WEIGHTED GOAL PROGRAMMING MODEL FOR ELECTIVE PATIENTS IN SURGICAL OPERATING ROOM BLOCK SCHEDULING

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DEDICATION

To my beloved mother and father, my siblings, my supportive supervisor, Dr Syarifah Zyurina and my fellow friends, thanks for all your prayer, love and support.

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ABSTRACT

Operating rooms represent the significant department in hospital as it has a high usage rate and the demand for it is still ongoing. However, limited resources such as equipment and surgical specialities within hospital services made the scheduling of surgical operating room become a complicated task. A well-designed schedule should take into account resources utilization as well as the welfare of patients and surgical teams. A multi-objective optimization model is proposed to tackle some conflicting goals to produce an optimal master surgical schedule (MSS). In particular, this study aims to minimize the underutilization of operating rooms and surgical specialities, increasing the satisfaction of surgeons toward operating room and prioritized patients in health risk condition. The decision problem in this study is two-fold, first is the assignation of operating rooms and a fair distribution of operation time among surgical specialities for a week horizon. The second problem is to schedule elective surgeries into the assigned date and operating rooms. A weighted goal programming (WGP) model is developed where the weights of goals reflect the preference of decision maker toward the relative importance of each goal. Then, a case study is conducted to demonstrate four scenarios of different weights for each goal. The experiment results have shown when all conflicting goals are equally important to be considered, a longer computational time is needed to obtain a feasible solution and has a higher deviation objective value. Furthermore, achieving high utilization of operating rooms and surgical specialities as well as prioritized patients could not coexist. In short, it is necessary for hospital administration to balance each factor in surgical room scheduling while improving management efficiency. The proposed model could describe well the current management system situation and suggests applying in hospital practice. Future study is suggested to consider other factors such as bed resources and waiting time of patient in waiting list to improve operating room efficiency.

ABSTRAK

Bilik pembedahan mewakili jabatan yang penting di hospital kerana ia mempunyai kadar penggunaan yang tinggi dan permintaannya masih berterusan. Walau bagaimanapun, sumber yang terhad seperti peralatan dan pakar bedah dalam perkhidmatan hospital membuat penjadualan bilik pembedahan sebagai tugas rumit. Jadual yang direka dengan baik harus mengambil kira penggunaan sumber serta kebajikan pesakit dan pasukan pembedahan. Model pengoptimuman pelbagai objektif dicadangkan bagi menangani beberapa matlamat yang bercanggah untuk menghasilkan jadual pembedahan yang optimum (MSS). Khususnya, kajian ini bertujuan untuk meminimakan kurang penggunaan ruang pembedahan dan kepakaran pembedahan, meningkatkan kepuasan para pakar bedah terhadap bilik pembedahan dan pesakit yang terdahulu dalam keadaan risiko kesihatan. Masalah keputusan dalam kajian ini adalah dua peringkat, pertama ialah peruntukan bilik pembedahan dan pengagihan masa pembedahan yang adil dalam kalangan kepakaran pembedahan selama satu minggu. Masalah kedua ialah menjadualkan pembedahan elektif dalam tarikh dan bilik pembedahan yang ditetapkan. Satu model pengatur matlamat wajaran (WGP) telah dibina di mana berat matlamat mencerminkan keutamaan pembuat keputusan terhadap kepentingan relatif setiap matlamat. Kemudian, satu kajian kes dilakukan untuk menunjukkan empat senario berat yang berbeza bagi setiap matlamat. Keputusan eksperimen telah menunjukkan apabila semua matlamat yang saling bertentangan sama pentingnya untuk dipertimbangkan, masa pengiraan yang lebih lama diperlukan untuk mendapatkan penyelesaian yang layak dan mempunyai nilai objektif sisihan yang lebih tinggi. Tambahan pula, pencapaian penggunaan bilik pembedahan dan pakar bedah yang tinggi serta bagi pesakit yang terdahulu tidak boleh wujud bersama. Ringkasnya, pentadbiran hospital perlu mengimbangi setiap faktor dalam penjadualan bilik pembedahan sambil meningkatkan kecekapan pengurusan. Model yang dicadangkan dapat menggambarkan keadaan sistem pengurusan semasa dan menyarankan penggunaan dalam amalan hospital. Kajian masa depan dicadangkan untuk mempertimbangkan faktor-faktor lain seperti sumber katil dan masa menunggu pesakit dalam senarai menunggu untuk meningkatkan kecekapan bilik pembedahan.

