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Surgical Theater Utilization and PACU Staffing

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***Abstract*—**In this work, the surgical theater of a local hospital in KSA was analyzed using simulation. The focus was on attempting to answer questions related to how many Operating Rooms (ORs) to open and to analyze the performance of the surgical theater in general and mainly the Post Anesthesia Care Unit (PACU) to assist making decisions regarding PACU staffing. The surgical theater consists of ten operating rooms and the PACU unit which has a maximum capacity of fifteen beds. Different sequencing rules to sequence the surgical cases were tested and the Longest Case First (LCF) were superior to others. The results of the different alternatives developed and tested can be used by the manager as a tool to plan and manage the OR and PACU.

***Keywords*—**Operating room, post anesthesia care unit, PACU staffing, sequencing, healthcare.

I. Introduction

A surgical operation is comprised of two main stages as shown in Fig. 1. The first stage is the operative stage which takes place in the operating room. This stage splits into three phases: the first phase is preparing the operating room for surgery; the second phase is the surgical procedure itself; and the third phase is cleaning the operating room. The surgical procedure begins with the patient setup and anesthesia, followed by surgery. The second stage is the post anesthesia stage which starts after the surgical procedure and takes place in the recovery room where the patient is monitored until complete recovery [12, 16, 23].

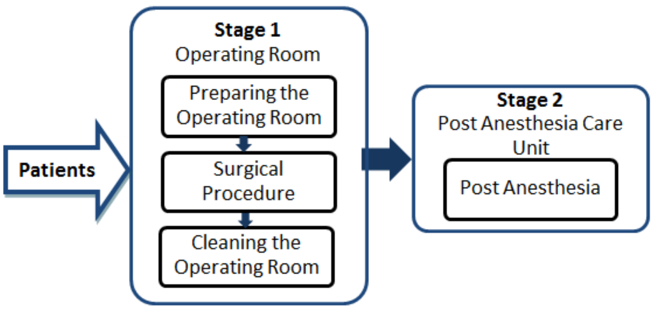

Fig. 1 Surgical operation stages

Operating room time is typically assigned to surgeons on a first come first serve (FCFS) basis (open scheduling) or a block basis (block scheduling). Open scheduling is a system where surgeons/surgical specialties compete for operating room time and the operating room time is assigned to surgeon/surgical specialty based on first come first serve basis. Block scheduling is a system where a block of operating room time is reserved for an individual surgeon or a designated group of surgeons. The given surgeon may hold several different blocks of time over a week and the blocks remain constant from week to week. Block scheduling is the frequently used method for scheduling cases in the operating room; however to increase flexibility of the schedule, blocks may be released 1, 2, or 3 days in advance and opened to other surgeons on first come first serve basis which result in a scheduling system that is a mix between open and block scheduling [9, 21]. Block scheduling is considered in this study; the sequencing of cases inside each block and the block start time were studied.

Post Anesthesia Care Unit (PACU) is the first step after the surgical procedure takes place. In addition, the high impact and relationship between the operating room and the PACU make this a relevant extension for studying the operating room. In most hospitals, the surgical procedure may halt unless there is both an available PACU room and PACU nurse at the end of the surgical procedure. If the surgical procedure has finished and no PACU room or PACU nurse is available, the patient will be held in the operating room until there is availability in the PACU. In both cases, the expensive operating room time will be wasted. Therefore, the scheduling of operating rooms with consideration of PACU will improve efficiency of the whole system.

A comprehensive review of the literature of the surgical theater problem was provided by Cardoen et al. [4] where they reviewed the recent operational research on operating room planning and scheduling; in part of their review they classified the literature on whether they studied the operating room alone or integrate it with other facilities.

Whichever approach used to analyze the surgical theater, it is of great importance to have accurate estimation of the times each surgical case uses in the different steps inside the surgical theater. One of the most important times to accurately estimate is the procedure duration. It is of great importance because it will help to efficiently allocate operating room time, estimate the starting time of procedures which helps in determining the sequence in which these procedures will be performed. Different approaches in the literature were used to estimate procedure times. Jebali et al. [16] used a log-normal distribution to estimate the procedure time with fixed minimum and maximum operating time and fixed setup and clean up times. Spangler et al. [22] presented an empirical study of methods for estimating the location parameter of the log-normal distribution to estimate surgery procedure times. Charnetski [7] used historical data along with Monte-Carlo Simulation to estimate the procedure times by operation type. Dexter et al. [11] assumed the case durations follow log-

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normal distribution. Macario et al. [19] used different statistical methods to estimate the case durations and they used bias and precision to assess the accuracy of the estimates. Bowers et al. [3] used the historical data to estimate the operating time distributions, but they didn't consider any setup or clean up times. In this work we estimated all the times needed for each step/process inside the surgical theater using 1 year of historical data for a local hospital.

