper concerns the consideration of hazard that can be occurred during the operation along with the productivity in the industry. This is the raw evidence that we can further develop our own paper to achieve job satisfaction along with industrial's needs.

2.2 Work-factor ergonomic on workforce scheduling

There is the evidence that sitting and working as standing surely has an impact on energy expenditure (D'Silva et al., 2020). Technically, the workers won't be sitting for the most cases, so sitting has to be neglected, as the worker standing and working at the same time there will be an impact on their pick-up point to the ward which will result them to use higher energy expenditure if the plan is inconsiderate. Walking exercises will basically break increasingly the energy expenditure (D'Silva et al, 2020). This is the solid evidence that as work related to the usage of biomechanics movement results in energy expenditure. There is a relationship on ergonomic and quality. From the point above, the properly fair amount of work should be assigned to the workers in the work designed environment (Jazani et al., 2014). The paper found the significant on improving ergonomic could result in better quality of work, by developing this rate of return would take about one year to recover the cost.

2.3 Quantitative research pursuing workforce scheduling

WSP is the work that is related to numerical results which will determine the best solution for scheduling. There are many methodologies in order to create an approach to workforce scheduling problem. For this study, optimization techniques will be conducted in order to solve the problem.

2.3.1 Optimization approach

The first technique for optimization that is inevitable is linear programming model. This is the most basic function that we can apply to the model. We have to separately run the model by classifying objectives into two. In fact, we will obtain a solution that are not subtle or compromise for two objectives. Garaix and Thierry (2018) indicate that the application of mixed integer could be applied to the model of WSP.

Goal programming is another potential technique that could be applicable since we have 2 objectives to be considered. There are only a few papers that uses GA in order to solve WSP. Ozkarahan, Irem, James E. Bailey (1988) uses GA to solve nurse scheduling problem in order to determine the conflicting goal between hospital and nurses by providing the relaxation to nurses and climax the hospital's goal.

Fuzzy multi-objective linear programming will be the main technique that will cope with the practical world. Since the model can cope with the fuzziness of parameters. Lu , Zhu, Wang, Xie, and Su (2019) established the model that solve the fuzziness in multiple objective for logistics related scheduling.

Table 2.4 Research Gap

Relate journals	Objective type		Objective Function															Constraints																							Method Used			
	Single Objective	Multi-Objective	Minimize makespan	Minimize routing cost	Minimize labour cost	Minimize penalty	Minimize number of employees	Minimize deviation of preferred number of nurses	Minimize unmet demand	Minimize the sum of the trucks' flow time	Minimize the weighted sum of missed shipments	Minimize total costs	Maximizing total labour and investment costs	Maximizes labour stability	Minimize the sum of fluactions	Minimize max energy residual	Minimize max time leftover	Travel times	Task Excecution	worker assignment	Start and end date	Consecutive day	Day-off	Number of work type	Real/lower kill	Employee Requirement	Total number of hours	Demand fullfilment	Connectivity of the route	restore or return	truck mode	single completion time	No explicitly assign truck	Available doors	Inbounds truck	Daily permissible limit of hazard exposure	Invesment cost not exceeded budget	firing and hiring	route occupation	Energy capacity limited	Linear Programming	Goal Programming	Fuzzy Linear Programming	Fuzzy Multi-Objective Linear Programming
Pereiraa et al., 2020	✓		✓															✓	✓																						✓	✓		
Guastaroba et al., 2020	✓			✓																✓	✓	✓																			✓	✓		
Özgüven et al., 2013	✓				✓															✓			✓	✓																	✓			
Shahnazari et al., 2013		✓				✓	✓																		✓	✓	✓															✓		✓
Topaloglu et al., 2010	✓							✓														✓				✓	✓	✓														✓	✓	
Li et al., 2019	✓								✓																				✓	✓											✓			
Tadumadze et al., 2019		✓								✓	✓																				✓	✓	✓	✓	✓						✓			
Beliën et al., 2012	✓											✓									✓	✓					✓														✓			
Wongwien et al., 2013		✓											✓								✓						✓									✓					✓	✓		
Florez et al., 2013.		✓			✓							✓		✓												✓	✓	✓									✓	✓			✓			
This paper		✓													✓	✓				✓								✓											✓	✓				✓

