International Journal of Business & Economic Strategy (IJBES)
Vol.5, Issue 1, pp. 158-165

Surgery case scheduling in a multistage operating room department: A literature review

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***Abstract*—Operating room planning and scheduling decisions play a key role in hospital management system while the operating theater is known as a highly strategic service in a hospital given it is the most expensive and complex sector. It involves both human and material resources. The operating theater interacts with other facilities such as the Public Health Unit (PHU), Intensive Care Unit (ICU), and/or Post-Anesthesia Care Unit (PACU). So, it is required to integrate the adjoincing facilities in the planning and scheduling decisions to improve the global performance.**

It is noted that a few authors addressed the operating theater planning/scheduling problem by considering PHU, PACU, and/or ICU as a stage of service or a resource. Also the research that studied literature reviews have presented detailed classifications of researchs based on research methodology, policy, decision models, resolution approaches and decision levels.

In this search, we presented the works which studied the surgery case scheduling in a multistage operating room deparement.

Keywords*—*Scheduling, Planning, Multistage, Operating theater, Literature review

I. INTRODUCTION

The management of operating room department has been widely the subject of many studies. It indicated that this area consists one of the most important sectors in a hospital which constitutes a melting pot between different systems and different actors.

Generally the methodologies for scheduling surgical problem include two sub-problems: the first step allowsthe allocation of surgeries to the operating rooms. In the second step, the surgeries are sequenced within each operating room.

The two subproblems are often treated as separate combinatorial optimization models.

An operating room departement involves three stages: Public Health Unit (PHU), Operating Rooms (OR) and Post-Anesthesia Care Unit (PACU).

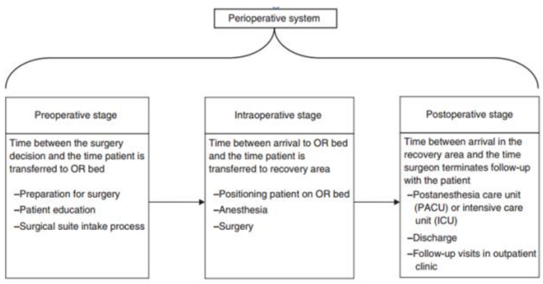

Fig. 1 The overall surgery process

Before the presentation of the previous studies, we describe the operating room process which manifested in three phases:

Pre-operative phase

This phase starts by decision to have surgery from the surgeon. Examinations or medical tests or administrative procedures may be required. It is often considered as a planning problem oriented on a strategic level.

A. The actual intraoperative phase

It seems as the most important part of the operating process which required different resources: operating rooms, recovery rooms, biology laboratories, sterilization facilities, surgical teams, surgical equipment, administrative services, logistics services, radiology and clinical

ISSN : 2356-5608
4ème Conférence internationale sur le commerce, l'économie, Marketing & Management Research (BEMM-2016)

services consultations. During this phase, patients are first anesthetized and transferred to the operating room where surgical teams will operate them. After being operated on, they will be transferred to the recovery room and stay there until the permit anesthesiologists to return to their hospitalization or intensive care areas. It is oriented on a tactical level that it concerns the scheduling of a master surgery.

B. The post-operative phase

After leaving the operating room, the patient will be directed to the inpatient department or to intensive care and resuscitation if the state of patient is critical. During this phase, all the care required is covered.

Many of the studies in literature focus in the actual intraoperative phase itself however other facilities of the surgical suite can affects the efficiency and the quality of service. Literally, there are closed intgaration between the OR on the one hand and preoperative and postoperative facilities on the other hand. For instance, if the PACU leads to patient backing up in ORs, causing longer than anticipated turnover times between surgeries. This could result in overtime or surgery cancellations.

The integration can also be inferred from the ICU rejection rate, which can mount up to 24% for elective cases [1]. Without close coordination with ICU, a scheduled elective case can be rejected on its surgery day owing to a full ICU, resulting in unused OR time and negative impact on the patient. Hence, only with regard to the whole OR suite's activities can an efficient use of resources be achieved.

Weinbroum, Ekstein and Ezri [2] identified the cause of OR idle time during the stages of surgery: 17% in PHU, 65% in OR which is portionned in: 30% in nurse shortage, 15% in PACU or ICU, 10% in surgeon unavailability and 3% in Transport. This study shows that is useful to take into account all necessary resources involved by the overall surgery process to enhance the utilization of operating theatre facility.

It is evident that integration must exceed facilities of the same hospital to covert multi-facility or multi-theater operating room planning and scheduling that are effectively emerging. This integration increased complexity both in formulation and in computation of the decision process. Therefore, this last seems as one of major reasons to see that almost half of the contributions limit their scope to an isolated operating theater.