Operating room sequencing decisions and its impact on operating room efficiency has been extensively addressed in the literature [5, 6, 8, 15, 17]. Sequencing decisions are important because they smooth the flow inside the operating rooms and will help determine the start time of cases. Jones et al. [17] developed an interactive simulation model for the management of the surgical. Huschka, et al. [14] described a discrete event simulation model for a newly designed surgical suite at Mayo Clinic. They investigated the impact of scheduling heuristics and daily surgical mix on performance measures. Gul, et al. [13] used simulation to evaluate 12 different sequencing and patient time appointment heuristics; one of their findings is that longest process time case first rule result in high overtime and shortest case first performs quite well

Few papers in the literature have studied the operating room in integration with the PACU, but recently there is more focus and emphasis on this integration. Hsu et al. [14] described a deterministic approach to schedule patients in an outpatient surgical center to minimize PACU nurses; their approach is applicable for a surgical theater of no more than six operating rooms. Dexter et al. [10] demonstrated that a reduction in the recovery time of PACU patients is unlikely to substantially decrease the number of PACU nurses. They note that standards set by The American Society of Post-Anesthesia Nurses (ASPAN) allow a PACU nurse to simultaneously care for several patients which implies that the number of PACU nurses needed in any given day depends on the peak number of patients during that day. Thus, they suggest that scheduling optimally the surgeries of individual patients in the operating suites to regulate patient flow from the suites to the PACU could potentially reduce the peak number of PACU patients and therefore reduce the number of PACU nurses.

Lowery [18] built a model to simulate the flow of patients through a hospital's critical care units including the operating room, PACU, and the intensive care unit with the objective of determining the critical care bed requirements. Barnoon et al. [2] used simulation to study the advantages and disadvantages of various schedules of the operating room. Marcon et al. [20] studied the impact of sequencing rules on PACU staffing and over-utilized operating room time resulting from delays in PACU admission. They tested seven sequencing rules over a wide range of scenarios and they concluded that the best rules are those that smooth the flow of patients entering in the PACU and they advice against using the Longest Case First or equivalent sequencing methods because they generate more over-utilized operating room time requiring more PACU nurses.

The work presented in this work focuses on studying the OR, the PACU, and the relation between them for a local hospital in KSA. After interviewing the hospital we identified two main problems to attempt to solve: 1) Study the impact of different sequencing rules on the utilization of the OR and the surgical theater (OR and PACU) with the goal of improving utilization and smooth the flow of surgical cases between the OR and the PACU. 2) Due to shortage of staff in the PACU, this work will study the flow of operation between the OR and PACU and recommend a sequencing rule for surgical cases inside each room and a level of operation for the surgical theater that will assist the OR manager in setting up a schedule the optimize the staff schedule and availability to serve cases; the PACU staffing schedule will be planned based on the number of occupied beds in the PACU and the ratio of nurse to patients per hospital policy and surgical operations' needs.

The analysis are done on weekly basis while taking the days into consideration; this way the OR manager can produce a schedule for the PACU staffing that is flexible, i.e. doesn't have to be the same schedule each day. The results of this work will present the OR manager with alternatives that combine decision on the sequencing rule, number of ORs to open, and the PACU staffing.

II. Problem Description

A. Hospital Background

The hospital under study is one of the largest and reputable hospitals in KSA. The hospital has fifteen ORs. Five of the ORs are dedicated for caesarean section surgery for baby delivery and kidney related cases; those five rooms will not be included in this analysis.

The surgical theater consists of a holding room, ORs, and PACU unit. The holding room has a capacity of ten beds and it is where the cases are prepared for surgery before entering the OR where the surgical act takes place. The PACU unit has a capacity of fifteen beds.

The surgical theater main working hours are from 8:00AM to 5:00PM six days a week from Saturday to Thursday.