CHAPTER 3
METHODOLOGY

The step number 1 is to build FMOLP model that will solve the uncertainty in the model. In step number 2, is to select the most suitable defuzzified method for our model and have the most potential to solve multiple objectives. Step number 3, once we obtain the result of FMOLP. We will consider single objective and observe that how bad it can be without mitigating it. Step number 4, verification and validation can be justified by observing constraints whether they have the correct value or not. Step number 5, once we obtain all solutions from both single and multiple values. We will check the performance by normalize them into the weight average measuring by Standard Deviation. Step number 6, plot all solution obtained from step number 5 into the scatter plot to visualize their weight deviation. Step number 7, conclude whether FMOLP helps to mitigate the solution of single objective or not.

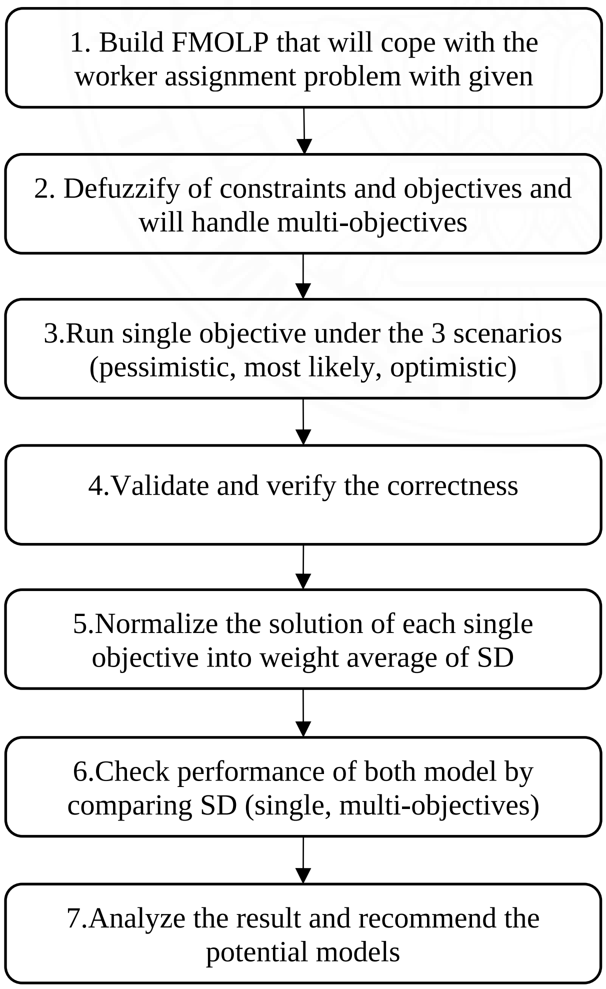


Figure 1. Methodological steps

3.1 Mathematical models

Indexes

i index of worker team $\{1, 2, \dots, I\}$

j index of route $\{1, 2, \dots, J\}$

k index of period $\{1, 2, \dots, K\}$

x index of fuzzy scenario {p – pessimistic, m – most likely, o – optimistic}

Parameters (add unit of measures for all parameters and variables

$\widetilde{TT_{jk}}$ Fuzzy time required by route j in period k (Minute)

$\widetilde{EE_{jk}}$ Fuzzy energy required by route j in period k (Kilocalorie)

TT_{jk}^{x} Time required by route j in period k in scenario x (Minute)

EE_{jk}^{x} Energy required by route j in period k in scenario x (Minute)

Cap_i Energy capacity of worker team i (Kilocalorie)

TA_i Available time of worker team i (Minute)

w_T^x Weight of satisfaction of leftover time in scenario x (Unitless)

w_C^x Weight of satisfaction of leftover energy in scenario x (Unitless)

$w1_T^x$ Weight of standard deviation of the percentage of leftover time per available time of all teams under scenario x (Unitless)

$w1_C^x$ Weight of standard deviation of the percentage of leftover energy per energy capacity of all teams under scenario x (Unitless)

Decision variables

X_{ijk} 1 if worker team i is assigned to route j in period k, 0 otherwise (Unitless)

$\widetilde{H_i}$ Fuzzy energy used by team I (Kilocalorie)

$\widetilde{C_i}$ Fuzzy percentage of leftover energy per energy capacity of team I (Kilocalorie)

