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Review Article

Operating Rooms Planning and Scheduling with Mix Integer Programming and Meta-Heuristic Method

Mehdi Askarizadeh*, Faieza Abdul Aziz, Mohd Khairol Anuar, Siti Azfanizam Binti Ahmad

Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University Putra Malaysia, Serdang, Malaysia

Email address:

askarizadeh.mehdi@yahoo.com (M. Askarizadeh)

*Corresponding author

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Abstract: The surgery department is required to improve its performance by efficient usage of its available resources. Surgery department interdependencies with other hospital functions and departments are numerous and complex, which causes some restrictions on surgery ward performance and consequently hospital performance. Operating room (OR) schedule determines day to day operations that take a place at the surgery department. Creating such a schedule is a complex task, due to a multitude of constraints, preferences and objectives that planners need to take into account. Meanwhile, the schedule has major effects on the performance of surgery department and the hospital. This paper provides a review of recent operational research on operating room planning and scheduling with focus on multi-objective simulation optimization with use meta-heuristic method: in operating room, as a practical suggestion for hospitals. Recent researches were collected based on some keywords including simulation optimization, and operating room by google scholar, Scopus, and Pubmed. The findings showed that, there are not much practical suggestion in this case and still there is a gap and needs to be discovered.

Keywords: Operating Room, Simulation Optimization, Meta-Heuristic

1. Introduction

Nowadays, because of the developing of the countries and increasing the population, and increasing the air pollution, physiological and psychological health parameters of individuals are affected and caring about health should be noted well by them [1, 2]. Health cost is one of the big issues for patients who need to use medicines or do any operation, regarding their issue, with referring to the hospital.

The single largest cost to a hospital delivering surgical care is incurred in the operating room (OR) [3, 4]. Salaries of OR staff account for most OR costs, particularly at hospitals with salaried nurse anesthetists and/or anesthesiologists. Consequently, in many hospitals, an OR manager or a governing body has the authority to organize care for surgical patients at the least cost [5]. To have an important impact on costs of patient care in the OR suite, OR managers must try to maximize "labor productivity" by using the least number of staff necessary to care for the patients without causing idle time or over time for surgeon or staff and also decrease waiting time for patients [4, 6].

Operating rooms, one of the most important resources of the hospitals, are considered bottlenecks along with recovery units (PACU) [4]. The operating room can be viewed as the Engine of the hospital. Activities of operating room affect a lot on the other departments and almost each activity within the hospital environment. Efficient use of operating rooms can be helpful for smooth operation of the hospital. ORs need large amount of capital and labor. They require a lot of supplies and sanitization attention. Hospitals' 9-10% revenue is spent on operating rooms, which is one of the most significant sources of expenditure [6, 7]. Pham et al. (2008) also mentioned OR account to be around 10-30% of hospital expenditures for different sized hospitals [8].

A recent joint study by the National Academy of Engineering and the Institute of Medicine (National Academy

of Engineering and Institute of Medicine, 2011) highlights the importance of health care and engineering partnership, and indicates scheduling in health care delivery systems, as one of the areas with significant research opportunities. Two types of variability are to be handled by health care management: natural and artificial variability. Natural variability is inherent in nature and cannot be controlled by management, but the later one, artificial variability is controllable as it is caused by poor planning and policies [9]. Well prepared operating room schedule can surely help minimize variability in demand of resources considering elective patients [10]. Variability affects productivity. Therefore, reducing and handling variability is one of the major challenges for health care professionals.

Extensive research has been carried out in the healthcare to schedule surgeries in different conditions in the last decade [7]. The health care systems of developed countries have different setups, but the intention is to serve patients better and faster with the efficient use of available resources. In the health care environment, hospitals need to be responsive to patients as fast as they can. Different types of patients need a different level of attention from hospitals. Likewise, the resource constraints such as Surgery team availability, OR availability, postsurgical unit capacity, nurses' availability, etc. affect a lot to schedule [11], but it is not clear yet, if there is a specific way to optimization with use simulation optimization and meta-heuristic algorithm together.