Cases for different specialties are performed in the surgical theater; these specialties are: Bariatric, CVT, Dental, ENT, General Surgery, Gynecology, Neurosurgery, Oncology, Ophthalmology, Orthopedics, Pediatric Surgery, Plastic Surgery, Urology, Vascular Surgery, Maxillofacial, Endoscopy.

The hospital follows a block scheduling policy. OR time is assigned for each specialty. However; if the OR time is not filled then the hospital uses FCFS policy to schedule the surgical cases to fill the OR available time.

Each case goes through a sequence of steps from their arrival till they leave the PACU. It starts by being called into the holding room so the patient can be prepared for surgery and for last minute tests if needed, and then transferred to the OR, and once the surgical procedure is finished patients are moved to the PACU which after that they are released from the hospital or transferred to their bed depending on the case.

Fig. 2 shows the steps that takes place inside the surgical theater.

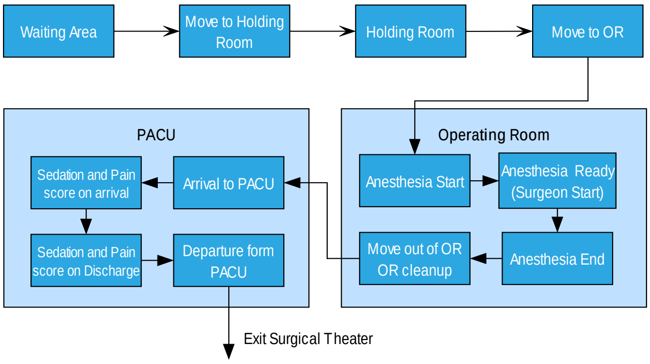

Fig. 2 Flow of process inside the surgical theater

Data were collected on the time needed for each step that takes places inside the surgical theater in addition to the OR scheduled time and the actual time that was consumed by each case from the OR time. Scheduled OR time is the estimated time needed from OR time for each case.

B. Data Collection and Analysis

Data were collected for one full year. Two weeks of data (Holiday break) were excluded in which the surgical theater wasn't scheduling any cases except emergency and urgent cases. The data collected were for over five thousands-five hundred surgical cases that were scheduled and performed during the year.

The hospital classifies cases that represent the demand for the OR into elective, urgent, and emergency. Elective cases represent 86.5% of the cases performed, and urgent and emergency cases represent 3.9% and 9.6% respectively. Table I shows the percentage of elective, urgent, and emergency cases performed for each specialty during the year under study.

The data were also analyzed to find the demand of each specialty from OR time for each working day from Saturday to Thursday; Table II shows the demand for each specialty as a percentage for each day.

The surgical theater has a master schedule for OR time available each week. The master schedule shows the available OR for each day and to which specialty the blocks of OR time in each room is assigned to.

Each case for each specialty is classified based on its complexity into Minor, Intermediate, or Major.

TABLE I
PERCENTAGE OF ELECTIVE, URGENT AND EMERGENCY CASES PERFORMED

	% Elective	% Emergency	% Urgent
Bariatric	94.35	5.65	0.00
CVT	90.45	4.49	5.06
Dental	99.61	0.00	0.39
Endoscopy	88.89	11.11	0.00
ENT	97.08	2.16	0.76
General	89.54	6.56	3.90
Gynecology	60.73	33.79	5.48
Maxillofacial	91.89	8.11	0.00
Neurosurgery	83.94	15.15	0.91
Oncology	92.54	4.48	2.99
Ophthalmology	97.06	2.21	0.74
Orthopedics	81.27	8.89	9.84
Pediatric	67.35	25.45	7.20
Plastic Surgery	76.92	16.72	6.35
Urology	92.41	3.79	3.79
Vascular Surgery	89.66	6.03	4.31
Total	86.50	9.59	3.91

The following information needed to for the simulation model was obtained by analyzing the hospital's data:

- Travel time from the waiting room to the holding room. Time distribution was estimated for all cases regardless of the specialty and the complexity of cases.
- Case duration in holding room.
- Travel time from the holding room to the OR. The travel time distribution was estimated for all cases regardless of the specialty and the complexity of cases.
- Travel time from the OR to PACU. The travel time distribution was estimated for all cases regardless of the specialty and the complexity of cases.
- Setup/Cleanup time. Time spent in setting up/cleaning up the OR to make it ready for the next case.
- OR scheduled time. It is the estimated time the surgical operation will take from the OR time. Usually it's estimated by the surgeon and the OR manager.
- OR actual time. OR actual time represents the actual OR time consumed by each case. The distribution of OR time used was collected for each specialty and complexity.
- PACU time. Duration of each case in the PACU unit. The PACU time was estimated for each specialty.
- Complexity percentage for each specially.