$\widetilde{CM}$ Fuzzy maximum percentage of leftover energy per energy capacity of all teams (Kilocalorie)

$\widetilde{TS_\iota}$ Fuzzy time used by team *I* (Minute)

$\widetilde{T_\iota}$ Fuzzy percentage of leftover time per available time of team *I* (Minute)

$\widetilde{TM}$ Fuzzy maximum percentage of leftover time per available time of all teams (Minute)

TS_i^x Time used by team *i* in scenario *x* (Minute)

T_i^x Percentage of leftover time per available time of team *i* in scenario *x* (Minute)

TM^x Maximum percentage of leftover time per available time of all teams in scenario *x* (Minute)

H_i^x Energy used by team *i* in scenario *x* (Minute)

C_i^x Percentage of leftover energy per energy capacity of team *i* in scenario *x* (Kilocalorie)

CM^x Maximum percentage of leftover energy per energy capacity of all teams in scenario *x* (Kilocalorie)

T_{sat}^x Satisfaction of maximum percentage of leftover time per available time of all teams in scenario *x* (Unitless)

C_{sat}^x Satisfaction of maximum percentage of leftover energy per energy capacity of all teams in scenario *x* (Unitless)

T_{Max}^x Maximum value of TM^xobtained from all single objective models (Minute)

C_{Max}^x Maximum value of CM^xobtained from all single objective models

T_{Min}^x Minimum value of TM^xobtained from all single objective models (Minute)

C_{Min}^x Minimum value of CM^xobtained from all single objective models

ST^x Standard deviation of the percentage of leftover time per available time of all teams under scenario *x* (Unitless)

$\widetilde{H_\iota}$ Fuzzy energy used by team *i* (Kilocalorie)

SC^x Standard deviation of the percentage of leftover energy per energy capacity of all teams under scenario *x* (Unitless)

$\overline{ST}$ Weighted average of standard deviations of the percentage of leftover time per available time of all teams under all scenarios (Unitless)

$\overline{SC}$ Weighted average of standard deviations of the percentage of leftover energy per energy capacity of all teams under all scenarios (Unitless)

Performance measures

There are two variables that are related to the quality of solutions perceived by the workers. They are T_i^x and C_i^x. If T_i^x and C_i^x are the same for all teams, the assignment is perfect. Thus, the standard deviation of T_i^x is calculated as ST^x using equation (3.1). Similarly, SC^x is the standard deviation of C_i^x, which is calculated using equation (3.2). Good solutions on the view point of workers should have relatively low values of ST^x and SC^x. Since ST^x and SC^x are triangular fuzzy numbers, they can be converted to constants to be interpreted easily by a weighted average method. The weighted average of ST^x and $SC^x$are calculated by equations (3.3) and (3.4), respectively. Therefore, $\overline{ST}$ and $\overline{SC}$ are used to evaluate the goodness of the solutions from all models. Note that the lower values of $\overline{ST}$ and $\overline{SC}$, the better performance of the solution.

$$ST^x = \frac{1}{I-1}\sqrt{\sum_i (T_i^x - \frac{1}{I}\sum_i T_i^x)^2} \tag{3.1}$$

$$SC^x = \frac{1}{I-1}\sqrt{\sum_i (C_i^x - \frac{1}{I}\sum_i C_i^x)^2} \tag{3.2}$$

$$\overline{ST} = \sum_x w1_T^x \, ST^x \tag{3.3}$$

$$\overline{SC} = \sum_x w1_C^x \, SC^x \tag{3.4}$$

Since $\overline{ST}$ and $\overline{SC}$ are non-linear, they cannot be use as objective functions for an LP (linear programming) model. We need to develop new linear objective functions to solve the problem efficiently.

Fuzzy multiple objective linear programming (FMOLP) model

$\widetilde{T_i}$ is the percentage of leftover time per available time of team *i*, which is a fuzzy number. The good solution should have similar values of $\widetilde{T_i}$ of all teams. A tactical way to make $\widetilde{T_i}$ of all teams equal is to minimize the maximum values of $\widetilde{T_i}$ of all teams. Based on constraint (3.12), $\widetilde{TM}$ is the maximum values of $\widetilde{T_i}$ of all teams. Therefore, the objective function (3.5) is to minimize $\widetilde{TM}$, which is a linear function. Similar to $\widetilde{T_i}$, $\widetilde{C_i}$ of all teams will be nearly equal when $\widetilde{CM}$ is minimized according to objective function (3.6).