Surgical cases have three stages: pre-operative, intra-operative and post-operative [8]. The overall surgery delivery process is consisting of a variety of activities that are performed through pre-operative, intra-operative and post-operative stages. First stage will not consider in this review, as it is not under our scope. In the post-operative stage, the patients from different ORs will share PACU resources, therefore there is a necessity to consider PACU and OR scheduling along with each other because PACU staff may encounter idle time or patients should wait at ORs for recovery until one PACU staff will be available at PACU if there is not appropriate scheduling of intra-operative-stage. In both cases, it is considerably more costly for hospital because it should pay to more than needed PACU staffs or it should take OR and surgeons time to take care of patient until one PACU staff will be available [12].

In this review two groups of surgeries are considered, namely, elective and non-elective (urgent) surgeries. In elective surgeries, everything is scheduled in advance, however, in non-elective (urgent) surgeries nothing is planned before and everything arise suddenly and unforeseen in the time block, so, in this case, there is a necessity for these non-elective surgeries to be added to schedule. Therefore, a part of OR capacity should be specified to urgent surgeries or a slack between elective surgeries should be considered in order to enable urgent surgeries to be planned between elective surgeries in an emergency time.

According to Ozcan (2005), there are two approaches for scheduling an OR, namely open scheduling and block scheduling [13]. In open scheduling, there are specific surgery times, and the hospital will allocate the specific surgery time to the first surgeon whom request this time, and each surgeon has a time limitation for his/her surgery. However, in block scheduling, a day of an OR will be divided to one or two time block (depend on the problem case), and the surgical group consist of several surgeons in the same specialty will be assigned to the time block. Based on Roland et al. (2006), the allocation of a specific surgical group to a time block will be done considering historical demands pattern, and surgeons' availability on that time block [14].

All of the previous studies mentioned about the importance of cost-benefit for simulation optimization in operation room, but still there is a lack of research about practical interaction between operating rooms and patients anesthetist care unit, specially based on the consider both wards together in using simulation optimization and also meta-heuristic method, and this is the reason for developing this review.

Statement of the Problem

Roland et al. (2006) investigations show that, the major expenditure of surgeries is not the costs of the materials that surgeons needs for operation [14]. They described that the most expenses specified to using the resource such as personnel, equipment, and support of administrative. Hence, using these resources efficiently is crucial. Therefore, an optimized OR planning can help hospital managers to reduce the expenses significantly and control cost associated with surgery such as operating costs regarding facilities and salary of personnel, by efficient use of OR time [15, 16].

Schedule of an OR is a complicated process because firstly, several stakeholders such as surgeons, patients, etc. with different priorities should be considered [6]. Secondly, the duration of surgeries is different and it depends on several factors such as, patient's situation, surgeon specified to that patient and operation etc. So, the accurate duration of the operation is indefinite and the hospital only can estimate the surgery duration for each patient from historical data. Thirdly, uncertainties of emergency patients, and considering time and service for these patients make the planning more complex and leading to surgeons overtime, and elongate the patients waiting time on the day of surgery [17]. Finally, only considering OR planning may lead to PACU staff idle time or surgeons' overtime.

According to Meskens et al.(2013), when the scheduling is inefficient, during the time block, surgery is inefficient and there is a necessity of working more than 6 estimated time for the personnel, hence the hospital should pay more salary to the staffs and also the expenses associated with using OR facilities will increase [17]. Therefore managers should avoid this situation. Therefore it is really necessary to improve the efficiency of OR planning.

According to Vermeulen (2009), heighten the hospital efficiency is complicated due to several factors, such as, existing different departments in a hospital, policies of planning and scheduling of each hospital, local objectives and policies that need to be considered in each department of the hospital, an interaction of different part of each department on each other [12]. Therefore, based on the Butler (2012), assigning and sequencing the patients for different parts in

surgery department with considering several constraints and goals make the OR scheduling more complicated [5]. Due to aging and increasing the size of the population, the number of catheterization procedures that needs to be performed grown significantly and makes heart specialization one of the most important specialties in the health care. Therefore, the number of catheterization procedures that needs to be performed grown significantly [3]. Based on Katzberg& Haller (2006) investigations, in USA, the number of cardiac catheterizations raises 390% between 1979 and 2005, and from 1992 to 2004, it increased by 112% in Europe [18]. The rapid expand of this problem makes catheterization procedure one of the most important clinical services.