TABLE II
PERCENTAGE OF SPECIALTIES DEMAND FOR OR TIME FOR EACH DAY

	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
Bariatric	10.5	9.6	9.4	20.6	15.6	34.2
CVT	14.5	22.3	20.5	22.4	16.7	3.7
Dental	18.6	2.9	24.2	19.6	3.5	31.1
Endoscopy	19.9	15.9	19.4	17.7	18.3	8.9
ENT	16.5	13.9	18.7	31.1	12.9	6.9
General Surgery	8.1	40.2	3.0	33.4	7.0	8.4
Gynecology	27.3	29.1	18.2	10.9	10.9	3.6
Maxillofacial	21.2	2.6	32.3	5.2	37.4	1.2
Neurosurgery	19.2	17.7	16.1	16.6	16.0	14.3
Oncology	7.3	3.7	39.3	9.9	20.2	19.7
Ophthalmology	10.7	20.3	18.8	18.4	21.9	9.9
Orthopedics	22.0	26.4	2.8	23.7	23.8	1.3
Pediatric Surgery	16.9	25.9	15.8	21.6	11.3	8.4
Plastic Surgery	9.8	7.5	61.7	15.8	4.5	0.8
Urology	10.4	11.9	29.9	11.9	35.8	0.0
Vascular Surgery	16.9	25.9	15.8	21.6	11.3	8.4
Total	15.9	17.0	19.2	19.6	16.7	11.6

- Elective cases are scheduled during the main working hours of the surgical theater. Emergency and urgent cases might arrive during the main working hours or any time after 5:00PM. Since the model will focuses on the main working hours of the surgical theater; any urgent or emergency case that arrive after 5:00PM or finishes before 8:00 will be excluded. The excluded cases represent 32% and 24% from emergency and urgent cases respectively.

C. Simulation Model

Simulation was used to evaluate and model the surgical theater. ARENA Simulation software Version 13.5 by Rockwell Automation Inc 2010 [1] will be used to model the weekly/daily operations of the surgical theater. Description of the simulation is as follows:

1. The OR time available will be based on the Master Schedule provided by the hospital.
2. The weekly OR time needed will be generated. The distribution of OR time weekly demand was estimated using the historical data. 51 weeks' worth of data were analyzed to estimate the amount of OR time needed
3. Cases will be generated based on the weekly and daily demand of each specialty from OR time.
4. Each generated case will be assigned a set of times needed by the model which are: travel time from the waiting room to the holding room, case duration in holding room, travel time from the holding room to the OR, travel time from the OR to PACU, and a Setup/Cleanup time
5. Each generated case will be classified based on specialty. There are sixteen specialties which are: Bariatric, CVT, Dental, ENT, General Surgery, Gynecology, Neurosurgery, Oncology, Ophthalmology, Orthopedics, Pediatric Surgery, Plastic Surgery, Urology, Vascular Surgery, Maxillofacial, Endoscopy. The percentage of cases from each specialty on each day from Table II will be used to classify the cases
6. Each case for each specialty will be classified into elective, urgent, or emergency using the percentages in Table I.
7. The emergency and urgent cases that do not take place during the main working hours of the surgical theater will be eliminated. They represent 32% and 24% from emergency and urgent cases respectively
8. Each case in each specialty that takes place during the main working hours of the surgical theater will be classified based on complexity to minor, intermediate, or major.
9. Each case will be assign a scheduling OR time. The scheduled OR time is based on the specialty and the complexity. The scheduling OR time will be used to add the generated case to the OR case list.
10. Each generated case will be assigned an actual OR time based on specialty and complexity. The Actual OR time is the duration of time that the case will use the OR.
11. Each generated cases is assigned a PACU time.
12. Different sequencing rules were tested to sequence the cases inside the OR. The rules are: First come First Served (FCFS) (in the order the cases were received and scheduled), Shortest Case First (SCF), and longest case first based on the OR scheduled time.

In the simulation model, Cases are processed through the surgical theater following steps shown in Fig. 2.