Constraint (3.7) is to calculate the total energy required by team *i*. Constraint (3.8) is to convert the energy required by team *i* to be the percentage of leftover energy per energy capacity of team *i*. Constraint (3.9) determines the maximum value of the percentage of leftover energy per energy capacity of all teams. Constraint (3.10) is to calculate the total time used by team *i*. Constraint (3.11) is to convert the total time used by team *i* to be the percentage of leftover time per available time of team *i*. Constraint (3.12) determines the maximum value of the percentage of leftover time per available time of all teams. Constraints (3.13 and 3.14) ensure feasible assignment of work teams to routes in all periods. A binary condition is started by condition (3.15).

Minimize $\widetilde{TM}$ (3.5)

Minimize $\widetilde{CM}$ (3.6)

Subject to

$$\sum_j \sum_k \widetilde{EE_{jk}} X_{ijk} = \widetilde{H_i}, \ \forall i \quad (3.7)$$

$$\left(Cap_i - \widetilde{H_i}\right) \div Cap_i = \widetilde{C_i}, \ \forall i \quad (3.8)$$

$$\widetilde{CM} \geq \widetilde{C_i}, \ \forall i \quad (3.9)$$

$$\sum_j \sum_k \widetilde{TT_{jk}} X_{ijk} = \widetilde{TS_i}, \ \forall i \quad (3.10)$$

$$\left(TA_i - \widetilde{TS_i}\right) \div TA_i = \widetilde{T_i}, \ \forall i \quad (3.11)$$

$$\widetilde{TM} \geq \widetilde{T_i}, \ \forall i \quad (3.12)$$

$$\sum_j X_{ijk} = 1, \ \forall i, k \quad (3.13)$$

$$\sum_i X_{ijk} = 1, \ \forall j, k \quad (3.14)$$

X_{ijk} is binary (3.15)

Methods to defuzzify fuzzy constraints and to handle multiple fuzzy objective functions

The constraints (3.7-3.12) are fuzzy constraints where both left and right sides are fuzzy. They are defuzzified into crisp constraints (3.21-3.26), respectively, using a ranking method (Liao et al., 2017)

There are two fuzzy objective functions (3.5 and 3.6). We need to convert them into an equivalent single objective function with all crisp parameters. Based on real data, $\widetilde{TM}$ and $\widetilde{CM}$ may have significantly different magnitude. Generally, the variable with higher magnitude may dominate the variable with lower magnitude when the compromised solutions are determined. To prevent this problem, TM^x and CM^x(the crisp form of $\widetilde{TM}$ and $\widetilde{CM}$) are converted to the satisfaction measures, which have common scale from 0.0 to 1.0, using constraints (3.19-3.20). When the TM^x and CM^xhave relatively low values, the associated satisfaction measures will have relatively high values. Therefore, minimizing $\widetilde{TM}$ and $\widetilde{CM}$ are equivalent to maximizing their associated satisfaction measures.

There are six elements of two satisfaction measures under three fuzzy scenarios. There are two approaches to integrate six elements into a single objective function. They are maximizing minimum satisfaction approach and maximizing weighted average satisfaction approach.

Maximize minimum satisfaction approach

This approach requires the objective function (3.16) and constraints (3.17 and 3.18). Constraints (3.17 and 3.18) determine the minimum value among six elements for the satisfaction measures. Objective function (3.16) is to maximize the minimum value of the six elements.