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LIST OF ABBREVIATIONS

ASC	-	Ambulatory surgical centre
CMP	-	Case mix problem
DM	-	Decision maker
FCFS	-	First-come-first-served
GP	-	Goal programming
ICU	-	Intensive care unit
ILP	-	Integer liner programming
LP	-	Linear programming
LGP	-	Lexicographic goal programming
MCDA	-	Multiple criteria decision aiding
MCDM	-	Multiple criteria decision making
MILP	-	Mixed integer linear programming
MOP	-	Multi-objective optimization problem
MMBJS	-	Multi-mode blocking job shop
MSS	-	Master surgical scheduling
OR	-	Operating room
PACU	-	Post anaesthetics care unit
PHU	-	Preoperative care unit
SSP	-	Surgery scheduling problem
WGP	-	Weighted goal programming

LIST OF SYMBOLS

$F_i(\boldsymbol{x})$	-	Linear function of decision vector $\boldsymbol{x}$
T_i	-	Target value for i^{th} goal
s_i^-	-	Negative deviational variable of i^{th} goal
s_i^+	-	Positive deviational variable of i^{th} goal
X	-	Feasible region of decision vector $\boldsymbol{x}$
G_i	-	i^{th} goal
ρ_i	-	Component of i^{th}deviational variable
w_i	-	Positive weights or penalty for i^{th}goal
h	-	Number of days of planning horizon
i	-	Index of patient
j	-	Index of time block
r	-	Index of operating room
s	-	Index of surgical team/ speciality
P	-	Patients
n	-	Number of patients
TB	-	Time blocks
m	-	Number of time blocks
R	-	Number of operating rooms
SS	-	Surgical teams/specialities
S	-	Number of surgical teams/ specialities
t_{jr}	-	Duration of block j of OR r
$T_s^{\min}$	-	Minimum time allocated to each surgical team/ speciality s
d_i	-	Expected surgery duration of patient i
pr_i	-	Assigned priority value of patient i
b_{ir}	-	Preferences value of surgical teams/ speciality about OR r for patient i
z_{is}	-	Binary number specifies surgical speciality s operating on patient i

x_{ijr}	-	Decision variable of patient i in time block j of OR r
y_{jrs}	-	Decision variable of surgical team/speciality s in time block j of OR r
u_{jr}^{-}	-	Underutilization of operating room hours for OR r TB j.
e_s^{-}	-	Sum of weights of surgery for surgical team s that are postponed.
r_s^{-}	-	Amount of negative deviation from the total number of preferences toward operating room made by surgical speciality s
h_s^{-}	-	Amount of underutilized hours of surgical speciality s from the total time assigned to them
k	-	Large constant number

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Health sector has always been restricted by limited budget to promote rationalization practice of resources with better service performance. However, the consumption is fast increasing caused by population ageing and baby growth, rising costs of medical instruments and adoption of new medical technology. Controlling the burdensome cost has made the decision making of the health care system more challenging because the stakeholder has to consider the limitation of resources while performing the best services to patients.

Operating room (OR) is one of the most critical and expensive resources in the hospital but it is also the greatest revenue unit in a hospital [1] [2] [3] [4]. It is estimated that more than 9% of the hospital's budget is expensed on the operating rooms [5] but at the same time, it accounts for approximately 40% of hospital revenue [1] [2]. A study predicts that the population growth and ageing pace increased the workload of the surgical fields by 14-47% by 2020, with vary by speciality [6]. Due to this reason, management in the operating room must be decisive and precise to uplift the efficiency of the surgical department, reducing costs and maximize the utilization of the resources to have a less financial impact on the hospital.

Scheduling is a plan of procedure to allocate available resources with reference to the sequence and time that aims to find an optimization in the work process. Indeed, it is an important tool in many practical applications, for instance, manufacturing sector, university timetabling and air flight scheduling. It is undeniable that a proper scheduling will enhance the performance and efficiency of the whole system. In general, scheduling helps to maximize the utilization of resources and profit and minimize the makespan.

OR scheduling often adopts block scheduling strategy by hospitals in Europe [7] where the OR capacity is predetermined and pre-allocated among surgical specialities or groups. OR capacity is divided into blocks or slots with different or same duration and assigned to every speciality. Each speciality can only perform their elective surgeries in their attributed time slot and this limitation must take into consideration when scheduling the OR. Elective surgery refers to a patient whose surgery is not in urgency and put into a waiting list of surgery. Those surgeries can be planned in advanced but keeping patients in waiting list is costly, both at the prevention and maintenance level [8].