III. Experimental Set Up and Procedure

The main goal of this work is to evaluate the current status of the surgical theater and to recommend a solution to assist in staffing the PACU and improve the utilization of the surgical theater.

The developed simulation was used to study different scenarios of running the surgical theater. The parameters that were changing are the number of OR and the sequencing rule to sequence the surgical operations inside each room for each day.

The model developed will study the performance of the OR for the different alternatives for each working day in the week to enable the scheduler to estimate the amount of demand in the PACU based on which he/she will staff the PACU.

The current status is that OR scheduler will add cases to the case list of the OR assigned for each specialty. The OR scheduler will follow the master schedule to load cases to the master schedule. Even though the master schedule shows an average of six OR open each day, two additional rooms are used to accommodate the level of demand they are facing. In this work the initial model will be based on the available ORs from the master schedule; however different scenarios will be studied by adding extra OR in increment of 1 at each time up to a maximum 3 extra room to see the impact on the surgical theater utilization and the PACU usage.

Different sequencing rules namely FCFS, SCF, LCF were used to surgical theater based on the available ORs in the master schedule and at each increase in the available ORs. SCF and LCF use OR scheduled time to rank cases.

IV. Results and Discussion

Results presented on this section are obtained from running the simulation model for 2000 replication. The model developed and used is terminating simulation because during the open hours of the surgical theater finite number of cases were generated and classified according to specialty, complexity, and nature of demand. The reference point/alternative for the results and analysis is based on FCFS sequencing rule and using only the specified ORs in the master schedule (i.e. six operation rooms).

Table III shows the percentage increase/decrease in the surgical theater completion time for all the cases for each sequencing rule and for different incremental increase in the available number of ORs. Table IV, Table V, and Table VI show the maximum number of cases that are present in the PACU in each hour of the day for the different sequencing rules

Table III indicate that the solution the hospital takes by opening more OR to satisfy the demand for the OR and complete cases during the surgical theater works based on the result from FCFS and the addition of extra ORs. For example, under FCFS, the surgical theater can finish all the cases for Saturday with a reduction of 12% by increasing the number of ORs available by 3. The increase in the number for ORs will help in reducing the completion time because more cases can be performed at the same time since all the cases for the day are available for surgery at the beginning of the day.

Comparing the completion time for the different sequencing rules; the LCF outperforms the other sequencing rules. The reduction in the completion time is almost the same regardless of how many ORs are added under the LCF rule which means the hospital can reduce the completion time by 15% without opening any extra rooms compared to 12 % using FCFS and adding additional three ORs. Fig. 3 shows the weekly average reduction/increase in the completion time for the different sequencing rules.

The next step is to find the maximum number of cases that are present in the PACU for the recommended solution which is using LCF and without opening any additional ORs. Tables III, IV, and V will give the OR manager a view of the maximum number of cases in PACU at each hour which will allows him to pick the sequencing rule, number of rooms to open on each day and the PACU staffing based on the number of cases in PACU

Fig. 4 shows the number of maximum cases in PACU for each hour of the day for each day of the week. The graph shows the data for FCFS and LCF without adding additional OR and with the addition of 2 ORs. These scenarios represent the current policies in place and the suggested ones.