Maximize $\quad Z \qquad (3.16)$

Subject to

$Z \leq T_{sat}^{x} \ , x \in \{p.m.o\} \qquad (3.17)$

$Z \leq C_{sat}^{x}, x \in \{p.m.o\}$ (3.18)

$T_{sat}^{x} = (T_{Max}^{x} - TM^{x})/(T_{Max}^{x} - T_{Min}^{x}), x \in \{p.m.o\}$ (3.19)

$C_{sat}^{x} = (C_{Max}^{x} - CM^{x})/(C_{Max}^{x} - C_{Min}^{x}), x \in \{p.m.o\}$ (3.20)

$\sum_j \sum_k EE_{jk}^{x} X_{ijk} = H_i^{x}, x \in \{p.m.o\}, \forall i$ (3.21)

$(Cap_i - H_i^{x}) \div Cap_i = C_i^{x}, x \in \{p.m.o\}, \forall i$ (3.22)

$CM^{x} \geq C_i^{x}, x \in \{p.m.o\}, \forall i$ (3.23)

$\sum_j \sum_k TT_{jk}^{x} X_{ijk} = TS_i^{x}, x \in \{p.m.o\}, \forall i$ (3.24)

$(TA_i - TS_i^{x}) \div TA_i = T_i^{x}\ x \in \{p.m.o\}, \forall i$ (3.25)

$TM^{x} \geq T_i^{x}, x \in \{p.m.o\}, \forall i$ (3.26)

and constraints (3.13-3.15)

Maximize weighted average satisfaction approach

This approach uses the objective function (3.27) to maximize the weighted average of the six elements of the satisfaction measures.

Maximize $\sum_x w_T^{x} T_{sat}^{x} + \sum_x w_C^{x} C_{sat}^{x}$ (3.27)

Subject to

Constraints (3.13-3.15, 3.19-3.326)

Single objective models

There are six single objective models. They have different objective functions and the same set of constraints. Each model has only one objective function as follows:

Minimize TM^{p} (3.28)

Minimize TM^{m} (3.29)

Minimize TM^{o} (3.30)

Minimize CM^{p} (3.31)

Minimize CM^{m} (3.32)

Minimize CM^{o} (3.33)

Subject to

Constraints (3.13-3.15, 3.21-3.26)

The single objective models have two main benefits. First, they are used as benchmarks to be compared with the multiple objectives compromised model. It can be seen that the single objective models have extreme solutions which are the best for some aspects but the worst for other aspects. The multiple objectives compromised models have compromised solutions which are moderate for all aspects of fuzzy scenarios. Second, the solutions from single objective models will be used to calculate T^{x}_{Max}, T^{x}_{Min}, C^{x}_{Max}, and C^{x}_{Min}, which are used to calculate T^{x}_{sat} and C^{x}_{sat}, which are required by the multiple objectives compromised models.

3.2 Data of the case study

For the case study under consideration, a day is divided into 6 periods. In each period, there are 5 routes of food delivery. When a work team is assigned to a route, the team of two workers needs to carry a food trolley with many food trays to visit a number of wards, and at the same time takes empty food trays back to kitchen for cleaning. Table 3.1 presents the time required by 5 routes in 6 periods. Since the time required is uncertain and cannot be estimated accurately as a constant, it is estimated as triangular fuzzy numbers under three fuzzy situations. Similarly, the energy required by 5 routes in 6 periods are estimated as triangular fuzzy numbers and shown in Table 3.2.2.

The available time per day for all teams, TA_i, are 8 hours. The energy capacities of worker teams are dependent on the total strength of bodies of team members, which are different among the teams. The energy capacities of team i, Cap_i, are 4400, 4300, 5200, 3900 and 4700, respectively.

Table 3.2.1 Time required by route *j* in period *k* in scenario *x*, TT_{jk}^{x} (change p and o, o has lower time and energy)

	Time requirement per each route in each shift(Min)																	
	Shift (1 round comprosed of 2 shift: Odd number - pick up, Even number - drop off)																	
Route	1			2			3			4			5			6		
	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p
1	55	56	67	53	57	63	56	59	66	65	76	87	70	72	79	55	60	67
2	50	51	55	50	56	64	56	66	70	56	58	64	62	70	72	53	55	60
3	50	59	68	47	48	55	45	49	57	68	76	93	60	63	65	65	79	80
4	47	50	55	46	49	55	51	53	56	63	70	78	62	69	79	56	60	66
5	55	59	62	47	50	52	60	61	65	67	78	86	59	65	68	68	70	74

Table 3.2.2 Energy required by route *j* in period *k* in scenario *x*, EE_{jk}^{x}