An elective surgery mainly passes through three stages namely preoperative stage, perioperative stage and postoperative stage [3] [9] [10]. Figure 1.1 highlights the involved stages and the resources required at each stage to perform an operation, and this common process is practised in many hospitals. Patients arrive will first enter preoperative holding unit (PHU) on the first day to do tasks related to surgery performed such as registration and document checking. Nurses, anaesthesiologist and the respective surgeon will confirm the operation procedure with patients to avoid error. Patients then enter the scheduled OR at the second day and this stage also called surgery stage. For a simple case of operation, member of surgical teams involved must belong to the same surgical speciality. After the surgery, patients enter recovery stage based on their recovery state. If the patients are under noncritical condition, then they are transferred to postanaesthetic care unit (PACU) to recover from the residual effects of anaesthesia. Otherwise, critical patients such as those performed cardiac or thoracic surgery are sent to intensive care unit (ICU) for further observation. Next, patients are transferred to ward for complete recovery and is able to discharge.

OR scheduling or surgical scheduling problem usually involved three stages [11] [12]. The first level determines the available OR capacity and divides the OR time to each surgical speciality. Second stage aims to build a block schedule which specifies the allocation of specialities to operating rooms and day. The last stage concerns the selected surgery scheduling for each day. This hierarchical decision levels are correlated and will be explained further in a later chapter.

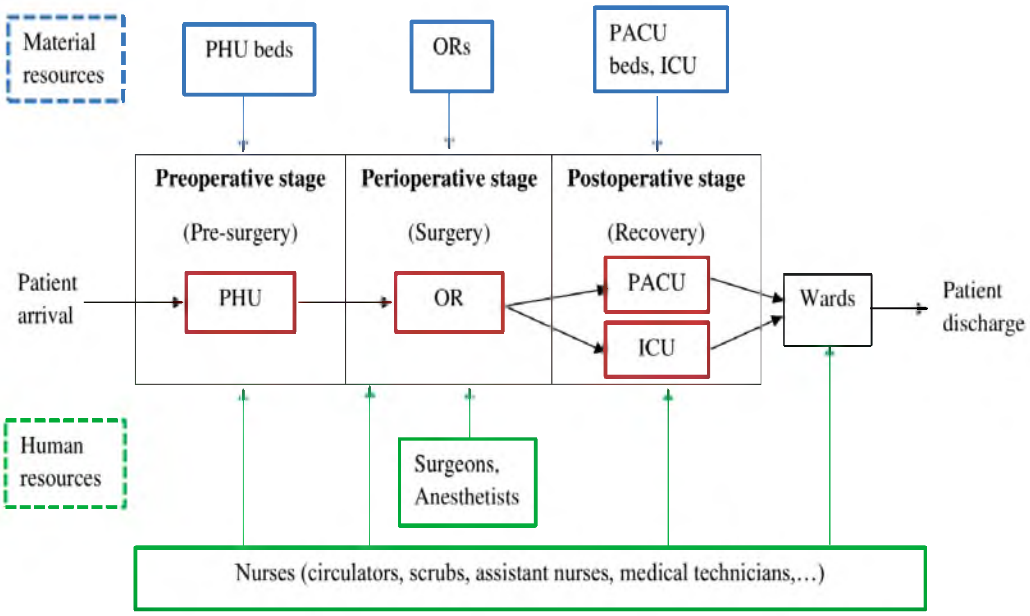

Figure 1.1 Stages and resources involved in OR management

Operating room planning and scheduling starts to attract the attention of researchers from the year 2000 due to the increasing budget of operating rooms at the end of the 1990s [13]. However, this scheduling problem is complex due to conflicting priorities and objectives to be satisfied with the aspect of OR, surgeons and patients. For instance, consideration of OR includes efficiency, overtime and undertime related cost, idling, and OR's team waiting. Surgeons' preferences, patients waiting time and priority, utilization of facilities (beds, post anaesthesia care unit capacity and surgical equipment) made the scheduling problem more complicated. Accomplish all the goals at one time is arduous or sometimes impossible and this could explain why cancellations and delays of surgeries are inevitable. Therefore, a vast variety of researches being carried out with different interest in performance measures.

Early researches of operating room scheduling problem mainly emphasis on single objective function, most of which are achieving high utilization rate of surgical room, minimizing the penalty cost and reducing patients' waiting time. This type of problem is easy to handle and save much calculation time. Meanwhile, solving multi-objective operating room scheduling problem still has a big research gap, especially when considering of different criteria. Finding feasible solutions for multi-objective problem is possible but is laborious as the solutions have to fulfil various conditions, not to mention searching for optimal solution. Weighted goal programming (WGP), a branch of multi-criteria decision analysis, is a well-known approach to overcome multiple goals problem and it is still new to apply in this area. It finds the solutions indirectly, where the main idea is to convert objective functions to goals and aims to minimize the deviations from the target values for respective goal. In some studies of multi-objective OR scheduling problem, researchers apply methods which require multiple steps [14] [15] or solve in hierarchical stage [16][17]. However, WGP is a flexible tool to allow decision maker takes all goals into account at once and choose his own preferences of priority for the goals. These advantages made WGP approach suitable to deploy in this study especially when considering more number of goals.

This study focused on multi-objective optimization of surgical room scheduling problem. Different objective functions established different mathematical models and many methods have been applied in this kind of problem which includes exact techniques, approximation approaches or even mixed of exact and approximation. All these methods are aimed to find an ideal way to schedule the operating rooms to meet the criteria of stakeholder.

1.2 Problem Statements

Operating theatre represents the most expensive unit in hospital as it consumes a large portion of expensive resources, but it is also the source of income of a hospital. Thus, the hospital management is essential to have an efficient way to schedule the operating room as such that all ORs are fully utilized under limited resources. In this way, overtime cost due to underutilization of resources and idle time of the operating room can be avoided at the same time shorten the waiting time of patients. However, operating room scheduling problem is conflicting as many factors are influencing the decision process. One of the causes is the elective patients' priority. Admin has to arrange the surgeries based on the priority (health condition) of the patients. An inappropriate arrangement will put the patient in health risk, or the waiting list becomes longer thus inefficient resources utilization and patient-related cost. Furthermore, surgical specialities have different preferences in the operating room which make the scheduling process more troublesome. This is because while balancing the utilization of ORs and assignment of patients to surgeons, it is crucial to reduce underutilization of surgeons by matching their preferences. Overall, OR scheduling is not an easy task but still essential.

Nevertheless, current methodology solving for multi-objective of OR scheduling problem is limited and exist more approaches to explore. Review done by [7] discovers that most studies adopt hybrid of exact and approximation method in solving multi-criteria surgical room scheduling problem. Weighted goal programming is another technique to address this type of problem but till date, none of the studies applies it to deal with above mentioned factors. Thus, this study will construct a multi-objective model with weighted goal programming approach to generate a deterministic OR schedule that concerns mentioned conflicting factors.

1.3 Objectives of Study

The objectives of the study are:

i. To develop a weighted goal programming model for operating room block scheduling.

ii. To solve a case study for operating room block scheduling using CPLEX.

iii. To analyse the results of the computational experiment based on four scenarios in the case study.

1.4 Scope of Study

This study focused on scheduling of operating theatre for elective surgical cases. Block scheduling strategy is used to build up a weighted goal programming model for deterministic OR scheduling problem. Operating room during the perioperative stage is the core part of this study where other resources such as beds, wards, ICU capacity, patient waiting area, nurses and anaesthetists are considered sufficient to carry out the operations. The planning horizon of the OR schedule is for a week. The main interest in this optimization problem is to maximize the utilization of ORs, minimize the underutilization of surgeon groups by matching their room preferences and increase the number of patients with high priority in scheduling. Durations of surgeries and total allocated OR time to each surgical specialities are considered when constructing the model. A simulation test is performed to evaluate the performance of proposed model using CPLEX version 12.9.

1.5 Significance of Study

Strategy Plan 2016-2020 of Ministry of Health Malaysia states that expenditure in government hospitals increases three-fold from RM7.32 billion to RM23.25 billion [18]. One of the strategies to strengthen delivery health system governance includes implementation of lean management initiative as well as revise the fee structure for public health facilities. Hence, it is essential to schedule surgery cases in an optimum way to increase the overall management efficiency of hospitals with a limited budget. A proper scheduling of operating rooms will make sure the optimal utilization of resources includes personnel (surgeons, nurses, anaesthetists) as well as facilities (beds, post anaesthesia care unit capacity, intensive care unit capacity and surgical equipment). Such this planning will ensure the surgeries performed on the scheduled time thus reduce the chances of cancellation or delay of surgeries, which are considered overtime cost and it is costly to patients and hospitals [5]. Furthermore, scheduling helps to maximize the patient flow or in other words reduce patients' waiting time in the stay list, hence increase profitability. Long waiting list in the operating rooms causes the low performance of healthcare system, patients' dissatisfaction and even increases the patients' health risk [19]. Thus, operating room planning and scheduling is definitely a crucial tool in a hospital management system.

1.6 Organization of Dissertation

This study made up of five chapters. Chapter 1 introduces a short background of operating room scheduling problem which helps to understand the gap of the study. It also includes problem statement, objectives, scope of study and significance of study. Chapter 2 presents the literature review on operating room planning and scheduling, multi-objective criteria and methods to solve OR scheduling problem. Next chapter establishes a weighted goal programming model to solve the multi-objective surgical room scheduling problem. Chapter 4 conducts a simulation test and the result is presented here. Analysis of solution with brief discussion will also be included in this chapter. Finally, conclusion of this study and recommendation for future work are delivered in Chapter 5.

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