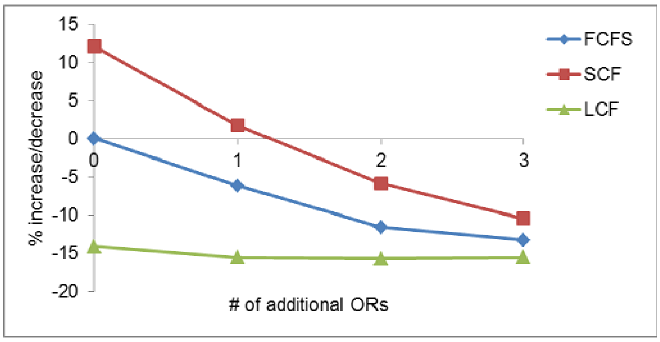

Fig. 3 Average week reduction/increase in completion time

TABLE III
PERCENTAGE INCREASE / DECREASE IN THE SURGICAL THEATER COMPLETION TIME

Day/Additional ORs	FCFS				SCF				LCF			
	0	1	2	3	0	1	2	3	0	1	2	3
Saturday	0.0	-6.6	-10.5	-12.0	9.5	-1.9	-8.1	-10.3	-12.0	-14.6	-14.6	-14.6
Sunday	0.0	-8.0	-11.9	-13.4	14.1	-1.0	-4.6	-8.8	-11.9	-13.4	-13.4	-13.4
Monday	0.0	-6.7	-12.6	-16.3	13.1	5.9	-8.2	-11.1	-17.7	-17.7	-19.6	-19.6
Tuesday	0.0	-6.4	-14.1	-15.2	9.8	2.9	-10.9	-13.6	-18.0	-21.9	-22.0	-22.0
Wednesday	0.0	-6.4	-10.3	-11.8	11.1	0.0	-4.7	-8.6	-10.3	-11.8	-11.8	-11.8
Thursday	0.0	-3.9	-12.2	-13.9	14.9	3.6	-0.6	-13.6	-15.1	-15.1	-15.1	-15.1
Weekly Avg.	0.0	-6.1	-11.6	-13.3	12.1	1.7	-5.8	-10.5	-14.2	-15.6	-15.8	-15.6

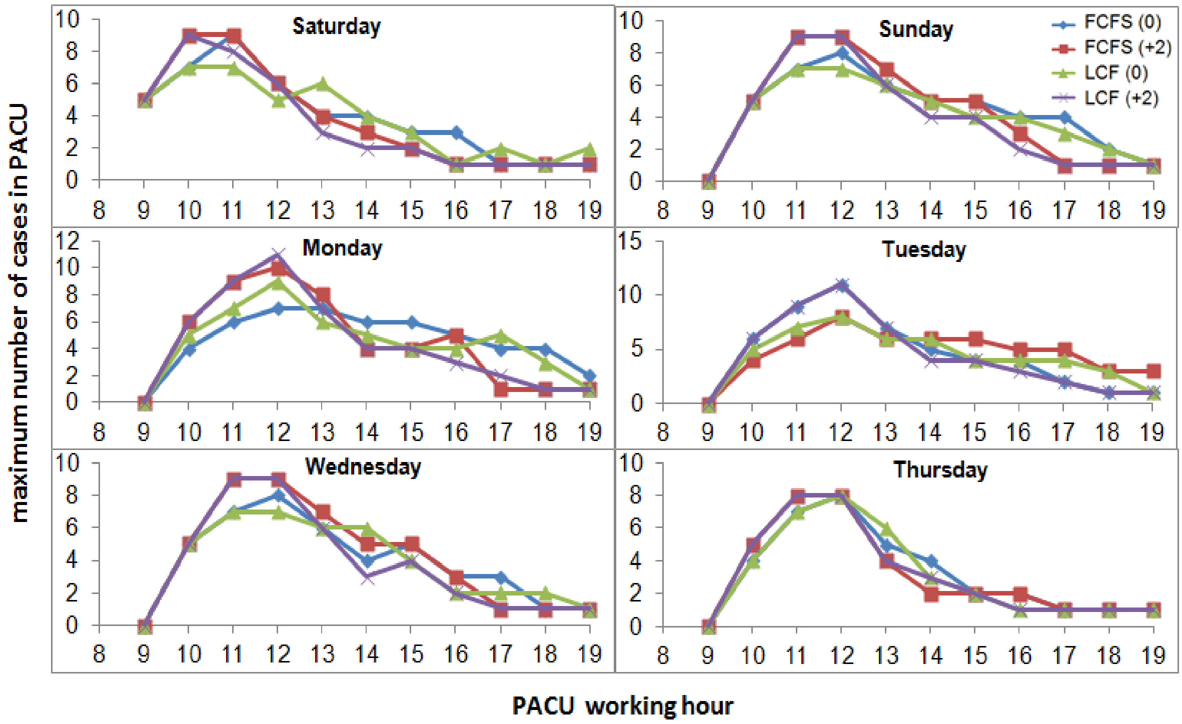

Fig. 4 Number of cases in PACU for FCFS and LCF

TABLE IV
MAXIMUM NUMBER OF CASES PRESENT IN PACU PER HOUR FOR EACH DAY FOR FCFS SEQUENCING RULE

Time/ Add./ OR	Saturday				Sunday				Monday				Tuesday				Wednesday				Thursday			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
9:00 AM	5	5	5	6	5	5	5	5	4	4	6	6	4	4	6	6	5	5	5	5	4	4	5	5
10:00 AM	7	8	9	8	7	8	9	8	6	8	9	9	6	8	9	9	7	8	9	8	7	7	8	8
11:00 AM	9	9	9	11	8	10	9	10	7	9	10	12	8	10	11	12	8	10	9	10	8	8	8	8
12:00 PM	6	6	6	6	6	7	7	6	7	7	8	7	6	7	7	8	6	7	7	6	5	4	4	4
1:00 PM	4	4	4	4	5	5	5	4	6	5	4	6	6	5	5	6	4	5	5	4	4	3	2	2
2:00 PM	4	4	3	2	5	5	5	4	6	6	4	5	6	6	4	5	5	4	5	3	2	2	2	2
3:00 PM	3	3	2	1	4	5	3	2	5	4	5	4	5	4	4	4	3	4	3	2	2	3	2	2
4:00 PM	3	1	1	1	4	2	1	1	4	4	1	1	5	4	2	2	3	2	1	1	1	1	1	1
5:00 PM	1	1	1	1	2	1	1	1	4	2	1	1	3	2	1	1	1	1	1	1	1	1	1	1
6:00 PM	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1
7:00 PM	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1

TABLE V
MAXIMUM NUMBER OF CASES PRESENT IN PACU PER HOUR FOR EACH DAY FOR SCF SEQUENCING RULE

Time/	Saturday				Sunday				Monday				Tuesday				Wednesday				Thursday			
Add. OR	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
9:00 AM	5	5	5	5	5	5	5	5	4	4	4	5	4	4	4	5	5	5	5	5	4	4	4	4
10:00 AM	6	7	7	7	7	8	8	8	7	8	9	9	7	8	9	9	7	8	8	8	6	7	8	8
11:00 AM	7	8	9	10	7	7	9	11	7	9	9	10	7	9	9	10	7	7	9	11	8	8	8	9
12:00 PM	7	7	7	6	6	7	9	8	6	7	9	11	6	7	9	11	6	7	7	7	7	6	4	3
1:00 PM	7	7	7	6	6	9	5	8	5	6	9	7	6	6	9	7	7	7	5	8	5	3	3	3
2:00 PM	6	7	6	3	8	8	10	4	6	7	7	9	6	7	7	9	6	8	9	4	5	2	3	3
3:00 PM	6	8	2	1	7	8	2	1	7	8	10	2	6	8	9	5	7	9	2	1	5	2	1	1
4:00 PM	9	1	1	1	6	3	1	1	7	8	1	1	7	8	2	1	10	1	1	1	1	1	1	1
5:00 PM	1	1	1	1	5	1	1	1	10	1	1	1	6	3	1	1	1	1	1	1	0	1	1	1
6:00 PM	1	1	1	1	1	1	1	1	1	1	1	1	8	1	1	1	1	1	1	1	1	1	1	1
7:00 PM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

TABLE VI
MAXIMUM NUMBER OF CASES PRESENT IN PACU PER HOUR FOR EACH DAY FOR LCF SEQUENCING RULE

Time/	Saturday				Sunday				Monday				Tuesday				Wednesday				Thursday			
Add. OR	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
9:00 AM	5	5	5	6	5	5	5	5	5	5	6	6	5	5	6	6	5	5	5	5	4	4	5	5
10:00 AM	7	8	9	9	7	8	9	9	7	8	9	9	7	8	9	9	7	8	9	9	7	6	8	9
11:00 AM	7	8	8	10	7	9	9	9	9	8	11	10	8	9	11	12	7	8	9	9	8	8	8	8
12:00 PM	5	7	6	5	6	7	6	6	6	7	7	6	6	7	7	6	6	7	6	6	6	4	4	4
1:00 PM	6	4	3	3	5	4	4	3	5	4	4	4	6	4	4	4	6	4	3	3	3	2	3	3
2:00 PM	4	4	2	3	4	5	4	3	4	5	4	3	4	5	4	5	4	4	4	3	2	2	2	2
3:00 PM	3	2	2	2	4	3	2	2	4	5	3	3	4	4	3	3	2	2	2	2	1	1	1	2
4:00 PM	1	2	1	1	3	2	1	1	5	3	2	2	4	3	2	2	2	2	1	1	1	1	1	1
5:00 PM	2	1	1	1	2	1	1	1	3	1	1	1	3	1	1	1	2	1	1	1	1	1	1	1
6:00 PM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7:00 PM	2	1	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	1	1	1	1	1	1	1

V. CONCLUSIONS AND RECOMMENDATIONS

We attempted to solve two problems for the surgical theater related to OR utilization and PACU staffing. We developed a simulation model with different scenarios resulting from a mix of different sequencing rules and the number of open operating rooms. The results obtained from the developed simulation model for the hospital under study will provide the manager different alternatives to plan and schedule the surgical theater in three areas:1) number of operating rooms to open, 2) PACU staffing, and3) sequencing rule to sequence surgical cases. The different alternatives offer flexibility to tradeoff of the different parameters of the problem under study.