In this study, we reviewed recently papers on operating theater planning and scheduling. We analyzed only the contributions which study the operating theater in interaction with other facilities on various levels. Sever surgery flow stages and various resources considered in OR management allows a comprehensive evaluation of scheduling result.

The recovery area can be the bottleneck for operating theater at certain times. Therefore, resources such as PACU, ICU and other hospital beds required after surgery and staff should be considered during the scheduling process [3].

II. SURGERY CASE SCHEDULING WITH INTEGRATION OF RECOVERY AREA

Many researchers have used simulation methods to analyze more complex multi-OR surgical environments with recovery areas. Schmitz et al. [4] used simulation to analyze a multi-OR surgical suite with recovery rooms to determine the number of ORs to open on a day given that the number of surgeries to be performed is known. They also study the impact of an increase in the number of ORs on recovery room usage and determine the need for recovery room capacity given that some of the surgeries are done in the outpatient setting.

Kwak et al. [5] test 5 simulation scheduling rules based on period's response and alarm clock. The authors do not determine the best rule scheduling but show that the choice of a rule has an impact on the rate use of OR and recovery area.

Kharraja et al. [6] consider the problem as a flow-shop hybrid with locking constraint, the patient remains in the operating room as a recovery bed is not available. They propose a heuristic approach with a goal of minimizing the makespan of the recovery room.

In [7], the autors use lagrangian relaxation for the scheduling of the ORs, recovery room and the rooms' clean-up activities with "no-wait" constraint. The objective to be minimized is a sum of the criteria: a criterion per patient and that is a function of the completion time of all activities related to this patient.

Fei et al. [8, 9] propose a genetic algorithm to minimize the makespan both of the recovery room than the operating rooms, with suggestion that thewake-up can start in the operative room.

In the first article [8], assuming that the allocation already respects the availability of the surgeons, so the scheduling does not question the assignment of patients to the operating rooms while in a second article [9] additional constraints for surgeons are taken into account so the assignment of patients to the operating rooms may be difficult in order that interventions of the same surgeon will be planned for the same period.

Cardoen et al. [10] propose a multi-objective model for the daily ambulatory surgery scheduling of a big Belgian hospital. Among their objectives the minimization of additional time in two recovery phases.

In their research, Hamilton and Breslawski [11] provided a complete inventory of potentially important factors to consider during the operative programming procedure. They identified several types of constraints. They considered the number of beds available in the recovery room and the availability of medical equipment as hard constraints. Criteria to optimize such as the number of expected events, the start time and the desired sequence of surgeries. Some other factors come from operating room environment management include late arrivals of staff, provision of incomplete patient records and lack of supplies which shows that good management involves solving organizational problems.

III. SURGERY CASE SCHEDULING IN A TWO-STAGE OPERATING ROOM DEPARTMENT

Guinet and Chaabane [12] study the advanced and allocation scheduling independently with objective functions respectively the minimization of waiting time and the operating room overload. The advanced scheduling was described as a planning model while the allocation scheduling was modelled as a hybrid flow-shop for two stages with constraint "no waiting" between stages, but no solution approach is attempted.

The same authors treated a similar two subproblems treated in [13], they focus primarily in the assignment phase. They study the scheduling problem with the possibility of change the assignment of patients to rooms and with the assumption of operating rooms identical. Using a heuristic based on the algorithm of Gilmore and Gomory, they try to optimize the makespan of the recovery room. Availability of surgeons and surgery’s time-window constraints are considered in their work. Both studies [12,13] consider a single recovery room. They supposed that the recovery beds are always available despite recovery stage is integrated in their models.

Like the work of Guinet and Chaabane [12], Jebali et al. [14] conserved the same objective function in the advanced scheduling and the same hybrid flow shop model for two stages in the allocation scheduling to minimize the total overtime.

They revolved the recovery bed availability as additional constraints. The authors developed a solution procedure based on this distinction. In the assignment step, they try to minimize overtime, undertime and patient waiting time between surgery and hospitalization day, whereas the objective in the sequencing step is limited to minimization overtime. Both objective functions are formulated in terms of costs and are optimized using a mixed integer programming approach.

Núñez et al. [15] treated a surgery case scheduling in a two stage operating room including the post anesthesia recovery to minimize the makespan. They considered all resources and the emergency surgeries in their study.

The work [16] elaborated a model for a surgical planning and scheduling problem. Their model allowsto decide during a given planning horizon the assignment of wards and ORs. Different resource constraints are considered such as maximum allowable overtime, length of stay of patient, available equipments and number of wards and ICU beds.

Marcon and Dexter [17] have investigated how sequencing surgical cases can affect the performance of the ORs and post PACU. Specifically, the sequence in which a surgeon performs cases in an OR on one day is taken into account and different sequencing rules, borrowed from the classical scheduling theory, are considered and tested.

The search of Hsu et al. [18] focus also in the sequencing phase.They founded a two-stage flow shop deterministic model for appointment scheduling of an ambulatory surgery clinic with no wait constraint. The first stage performed the operating rooms with considering the surgeons as main resource whereas the second stage performed the recovery room with considering the nurses as the main resource**.** They proposed a tabu search based heuristic approach in order to minimize the makespan of the last patient in a single PACU and the number of nurses associated with this unit.

Dexter et al. [19] evaluate strategies in order to minimize delays in admission into the PACU from ORs. These delays cause blocking in the ORs due to full or insufficiently staffed PACU beds. According to their study, the best practice is to adjust PACU staffing on the day of surgery by asking nurses to work overtime or getting help from qualified nurses of other departments, since the benefits of having scheduled cases performed outweigh the costs of working overtime due to PACU admission delays.

Kim and Horowitz aim to simplify the admittance of the ICU and to minimize the rate of canceled elective surgeries caused by ICU bed shortages without affecting the waiting times of other patients who are seeing admission to the ICU [20].

Fei et al. [21] addressed a weekly operating theatre planning and scheduling separately. The advanced scheduling was represented as a multi-objective mathematical model with the objective functions maximizing utilization, minimizing cost caused by the overtime and idle time in surgery. Then, a daily scheduling problem was defined as a two-stage hybrid flow-shop problem with the same objectives.

For the stochastic nature of two stage scheduling problems, the works of Denton et al. [22,23appear the most interesting].In [22], Denton and Gupta proposed a two-stage stochastic appointment scheduling model. The objectives of their model are expected patient waiting time, expected OR idle time and expected overtime respecting a defined length of day. The authors use a continuous distribution to present the durations of surgeries. They developed an iterative approximate approach based on upper and lower bound whose goal is to establish the best start times of surgeries.

Denton et al. [23] developed a two-stage stochastic MIP model. They presented uncertainty in surgery duration by different scenarios.Their objective to minimize the maximum cost that may generated by the uncertainty of the surgery duration.

IV. SURGERY CASE SCHEDULING IN A MULTI-STAGE OPERATING ROOM DEPARTMENT

Since the operating room schedule related with other facilities in the hospital, researchers also attented, to a smaller extent, to the utilization of resources other than the operating room aiming to cover all the overall surgery process.

In Chaabane et al. [24], the authors extend their approach in [12] by considering the stretcher as third stage flow-shop hybrid with precedence. The authors performed a comparative study of several scheduling rules and identify the best.

Lowery [25] modeled patient flow through a hospital's critical care units involving ORs, ICU and PACU beds. Using discrete event simulation, they established the requirement number of beds for these recovery units.

Augusto et al. [26] developed an open scheduling strategy as a four-stage flow-shop scheduling problem comprising the preoperative stage and the transporting stage. They measured the impact of allowing patient recovery in the operating room when a recovery bed is not available, which makes realistic model. They considered operating rooms, transporters and recovery beds, however other personnel resources constraints were not identified.

Darvish et al. [27] introduced a fuzzy model for an open shop scheduling problem with fuzzy processing times and fuzzy due dates to minimize total completion time and total weighted tardiness during the three stages of surgery process.

Yih et al. [28] focused on generating an optimal surgery schedule of elective patients in multiple operating theatres, which considered three stages: the preoperative, operative and post operative. The problem consists of assigning patients to different resources at each surgical stage in order to minimize the satisfaction of patients.

Saremi et al. [29] addressed the apppoitment scheduling of a specified number of patients in order to minimize the waiting time of patients, completion time and number of cancellations. The cancellation account for the patients who could not be served due to the lack of time or resources. They considered several patient types with stochastic service time in any stage whose arrivals are punctual. In addition, the problem considers resources such as available ORs and available beds in PACU.

They proposed three simulation based tabu search method for outpatient scheduling in OR department. They integrated the simulation model with metaheuristics since the simulation technique allows the study of large systems and to study the behavior of a dynamic system

Adan et al. [30] investigated Stochastic Length of Stay (LOS) for intensive care unit ICU and medium care unit MCU for fundation of the Thorax Centre Rotterdam.They used to compare their approach with that of Vissers et al. [31] that considered deterministic LOSs for ICU and MCU. The applied approach led to substantial savings, 20% reduction in number of days and up to 20% increase in operating room utilization.

Pham and Klinkert [32] considered the scheduling problem as a generalized job-shop with the objective of minimizing the makespan. They taked into account the operating rooms, the recovery area, ICU and surgical team. They use programming mixed numbers for resolution.

Their work seems as the most complete schedule until now.They integrated all resources associated with an entire surgery. Although they grouped the human resources into defined modes that bounded the combination of resource allocation, resources such as nurses, anesthetists can be open to the different specialties of surgeries in OR management unlike surgeons who can only be available to specific surgery and to a specific time window.

Based on the work of Pham and Klinkert [32], W.Xiang et al. developed recently many interested searchs which solve a case surgery problem in a three-stage departement room. In their first paper [33], their attempt is to remedy the inconvenience of the work of Pham and Klinkert by making constraints closer to the actual operating theater among the three stages. Their approach handles both the advanced and allocation scheduling problems simultaneously. In other search [34], W.Xiang and al. proved the advantage of integrating the surgery scheduling with the nurse scheduling among the three-stage surgery flow. To solve the surgery scheduling problem with daily nurse roster, an efficiently an ant colony optimization ACO was proposed.

W.Xiang et al. [35] are not limited to solve only a mono-objective surgery scheduling problem but also they presented a multiobjective model with multiple objectives of minimizing makespan, overtime and balancing resource utilization. They considered multiple resources required in the complete process surgery. In [36] Wei et al. the same authors proposed a modified ant colony optimization (ACO) approach to efficiently solve the same model which they are developed in [33]. Three benchmark cases are built based on the raw data from hospital with different surgeries problem size and resources availability. The modified ACO algorithm is compared with the scheduling generated by a simulation approach on SIMIO on those three test cases. Numerical results indicate the effectiveness of the algorithm in makespan, overtime and the variation coefficient of working time.

V. REVIEW METHOD OF SOLVING THE SURGERY CASE SCHEDULING IN A MULTISTAGE OPERATING ROOM DEPARTEMENT

The combinatorial nature of the surgery scheduling problem makes it computationally difficult to solve it optimally. The problem becomes more difficult when different with the consideration of several specialities and resources for all three surgery stages in the surgery scheduling model. As a consequence heuristics or meta-heuristic procedures are often developed to efficiently solve the problem.

Niu et al. [37] use simulation model in which scenarios are tested with adapted resource capacities. They study the variation of the patient stay ' length depending on change of number of ORs, holding unit capacity and beds in the PACU or transporters.

Ozkarahan [38] introduced a goal programming model for scheduling surgeries in operating theater. Multiple objectives treated in her model such as OR utilization, surgeon preferences and ICU capacity. A goal is identified for each of these objectives. This works aims to minimize the deviations from these goals.

Mathematical programming methods are well applied in the surgery case planning and scheduling literature. Taking into consideration the resulting consumption of multiple resources such as the ICU, PACU and ward or holding unit, Mulholland et al. [39] use a linear programming (LP) model to optimize financial outcomes for both the hospital and physicians under the capacity constraints of general care beds, ICU beds, operating room times and recovery room times. Microsoft Excel Solver was used to determine the optimal mix of surgical procedures to maximize hospital total margins plus professional payments and to apply a sensitivity analysis study.

Using a sample average approximation method, Min and Yih [40] solved a stochastic programming model for case scheduling. They studied OR and surgical intensive care units that consider multiple specialities. However, the model did not present the intake procedure and other resources such as surgeons, equipment and nurses are ignored.

To minimize the required number of nurses and the completion time in the PACU, Hsu et al. [17] proposed a heuristic approach which solves two subproblems interactively. The first finds the minimum number of PACU nurses subject to a given upper bound of makespan and the second minimizes the makespan at a fixed number of PACU nurses.

W.Xiang et al. [33,34,35] use an Ant Colony Optimization algorithm to solve the surgery case scheduling. The ACO algorithm has a capacity to adapt in robust and complex environment. Since the ACO approach was adapted to solve the surgery case scheduling problem in all recently works of Wei et al., future research can be in the direction of developing other metaheurists.

Sandberg et al. [41] suggested a new design for operating room suite design for technologically intensive surgeries with an intake room and early recovery area attached to the OR. With this new structure, the objective is to introduce anesthesia induction in the induction room while the OR is prepared for surgery. Early recovery is provided by an additional perioperative nurse while the anesthesia personnel can move to the intake of the next patient.

VI. CONCLUSIONS

This paper presented a review of recent studies on operating theater planning and scheduling. We classify the literature review according to whether they studied the operating theater in integration it with other facilities. These interactions have thus far not received much attention in the literature. Only a few consider together OR and PACU, while the interaction with PHU was not really dealt until now.

Throughout the literature review, we identify that planning and scheduling in a multi-stage operating room departement deserves further study in the future. They are incited by the aim of overall surgery stages' optimization in parallel to minimize overtime and maximize throughput.

Further research is required to analyze the impact of new design, which will likely lead to opportunities to improve the efficiency of surgery scheduling.

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