2. Methods

In this study, systematic review methods are used based on the purpose of research [19]. A systematic investigation of recurrent literature databases was navigated between 2009 and 2016. Science Direct, PubMed and Scopus were searched for the subsequent key words: simulation optimization, and operating room. Papers were also recognized and used by the chief author's collected works. Initially 200 researches were recognized. As there are a huge number of researches about operating room and stimulation optimization, we could not analyse all the original articles, so we analysed and reviewed previous researches. In some cases, based on the importance of the study, we have incorporated the original articles that were cited in the previous review articles. Moreover, it must be noted that, the results of this review are dictated by our search terms.

3. Results

The results of this review showed that, scheduling and timing is an important and crucial parameters for surgurists, patients and hospital. It not only affect the performance of surgerists, and health of patients, but also have a significant effect on economic costs for hospitals. Some of the suggested ways to modify this issue are acceptable but there is a lack to find a cost-based solution with data envelopment analysis combine with genetic algorithm in operating room. In Table 1, we have summarized the findings.

Table 1. *Current studies on multi-objectives optimization on different area with simulation.*

Author	Year	Mathematical model	Solution approach
Jerbi & Kamoun	2011	simulation and goal programming	Exact method
Xiang, Yin, & Lim	2015	Ant Colony Optimization (ACO)	Exact method
Cardoen et al.	2009	Mixed integer programming Multicriteria optimization	Exact method
Lin, Sir, & Pasupathy	2013	simulation optimization with DEA and GA	Heuristic method
Meskens et al.	2013	constraint method	Exact method
Molina & Framinan	2009	Mixed integer programming	Exact method
Xiao et al.	2016	stochastic programming	Exact method
Cardoen et al.	2010	Mixed integer programming Multicriteria optimization	Heuristic method
M'Hallah & Al-Roomi	2014	simulation	Heuristic method
Li & Yang	2009	simulation and SOMO algorithm	heuristic
Tànfani & Testi	2010	0–1 linear programming	heuristic
Li & Yang	2009	mixed integer programing, simulation	heuristic
Jerbi & Kamoun	2011	mixed integer programing, simulation	Exact method
Saremi, Jula, ElMekkawy, & Wang	2013	Tabu search	heuristic

4. Discussion

The results of this review paper showed that, the most important performance metrics for a heart surgery ward are surgeon and PACU staff preferences, PACU staff idle time, surgeons overtime, patient waiting time on the waiting list and on the day of surgery. Several researchers mentioned the significance of these metrics for OR planning [4, 17, 22], however, to the best of the writer knowledge no OR planning models have been proposed that consider all these matrices together.

Several researchers [6, 17] optimize OR planning by dividing it into two phase namely, planning phase and a scheduling phase. All of these researchers considered each phase separately, however, according to Lin et al. (2012), in reality not only each phase interact with the others but also the objectives of each phase interact with each other [22]. They described that a bad schedule in planning phase will influence on the efficiency of scheduling phase. Therefore, this review paper will open a new perspective in planning and scheduling operating rooms for hospitals that wants to enhance their efficiency, based on the results of previous studies.

The surgery scheduling problem involves several conflicting objectives, such as patient satisfaction and operational cost. Optimize one objective have effect on other objectives. In traditional approaches to improving multiple objective optimizations try to convert the multi-objectives into a single objective in which can obtain one global optimal point but many disadvantages exist when we scalarize objectives, such that the priority vector is playing a key role in the final solution, and some alternative solutions may not be available to decision makers without changing the priority vector. Some techniques for optimization used like goal programming, tabu search, genetic algorithms, and simulated annealing to be used multiple objectives.

Discrete event simulation is one of the powerful tools to evaluate the health care as complex systems and answer "what

if" questions. Many studies are used to apply DES in health care operations [9]. It help managers in hospitals to include most of the randomness in reality but practical questions are often seeking optimum values for the decision variables and thus exploratory process for optimal solutions is needed.

Simulation optimization is the process of finding the best values of some decision variables for a system where the performance is evaluated through simulation [15]. It overcomes the problems to find the efficient optimal solution to incorporate randomness and guides the simulation. There have been many studies to effort to apply simulation optimization in health care because of the uncertainty in this area [21].