	Energy Expenditure per each route in each shift(Kcal)																	
	Shift (1 round comprosed of 2 shift: Odd number - pick up, Even number - drop off)																	
Route	1			2			3			4			5			6		
	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p
1	495.0	672.0	971.5	583.0	684.0	831.6	448.0	560.5	699.6	390.0	532.0	739.5	595.0	648.0	948.0	341.0	420.0	737.0
2	225.0	331.5	363.0	430.0	560.0	832.0	453.6	594.0	658.0	196.0	232.0	428.8	434.0	532.0	712.8	265.0	308.0	450.0
3	290.0	354.0	455.6	455.9	489.6	627.0	292.5	347.9	450.3	666.4	836.0	1116.0	420.0	459.9	565.5	650.0	948.0	1280.0
4	230.3	250.0	379.5	358.8	392.0	495.0	306.0	424.0	476.0	422.1	686.0	803.4	446.4	552.0	869.0	448.0	540.0	726.0
5	495.0	719.8	775.0	517.0	600.0	686.4	576.0	750.3	845.0	509.2	780.0	1032.0	548.7	988.0	1088.0	707.2	770.0	962.0

CHAPTER 4
RESULT AND DISCUSSION

4.1 Validation of results

The compromised solution from maximizing weighted average satisfactions approach is used to demonstrate that the solution is reasonable and the model is validated. The optimal team-route assignment in all periods are presented in Table 4.1. Table 4.1.1 shows for example that team 1 is assigned to routes 2, 2, 3, 4, 4, and 5, in periods 1 to 6, respectively. Based on the optimal team-route assignment in Table 4.1.1, the energy used by each team in each period under three fuzzy scenarios are presented in Table 4.1.2. Similarly, the time used by each team in each period under three fuzzy scenarios are presented in Table 4.1.3. The total energy used in all periods and the leftover energy of each team under three fuzzy scenarios are presented in Table 4.1.4. From Table 4.1.4, the percentages of leftover energy of each team under the same fuzzy scenario are not much different. As a result, the standard deviation of the percentages of leftover energy of all teams under each fuzzy scenario is relatively low. Finally, the weighted average of the standard deviations of leftover energy in all fuzzy scenarios ($\overline{SC}$) is relatively low (only 2.08 %). Similar to Table 4.1.4, Table 4.1.5 indicates that the weighted average of standard deviations of leftover time in all fuzzy scenarios ($\overline{ST}$) is very low (0.66%). Relatively low values of $\overline{SC}$ and $\overline{ST}$ indicate that the proposed model and method are effective to determine the compromised solutions between the time and energy used by each team under all fuzzy scenarios.

The results in Tables 4.1.4 and 4.1.5 clearly show that the uncertain (fuzzy) parameters, which are time and energy required by route *j* in period *k*, play an important role in the analysis. From Table 4.1.4, it is shown that the leftover energies under pessimistic scenario of all teams are very low and are slightly different (range from 1.29 % to 2.77 %). They are non-negative which means that there is no team that uses energy more than the energy capacity of that team. This result indicates that the proposed model and method can effectively balance the energy used by each team. Similarly,

Table 4.1.5 indicates that the times used by all teams are very well balanced in all fuzzy scenarios.

Table 4.1.1 Optimal team-route assignment in each period

Worker Assignment	Shift	1	2	3	4	5	6
Team	Team 1	Route 4	Route 2	Route 3	Route 4	Route 4	Route 5
	Team 2	Route 3	Route 3	Route 4	Route 2	Route 1	Route 3
	Team 3	Route 5	Route 4	Route 5	Route 3	Route 5	Route 1
	Team 4	Route 2	Route 1	Route 1	Route 1	Route 2	Route 2
	Team 5	Route 1	Route 5	Route 2	Route 5	Route 3	Route 4

Table 4.1.2 Energy used by team *i* under fuzzy scenario *x* in each period

Energy	Shift (k)																	
Team (i)	1			2			3			4			5			6		
	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p
1	230.3	250	380	430	594	832	293	348	450	422	686	803	446	552	869	707	770	962
2	290	354	456	456	490	627	306	424	476	196	532	429	595	648	948	650	948	1280
3	495	720	775	359	392	495	576	750	845	666	836	1116	549	988	1088	341	332	737
4	225	560	363	583	684	832	448	561	700	390	532	740	434	308	712.8	265	406	450
5	495	672	972	517	600	686	454	232	658	509	780	1032	420	460	565.5	448	660	726

Table 4.1.3 Time used by team *i* under fuzzy scenario *x* in each period

Time	Shift (k)																	
Team (i)	1			2			3			4			5			6		
	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p
1	47	50	55	50	56	64	45	49	57	63	70	78	62	69	79	68	70	74
2	50	59	68	47	48	55	51	53	56	56	58	64	70	72	79	65	79	80
3	55	59	62	46	49	55	60	61	65	68	76	93	59	65	68	55	60	67
4	50	51	55	53	57	63	56	59	66	65	76	87	62	70	72	53	55	60
5	55	56	67	47	50	52	56	66	70	67	78	86	60	63	65	56	60	66

Table 4.1.4 Energy used and leftover energy of each team

Team(i)	Expenditure in each scenario (H_i)			Leftover in Percentage (C_i)		
	o	m	p	o	m	p
1	2,528.50	3,199.90	4,296.20	42.53%	27.28%	2.36%
2	2,492.90	3,395.60	4,215.40	42.03%	21.03%	1.97%
3	2,985.90	4,017.60	5,056.00	42.58%	22.74%	2.77%
4	2,345.00	3,050.50	3,796.50	39.87%	21.78%	2.65%
5	2,842.80	3,403.90	4,639.40	39.51%	27.58%	1.29%
Performance	Max residual energy (C_{max})			42.58%	27.58%	2.77%
	Standard deviation (SC^x)			1.49%	3.11%	0.60%
	$W^1{}_C \ldots n$			0.25	0.5	0.25
	SC bar			2.08%		

Table 4.1.5 Time used and leftover time of each team

Team(i)	Time consumptionin each scenario (TS_i)			Leftover in Percentage (T_i)		
	o	m	p	o	m	p
1	335.00	364.00	407.00	30.21%	24.17%	15.21%
2	339.00	369.00	402.00	29.38%	23.13%	16.25%
3	343.00	370.00	410.00	28.54%	22.92%	14.58%
4	339.00	368.00	403.00	29.38%	23.33%	16.04%
5	341.00	373.00	406.00	28.96%	22.29%	15.42%
Performance	Max time leftover Tmax			30.21%	24.17%	16.25%
	Standard deviation (ST^x)			0.62%	0.68%	0.67%
	Weight ($W^1{}_T \ldots n$)			0.25	0.5	0.25
	ST bar			0.66%		

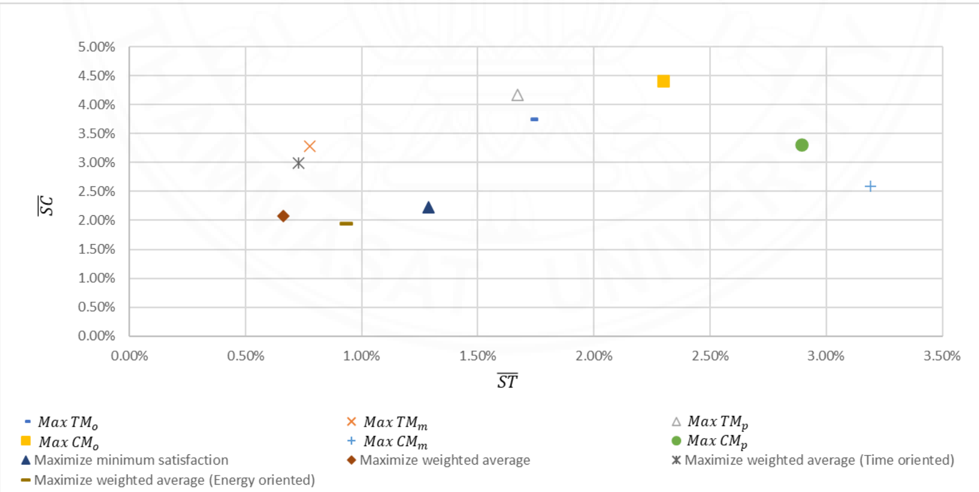
4.2 Comparison between single and multiple objective models

From Section 3.1, there are 6 single-objective models that minimize TM^p, TM^m, TM^o, CM^p, CM^m, and $CM^o$and 2 multi-objective models that maximize minimum satisfaction and maximize weighted average satisfactions. All models are solved for the optimal team-route assignment, and the values of $\overline{SC}$ and $\overline{ST}$ are calculated accordingly. Then, a scatter pot based on the values of $\overline{SC}$ and $\overline{ST}$ of eight solutions are shown in Table 4.6. It is seen clearly that the compromised solution from the multiple objective model that maximize the weighted average satisfactions is the best solution that dominates other solutions because both $\overline{SC}$ and $\overline{ST}$ are lower than those of other solutions. This solution is a non-dominated solution or Pareto optimal solution.

From Table 4.2.1, there are six solutions from six single-objective models. None provides a good solution since each model considers only one objective (either time or energy used but not both) under only one fuzzy scenario. Other objective under other fuzzy scenarios that the model does not consider may have unbalanced time and energy used by each team. Therefore, the performances measures ($\overline{SC}$ and $\overline{ST}$) are not good when compared with the suitable multiple-objective model.

The performances measures proposed in this paper ($\overline{SC}$ and $\overline{ST}$) are nonlinear which is difficult to be optimally solved by mathematical programming technique. Therefore, this paper develops linear objective functions to be easily solved to generate the compromised solutions that have good performance measures. The results of the weighted average satisfactions approach presented in Table 4.2.1 confirm that the compromised solution from the proposed model has good performances.

Table 4.2.1 Performance comparison of various methods



The required computational times of the proposed method are very short, which are 2 to 11 seconds when it is solved by OpensSolver version 2.9.3 installed on Microsoft Excel software , using intel core i7-10875H CPU, 2.30 GHz and 16 RAM. It is very convenient for any hospital to solve real problems using the proposed method. For time and energy oriented, we assign unequal weight to two goals (0.6 and 0.4). It means that when goal is being oriented. The weight assigned to that goal will be more than another goal.

4.3 Practical applications of the proposed models and method

Many hospitals have a common problem in meal delivery to many wards in that total delivery time and total energy used in each day are not balanced among worker teams. The experimental results in this paper indicate that it is possible to assign work teams to routes in each period of a day to balance the time and energy used among all work teams. This paper extends a linear assignment model to have two fuzzy objectives of balancing fuzzy time and fuzzy energy used by all teams. Practically, it is difficult to accurately estimate the required time and required energy of each route in each period as constant parameters. This paper proposes to estimate these parameters as triangular fuzzy numbers since it is the simplest form of fuzzy number with only three parameters. Therefore, two objectives are fuzzy objectives. Fuzzy objectives significantly contribute to effective practical applications since it guarantees that if the real parameters are not beyond the pessimistic and optimistic parameters, the performances of the solutions from the proposed model will not be worse than the predicted performances from the model

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 General conclusion

In conclusion, single objective optimization cannot cope with multi-objectives. In practices, FMOLP will help to mitigate by trading off some amount that being better in the single objective case. This is because single objective only aims for the best solution that one objective is being optimized and worsen another goal. However, FMOLP will generate the compromised solution which will settle the unarguable points where they are the most subtle. However, if we decide to assign unequal weight to these two objectives. The result will be a trade-off between the two.

5.2 Contribution

In the hospital or any industry that is workforce scheduling, typically, employee's satisfaction is usually not taken into account. Thus, the environment becomes worse rapidly and result in high turn-over rate. Hence, this paper tends to promote welfare to workforce scheduling that enhances welfare among the worker which can promote work life balance in the sense that ergonomics and bionomical movements are compulsory measurements in order to optimize the friendly workplace environment measuring by energy expenditure parameter which indicates intensity of work along the daily job. Purposing energy expenditure that can be reduced to the redundant of work to the low-capacity team and increase workload for the high-capacity team to the point that they share the equivalent amount of work.

5.3 Limitation and further studies

There are some limitations and recommendations for further studies. First, this paper uses the standard deviations ($\overline{SC}$ and $\overline{ST}$) as performance measures. Since the standard deviation is nonlinear, the proposed models use alternative objective functions, which are linear. Thus, the compromised solutions from the proposed models may not be the best. A further study to develop the model that directly minimize $\overline{SC}$ and $\overline{ST}$ and solved by meta-heuristics is recommended. Second, this paper proposes two objectives of balancing time and energy used by all teams. The proposed model may be extended to have more objectives, for example, maximizing satisfaction of patients, and maximizing freshness of meals.

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