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REFERENCES

[1] Arena Version 13.5 – Year 2010 Rockwell Automation Solutions.
[2] Barnoon S, Wolfe H (1968) Scheduling a multiple operating room system. Health Services Research 3:272-285.
[3] Bowers J, Mould G (2004) Managing uncertainty in orthopedic trauma theaters. European Journal of Operational Research 154:599-608.
[4] Cardoen B, Demeulemeester E, Beliën J (2010) Operating room planning and scheduling: A literature review. European Journal of Operational Research 201:921-932.
[5] Cardoen B, Demeulemeester E, Beliën J (2009) Optimizing a multiple objective surgical case sequencing problem. International Journal of Production Economics 119:354-366.
[6] Cardoen B, Demeulemeester E, Beliën J (2009) Sequencing surgical cases in a daycare environment: An exact branch-and-price approach. Computers and Operations Research 36:2660-2669.
[7] Charnetski JR (1984) Scheduling operating room surgical procedures with early and late completion penalty cost. Journal of Operations Management 5:91-102.
[8] Denton B, Viapiano J, Vogl A (2007) Optimization of surgery sequencing and scheduling decisions under uncertainty. Health Care Manage Science 10:13-24.
[9] Dexter F, MacarioA, Traub R, Hopwood M, Lubarsky D (1999) An operating room scheduling strategy to maximize the use of operating room bock time. The Journal of the American Society of Anesthesiologists 89:1:7-20.
[10] Dexter F, Tinker J (1995) Analysis of strategies to decrease post anesthesia care unit costs. Anesthesiology 82:94-101.
[11] Dexter F, Traub R (2000) Statistical method for predicting when patients should be ready on the day of surgery. The Journal of the American Society of Anesthesiologists 93:4:1107-114.

[12] Ernst E, Lasdon L, Ostrander L, Dwell S (1973) Anesthesiologist scheduling using a set partitioning algorithm. Computer and Biomedical Research 6:561-569.

[13] Gul S, Denton B, Fowler J, Huschka T (2011) Bi-Criteria scheduling of surgical services for an outpatient procedure center. Production and Operations management 20:406-417.

[14] Hsu V, Matta R, Lee C (2003) Scheduling patients in an ambulatory surgical center. Naval Research Logistics 50:218-238.

[15] Huschka T, Denton B, Gul S, Fowler J (2007) Bi-criteria evaluation of an outpatient procedure center via simulation. Proceedings of the 2007 Winter Simulation Conference 1510-1518.

[16] Jebali A, Alouane A, Ladet P (2006) Operating rooms scheduling. International Journal of Production Economics 99:52-62.

[17] Jones A, Sahney V, Kurtoglu A (1978) A discrete event simulation for the management of surgical suite scheduling. Proceeding of the Annual Symposium on Simulation 263-278.

[18] Lowery J (1992) Simulation of a hospital's surgical suite and critical care area. Proceedings of the 1992 Winter Simulation Conference 1071-1078.

[19] Macario A, Dexter F (1999) Estimating the duration of a case when the surgeon has not recently scheduled the procedure at the surgical suite. Anesthesia and Analgesia 89:1241-1245.

[20] Marcon E, Dexter F (2006) Impact of surgical sequencing on post anesthesia care unit staffing. Health Care Management Science 9:87-98

[21] Murphy D, Sigal E (1985) Evaluating surgical block schedules using computer simulation. Proceedings of the 1985 winter Simulation Conference 551-557.

[22] Spangler W, Strum D, Vargas L, May J (2004) Estimating procedure times for surgeries by determining location parameters for the lognormal model. Health Care Management Science 7:97-104.

[23] Weissman C (2005) ,The enhanced postoperative care system. Journal of Clinical Anesthesia 17:314-322.