In real-world production environments scheduling must be done often to achieve several objectives simultaneously. Multi-objective optimization aims at optimizing several performance criterion of an objective function vector. These types of problems differ from the single-objective problem, in a sense that the multi-objective problem does not have a single best solution. One of the approaches to deal with these solutions is the Pareto method. In this approach, a set of solutions known as the Pareto-optimal solutions are usually formed. Any solution of this set is optimal with respect to certain condition that is no improvement can be made on one objective without degrading the other objective of the vector [27]. Pareto Front is the line joining the minima of each of the Pareto points.

In previous researches waiting time and overtime were conflicting objectives; there is a need for human judgment to find a balance between them. Waiting time is a critical indicator to patient satisfaction. Waiting time is the time that patient must wait beyond their scheduled appointment time on day of surgery [24]. On the other hand, overtime is related to surgeon performance. Overtime is the positive difference between the latest end time of every surgery of an OR-day and the end time of regular working hours, for that OR-day [17]. Therefore minimizing the 50 bove two performance measures enhances the efficiency in a direction which most of the today's operating rooms aim at.

Many techniques were developed [17, 28] to deal with multi-objective fitness functions ranging from naive combination methods to game theory strategies. Some of the well-known approach applied to multi-objective planning and scheduling problems on health care are weighed sum approach, constrain methods and goal programming.

There have been several efforts in developing simulation optimization models for solving problems in healthcare management in the last decade, though none has been found in surgical scheduling. Tanfani et al., [11] designed a decision support system for the operation of an emergency department that uses simulation optimization to determine the optimal number of staff to maximize patient throughput and to reduce patient time in the system subject to budget constraints. Katzberg et al (2006) introduced an approach by integrating simulation optimization for appointment scheduling in health care [18].

Saremi et al. (2013) used generalized DEA as a selection function in GA to find efficient frontiers in deterministic multi-objective optimization problems [26]. This is similar to that developed by Yun et al. (2001) except that other use discrete-event simulation to evaluate multiple performance measures for a given design point like Roland et al., (2000) and also this framework has been introduced with Rung-Testi et al., (2009) for resource allocation in operating rooms [14, 16]. There have been attempts in the literature to combine DEA and simulation in a mutually supporting role. For example, Guerriero (2011) developed a three- stage process to improve the performance of operating units [6]. Lee et al., for instance, considered a multi-objective ranking and selection problem, where there is multiple performance measures associated with a design point [25]. They define a performance index indicating the extent to which a design point is non-dominated and define a simple procedure to allocate simulation replications subject to a limited simulation budget. One notable study is by Lee et al., who developed a multi- objective simulation optimization framework integrating genetic algorithm with a multi-objective computing budget allocation method to solve an aircraft spare parts allocation problem [25]. In their framework, they define a performance index, which measures the probability that a design point is non-dominated, and use this index to evaluate the fitness of a design point in the GA selection process.

5. Conclusion

This review paper looked at the basic definition of terminologies in the field of planning and scheduling in different wards of hospital. The review also looked at literature on various methods for planning and scheduling in this area. Particularly, the current methods for operating rooms were reviewed, and the review has revealed the extent and gap of research in the field of planning and scheduling in operating room and the gap in research. We conclude that no instant solution or model for our problem is available from the literature to cover all critical objective and also interaction between PACU and ORs. It is suggested to develop latest model and design several alternatives for improving the surgery scheduling system.

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Biography

Mehdi Askarizadeh was born in Shiraz-Iran. He finished his Bachelor in field of industrial engineering in 2008 from Shiraz Azad University then got his industry management Master degree in 2011 at same university in Iran. He has several years' experience as head of project control before he entered to University Putra Malaysia for his PhD degree at Industrial engineering in 2014.

Associate Professor. Dr. **Faieza Binti Abdul Aziz** is a Senior Lecturer at Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, UPM. She graduated in B. Eng. (Hons.) Mechanical Engineering in 1995 from University of Bradford, UK. She has several years working experience as a Product Engineer before she pursues her Master degree in Mechanical Engineering. She obtained her PhD in Systems Engineering from Cardiff University, UK in 2006. She is involved in teaching Manufacturing Engineering modules for undergraduate as well as postgraduate degree.

Associate Professor Ir. Dr. **Mohd Khairol Anuar bin Mohd Ariffin** is a lecturer in Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia. He took his PhD. In field of Mechanical in University of Sheffield, United Kingdom.

Dr. **Siti Azfanizam Binti Ahmad** is a lecture Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia