Master Surgical Schedule with Minimized Blocking Between Stages and Leveled Bed Occupancy

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Abstract

A master surgical schedule (MSS) determines the allocation of surgical specialties on operating rooms (ORs) over a time horizon. In this paper, an integer linear programming model is formulated to solve the problem of creating MSS while considering the downstream resources. The proposed model is concerned with the minimization of the number of possible blockings between intraoperative and postoperative stages and the minimization of variability in postoperative beds occupancy. The model includes constraints related to ORs, surgical groups, and nurses. The model is applied in a private hospital at Alexandria, Egypt. The results showed a reduction in number of blockings between stages and a balanced daily postoperative beds occupancy when compared to the hospital's current schedule. Additional analysis is carried out to show the effect of changing the number of arriving patients and the length of stay in the postoperative stage on the performance of the developed MSS.

Keywords
Master Surgical Scheduling, Block Scheduling, Integer Programming, Optimization

1. Introduction
Healthcare management in developing countries is an important issue since billions of US dollars are spent annually for improving and upgrading medical services. Hospitals face many challenges and constraints including limited resources, high cost of medical technology and medication, and high demand and customer needs for good medical services. Therefore, healthcare systems should focus on optimizing their processes to control and lower operation costs and enhance the provided service level (Abdelrasol et al. 2020). In hospitals the operating theatre, which includes operating rooms (ORs) and recovery rooms, is among the most critical and expensive resources. OR is considered a key hospital resource as 60–70% of hospital admissions are due to surgical interventions and it has been estimated that it represents more than 40% of the total hospital expenses (Guerriero et al. 2011). Hence, ORs planning and scheduling is crucial to assist in minimizing the operating costs and enhancing the utilization of the available resources.

OR planning and scheduling problem can be classified into three sub-problems, namely (1) Case Mix Problem (CMP), (2) Master Surgery Scheduling Problem (MSSP), and (3) Surgery Scheduling Problem (SSP) (Molina et al. 2015, Samudra et al. 2016). The CMP is a strategic level (long-term) sub-problem in which the allocation of OR time among the surgical specialties is addressed. While MSSP is a tactical level (medium-term) sub-problem in which the master surgical schedule (MSS) is developed to show the allocation of ORs on the surgical groups (Santibáñez et al. 2007). The MSSP has three strategies namely; open scheduling, block scheduling, and modified block scheduling (Fei et al. 2010, Bouguerra et al. 2015). SSP is the operational level (short-term) sub-problem in which the schedule of individual cases is determined. It determines the time, day, and the OR for each surgical case (Stuart et al. 2012, Heydari et al. 2016).

In an operating theatre, the preoperative process includes three stages: preoperative, intra-operative and post-operative stages. Preoperative stage is a preparatory stage before the surgery, surgeries are performed in ORs in the intraoperative stage, and patients are sent after surgery for recovery to post-anaesthesia care units (PACU) and intensive care units (ICU) in the postoperative stage. Assigning ORs to surgery groups should be synchronized with the occupancy of downstream resources (postoperative beds). If the occupancy reaches its maximum capacity, the patient cannot be sent from OR to the next stage and will stay in the OR until a bed is available. This means that a blocking has occurred between the intraoperative and postoperative stages. These blockings lead to lower OR utilization, increased waiting time, longer length of stay, unnecessary overtime (Abedini et al. 2017). Therefore, downstream resources should be considered while developing the MSS.

1.1. Objectives

The aim of this study is to propose an integer linear programming model to solve MSSP considering constraints related to ORs, surgical groups, and nurses. The proposed model determines the allocation of ORs on the surgical groups with the objective of minimizing the number of expected blockings between intraoperative and postoperative stages and minimizing the fluctuations in daily postoperative beds occupancy.

2. Literature Review

The deterministic mathematical models that support the production of master surgical schedule (MSS) are reviewed. Blake et al. (2002) illustrated a hospital's experience using an integer programming (IP) model to assign surgical groups to available operating room (ORs) within one-week horizon. The model's objective is to minimize the sum of undersupplied OR hours (the difference between the allocated hours and the targeted hours). Blake and Donald (2002) developed a straightforward enumerative algorithm (post-solution heuristic) to improve the MSS produced by the IP model presented in the previous work. Santibáñez et al. (2007) formulated a mixed integer programming (MIP) model to determine which days and ORs should be assigned to each surgical specialty at multiple hospitals in British Columbia Health Authority under two different objectives: minimizing the maximum daily bed utilization and maximizing the throughput of patients. The model was tested on several scenarios to identify block schedules that may result in a lower variability of bed utilization. In addition, they studied the benefits of creating joint block schedules for hospitals in adjacent geographical regions. Zhang et al. (2009) presented a MIP model to determine the weekly ORs schedule that minimizes the penalties due to delay in meeting surgery demand, unmet demand, and undersupply of OR hours to each specialty. A simulation analysis was used to assess the quality of the MIP solution in terms of inpatients' waiting time for surgery and OR utilization. Price et al. (2011) proposed an IP model to determine the surgical block schedule. The model's objective is to reduce post-anaesthesia care unit (PACU) boarding through balancing the patient inflow and outflow of the intensive care unit (ICU). They suggested rules of thumb to refine the schedule obtained from the IP model and used simulation model to compare the IP model schedule with alternative schedules. Visintin et al. (2016) used a MIP model and evaluated how flexible practices regarding the surgical teams, ORs, and surgical units can affect MSS efficiency in terms of number of scheduled surgeries. Yahia et al. (2014) introduced a MIP model to construct MSS that levels beds occupancy and nurse workloads. They also took into consideration the surgeons' preferences in their model. Li et al. (2017) suggested two mixed integer linear goal programming models to study the tactical elective surgery scheduling problem. The models aim at minimizing the number of waiting patients, the underutilization of OR time, the maximum expected number of patients in the recovery unit, and the expected range of patients in the recovery unit. They assessed the performance of the proposed models through a numerical study. Marchesi and Pacheco (2016) built a model to solve the problem of assigning specialties to ORs over one-week planning horizon. The proposed model minimizes the difference between OR time given to each surgical specialty and its demand and minimizes the unmet demand. They tested using a genetic algorithm in solving the proposed model. Abedini et al. (2017) introduced an optimization model to minimize the number of blockings between intraoperative and postoperative stages by using an IP model. The model allocates OR blocks to surgery groups in such a way that the postoperative occupancy does not exceed postoperative capacity. They used a simulation model to test the robustness of the model under presence of length of stay and number of patients per block variability. Table 1 summarizes the main characteristics of the mathematical model, solution approaches, and the model application in the papers reviewed in this section.

Table 1. Summary table of reviewed literature

Reference	**Blake et al. (2002)**	**Blake and Donald (2002)**	**Santibáñez et al. (2007)**	**Zhang et al. (2009)**
Considered Resources	ORs Surgical Groups	ORs Surgical Departments	ORs Surgical Specialities Beds	ORs Medical Specialties
Planning Horizon	One Week	One Week	4 Weeks	One Week
Model Formulation	Integer	Integer	Mixed Integer	Mixed Integer
Objective	Minimize undersupply	Minimize undersupply	Minimize maximum	Minimize penalties

Function(s)	of OR time	of OR time	daily bed utilization and Maximize throughput of patients	due to delay in meeting surgery demand, unmet demand, and undersupply of OR hours
Solution Approach	Exact	Exact+Heuristic	Exact	Exact+Simulation
Data for Application	Real Data	Real Data	Real Data	Real Data

Reference	**Price et al. (2011)**	**Visintin et al. (2016)**	**Yahia et al. (2014)**	**Li et al. (2017)**
Considered Resources	ORs Surgical Groups Beds	ORs Surgical Groups Beds	ORs Surgical Groups Nurses Beds	ORs Surgical Teams Recovery Unit
Planning Horizon	5 Weeks	Weeks	One Week	Days
Model Formulation	Integer	Mixed Integer	Mixed Integer	Mixed Integer Goal
Objective Function(s)	Minimize number of expected arrivals to ICU beyond expected number of discharges from ICU	Maximize number of scheduled surgeries	Minimize peaks in daily bed occupancy and in daily nurse workloads	Minimize number of waiting patients, underutilization of OR time, maximum expected number of patients in the recovery unit, and expected range of patients in the recovery unit
Solution Approach	Exact+Heuristic +Simulation	Exact	Exact	Exact
Data for Application	Real Data	Randomly Generated Data	Real Data	Randomly Generated Data

Reference	**Marchesi and Pacheco (2016)**	**Abedini et al. (2017)**	**This Paper**
Considered Resources	ORs Specialities	ORs Surgical Groups Beds	ORs Surgical Groups Nurses Beds
Planning Horizon	One Week	5 Weeks	4 Weeks
Model Formulation	Integer	Integer	Integer
Objective Function(s)	Minimize unmet demand and difference between OR time given to each surgical specialty and its demand	Minimize number of blockings between intraoperative and postoperative stages	Minimize number of blockings between intraoperative and postoperative stages and variability in postoperative beds occupancy
Solution Approach	Genetic Algrorithm	Exact+Simulation	Exact
Data for Application	Randomly Generated Data	Real Data	Real Data

Based on the explored literature, only one paper included the surgical nurses as a resource while building the MSS. In addition, none of the papers considered the availability of postoperative beds and levelling of daily postoperative beds occupancy while assigning ORs to surgical groups. Our proposed model is based on Abedini et al. model (Abedini et al. 2017). However, they did not consider the surgical nurses and levelling the daily beds occupancy in their model. Therefore, this study proposes an integer programming model to solve MSSP considering constraints related to ORs, surgical groups, and nurses. The proposed model minimizes the number of blockings between intraoperative and postoperative stages and minimizes the variability in postoperative beds occupancy.

3. Methods

3.1. Model Description

A new integer programming (IP) model is formulated to develop a master surgical schedule (MSS) over a planning horizon of D days. The proposed model assigns operating room (OR) blocks (block means one OR for the whole day) to each surgery group on particular days during the planning horizon. The models aim to reduce the possible blockings between intraoperative and postoperative stages and level the daily postoperative beds workloads. The model considers patients length of stay (LOS) and four important resources: (1) ORs: number of ORs available and their operating hours; (2): Surgeons: Surgery groups, group demand, group daily restrictions, and surgeries duration; (3) Surgical nurses: required nurses and available nurses; (4) Postoperative Beds: available beds and daily occupancy.

3.2. Model Assumptions

The following assumptions are considered:

- The operating rooms are multifunctional (can be used by any surgery specialty).
- The preferences of the surgeons are not considered.
- The surgical nurses are available for any specialty.

3.3. Model Elements

3.3.1. Indices

g — Index of surgery groups in the hospital and groups are categorized in order from the easiest to the hardest, $g \in G = \{1,2, \ldots, G\}$.

d, t — Index of days, $d \in D = \{1,2, \ldots, D\}$, $t \in T = \{1,2, \ldots, d-1\}$.

3.3.2. Decision Variables

b_{gd} — Number of OR blocks allocated to surgery group g on day d.

P_d — Number of patients in the postoperative stage on day d.

3.3.3. Model Parameters

h_g — Total number of OR blocks that surgery group g needs.

R — Number of available ORs in the intraoperative stage.

E_g — Expected number of patients per block for surgery group g.

m_g — Length of stay in the post-operative stage for surgery group g.

M_g — Minimum number of OR blocks allocated for surgery group g per day.

U_g — Maximum number of OR blocks allocated for surgery group g per day.

B — Number of available beds in the postoperative stage.

f_g — Required number of nurses per block for surgery group g.

N_d — Number of available nurses in the intraoperative stage in day d.

3.3.4. Objective Function

$$\mathrm{Min}\left(\sum_{d=1}^{d} |P_d - B| + \sum_{d=2}^{d} |P_d - P_{d-1}|\right)$$

The model's objective is minimizing the occurrence of blocking between intraoperative and postoperative stages and minimizing the peaks in daily postoperative beds occupancy. The objective function consists of two parts; the first part aims at minimizing the difference between the number of patients and available beds in the postoperative stage, while the second one aims at minimizing the difference between the daily postoperative stage occupancy.

3.3.5. Constraints

$\sum_d b_{gd} = h_g \quad \forall g$ **(1)**

$\sum_g b_{gd} \le R \quad \forall d$ **(2)**

$\sum_g f_g * b_{gd} \le N_d \quad \forall d$ **(3)**

$P_d = \sum_g E_g b_{gd} X_{gd} + \sum_{t<d}^{t} \sum_g E_g b_{gt} Y_{gt} \quad \forall d$ **(4)**

$X_{gd} = \begin{cases} 1 & \text{if } m_g > 0 \\ 0 & \text{Otherwise} \end{cases} \quad \forall d, g$ **(5)**

$Y_{gt} = \begin{cases} 1 & \text{if } m_g - (d-t) > 0 \\ & 0 \text{ Otherwise} \end{cases} \quad \forall g, t < d$ **(6)**

$M_g \le b_{gd} \le U_g \quad \forall g, d$ **(7)**

$b_{gd} \ge 0 \text{ and integer} \quad \forall g, d$ **(8)**

Constraint (1) shows that the total number of assigned OR blocks is equal to required number of OR blocks for each group. In constraint (2), the number of assigned OR blocks should not exceed the number of available ORs per day. In constraint (3), the required number of nurses per block for each surgery group g should not exceed the available number of nurses. Constraint (4) describes the occupancy of the postoperative stage on day d. The term $\sum_g E_g b_{gd} X_{gd}$ determines the number of patients sent from OR to the postoperative stage on day d and the term $\sum_{t<d}^{t} \sum_g E_g b_{gt} Y_{gt}$ determines the number of patients in the postoperative stage moved to day d from previous days. Constraint (5) defines the binary decision variable X_{gd}. X_{gd} is equal to one if LOS in the postoperative stage of group g is greater than zero (means that the patient will be sent to the postoperative stage). Otherwise, the patient will be sent to a bed in the hospital. Constraint (6) defines the binary decision variable Y_{gt}. Y_{gt} is equal to one if the patient still needs to stay in the postoperative stage. Otherwise, the patient should be sent to a bed in the hospital. Constraint (7) restricts the daily number of OR blocks assigned to each group between specified minimum and maximum number of OR blocks for each group. Constraint (8) illustrates that the number of OR blocks assigned to each group must be a positive integer.

4. Implementation of the Proposed Model

4.1. Case Description

The present model of operating room (OR) block scheduling is applied in a private hospital in Alexandria Governorate, Egypt. The hospital includes five departments (Critical Care Unit, Emergency Unit, Post Critical Care Unit, Outpatients Clinics Unit, and Internal Unit). The planning horizon is four weeks (6 days per week) and Saturday is the first day of each week. The staff works eight hours/day (8:00 AM to 4:00 PM). The specialties in the hospital is divided into three groups according to the average length of stay (LOS) in the operating theatre. Specialties in group one (Ophthalmology and Urology) have the shortest LOS, and the specialties in group two (General, Oral, Otolaryngology, Plastic, and Vascular) have a medium LOS, and finally the specialties in group three (Neurosurgery, Orthopedics, Surgical Oncology, and Thoracic) have the longest LOS. The average LOS in the postoperative stage for each surgery group is [1 1 2] days. The hospital has 16 beds available in the postoperative stage and five OR blocks available. The daily available number of nurses during the planning horizon is eight nurses except on Saturday seven nurses are available. Each surgery group needs [1 1 2] surgical nurse. The hospital is currently using a manually generated schedule for all surgeries. The creation and update of the manual schedule takes a long time.

4.2. Required Data

To obtain the surgery times for all specialties, we have collected the data of 200 surgeries from each specialty (during six months between March 2019 and August 2019) and assumed that there is half an hour for setup time and cleaning of OR (based on real information from the studied hospital). The average total time allocated for surgeries for each specialty and each group are summarized in table 2. The current master surgical schedule (MSS) of the hospital is shown in table 3. Table 4 shows the minimum and maximum daily OR blocks, daily number of patients per block, and the total number of required OR blocks for each group during the study period. Minimum, maximum, and total blocks are inputs from studied hospital data. The number of patients per block is computed by dividing the time available for surgeries by the average surgical total time of the group.

Table 2. Surgery allocated time

<table>
<tr><th>Group Number</th><th>Specialties</th><th>Average Surgical Times + Cleaning Time + Setup Time (Min)</th><th>Weighted Average Surgical Total Time (Min)</th></tr>
<tr><td rowspan="2">Group 1</td><td>Ophthalmology</td><td>118.9</td><td rowspan="2">160</td></tr>
<tr><td>Urology</td><td>190.71</td></tr>
<tr><td rowspan="5">Group 2</td><td>General</td><td>209.37</td><td rowspan="5">240</td></tr>
<tr><td>Oral</td><td>221.56</td></tr>
<tr><td>Otolaryngology</td><td>168.09</td></tr>
<tr><td>Plastic</td><td>224.08</td></tr>
<tr><td>Vascular</td><td>212.09</td></tr>
<tr><td rowspan="4">Group 3</td><td>Neurosurgery</td><td>259.66</td><td rowspan="4">240</td></tr>
<tr><td>Orthopedics</td><td>237.71</td></tr>
<tr><td>Surgical Oncology</td><td>255.82</td></tr>
<tr><td>Thoracic</td><td>232.38</td></tr>
</table>

Table 3. Manual master surgical schedule during 4-weeks horizon

<table>
<tr><th>Day</th><th>Sat</th><th>Sun</th><th>Mon</th><th>Tue</th><th>Wed</th><th>Thurs</th><th>Sat</th><th>Sun</th><th>Mon</th><th>Tue</th><th>Wed</th><th>Thurs</th></tr>
<tr><td>OR #1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td rowspan="2">Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td></tr>
<tr><td>OR #2</td><td>Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td>Gr.2</td><td>Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td></tr>
<tr><td>OR #3</td><td rowspan="2">Gr.3</td><td rowspan="3">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td>Gr.2</td></tr>
<tr><td>OR #4</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td>Gr.3</td><td rowspan="2">Gr.3</td></tr>
<tr><td>OR #5</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Day</td><td>Sat</td><td>Sun</td><td>Mon</td><td>Tue</td><td>Wed</td><td>Thurs</td><td>Sat</td><td>Sun</td><td>Mon</td><td>Tue</td><td>Wed</td><td>Thurs</td></tr>
<tr><td>OR #1</td><td rowspan="2">Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td rowspan="2">Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td></tr>
<tr><td>OR #2</td><td>Gr.2</td><td rowspan="3">Gr.2</td><td rowspan="2">Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td></tr>
<tr><td>OR #3</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td>Gr.2</td></tr>
<tr><td>OR #4</td><td>Gr.3</td><td>Gr.3</td><td>Gr.3</td><td>Gr.3</td><td>Gr.3</td><td>Gr.3</td><td rowspan="2">Gr.3</td></tr>
<tr><td>OR #5</td><td>Gr.3</td><td></td><td>Gr.3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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Table 4. OR block related data

Group #	Min. Blocks	Max. Blocks	Patient per Block	Total Required Blocks
Group 1	1	3	3	27
Group 2	1	3	2	40
Group 3	1	3	2	40

5. Results and Discussion

The model was coded and solved using Matlab (R2018a). Table 5 shows the optimized master surgical schedule (MSS) during the planning horizon. The results reveal that the number of days in which postoperative stage occupancy reaches or closes to the maximum number of available beds has significantly decreased in the optimized solution when compared to the manual solution. The number of expected blockings between stages has decreased approximately 70%. The reduction in number of blockings helps the hospital in serving more patients. Moreover, a balanced postoperative beds occupancy on daily basis was achieved in the optimized solution when compared with the manual solution (figure 1). This levelling helps the hospital in lowering congestion in the postoperative stage and absorbing unexpected number of patients.

Table 5. Optimized master surgical schedule during 4-weeks horizon

<table>
<tr><th>Day</th><th>Sat</th><th>Sun</th><th>Mon</th><th>Tue</th><th>Wed</th><th>Thurs</th><th>Sat</th><th>Sun</th><th>Mon</th><th>Tue</th><th>Wed</th><th>Thurs</th></tr>
<tr><th>OR #1</th><td rowspan="3">Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td><td>Gr.1</td></tr>
<tr><th>OR #2</th><td rowspan="2">Gr.2</td><td>Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="3">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="3">Gr.2</td><td>Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td></tr>
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<tr><th>OR #4</th><td>Gr.2</td><td rowspan="2">Gr.3</td><td>Gr.3</td><td rowspan="2">Gr.3</td><td>Gr.3</td><td></td><td rowspan="2">Gr.3</td></tr>
<tr><th>OR #5</th><td>Gr.3</td><td></td><td></td><td></td><td>Gr.3</td><td></td><td>Gr.3</td><td></td></tr>
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<tr><th>OR #2</th><td>Gr.2</td><td>Gr.2</td><td>Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="3">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td rowspan="2">Gr.2</td><td>Gr.2</td><td rowspan="2">Gr.2</td></tr>
<tr><th>OR #3</th><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td rowspan="2">Gr.3</td><td>Gr.2</td><td rowspan="3">Gr.3</td></tr>
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<tr><th>OR #5</th><td></td><td></td><td></td><td></td><td></td><td>Gr.3</td><td></td><td></td></tr>
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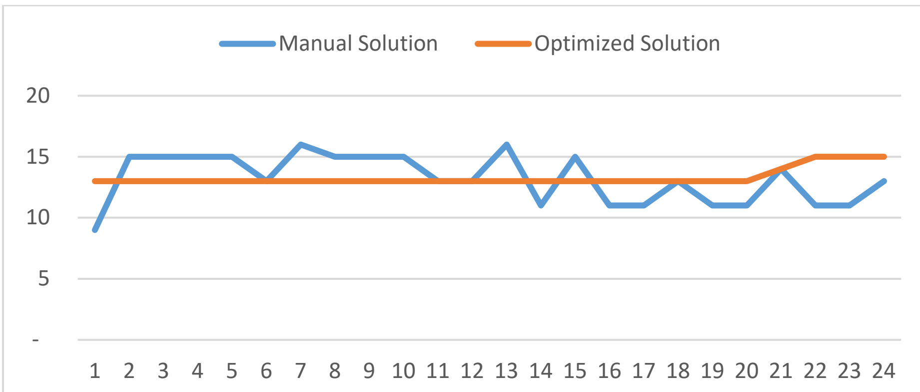

Figure 1. Daily postoperative stage occupancy of optimized and manual solution

Additional analysis is conducted to study the impact of changing the number of patients per block and length of stay (LOS) in the postoperative stage on model results. Two performance measures (average of postoperative beds occupancy and number of blockings between stages) are used to evaluate the constructed MSS. First, the effect of varying the number of patients per block is discussed. Four experimental cases are carried out representing the increase in expected number of patients per block in each surgery group and the increase in all surgery groups. Table 6 illustrates the results of the original case and the four different cases. In the first case, the postoperative beds occupancy and the number of blockings did not change significantly. However, in the second and third cases, the beds occupancy is almost at maximum capacity. In addition, the number of blockings between stages has significantly increased when compared with the original case. Finally, the model gave an infeasible solution in the case of changing the number of patients for all surgery groups.

Table 6. Effect of changing the number of patients per block

Patient per Block	Beds Occupancy Average	No. of blockings
[3 2 2]	13.29	3
[4 2 2]	14.42	5
[3 3 2]	14.96	20
[3 2 3]	15.92	23
[4 3 3]	----	----

Second, the influence of changing the LOS in postoperative stage is tested through four case studies. Table 7 shows the results of the original case and the four different cases. It was noticed that the model gave infeasible solution in the last case. While, in the other three cases, the postoperative stage occupancy is nearly full and the blockings between stages are expected to occur almost daily.

Table 7. Effect of changing the length of stay

Length of Stay	Beds Occupancy Average	No. of blockings
[1 1 2]	13.29	3
[2 1 2]	15.83	23
[1 2 2]	15.71	23
[1 1 3]	15.54	23
[2 2 3]	----	----

6. Conclusion

The Master Surgery Scheduling Problem (MSSP) involves developing operating rooms (ORs) schedule. The schedule shows the distribution of ORs on different surgery groups. In this study, an integer linear programming optimization model is formulated to solve the MSSP problem under block scheduling strategy. The objective of the model is to minimize the number of possible blockings between intraoperative and postoperative stages and to minimize the fluctuations in postoperative beds occupancy. The model takes into consideration the current postoperative occupancy of patients and the parameters related to ORs, postoperative beds, and surgical nurses. By applying the model in a private hospital, a reduction in number of blockings between stages and levelled beds occupancy were achieved. Additional analysis was carried out to give the hospital administration an overview on the effect of varying the number of patients per block and length of stay in the postoperative stage on the developed master surgical schedule. Increasing the number of patients per block has significantly increased the number of blockings between stages in nearly all cases. Also modifying the length of stay in postoperative stage led to occurrence of blockings between stages almost daily in all cases. Further work could be performed by including the preferences of surgeons, number of served patients, number of waiting patients, and costs to the proposed mathematical model. In addition, the use of a heuristic or meta-heuristic algorithm to solve the research problem could be investigated.

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