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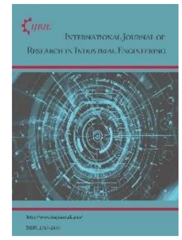

A Mathematical Model for Integrated Operating Room and Surgical Member Scheduling Considering Lunch Break

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ABSTRACT

Operating Rooms (ORs) are among the most influential departments of a hospital that a major portion of its expenditures and revenues originate from it. Due to the limited resources and the presence of different stockholders, effective management, and the optimal planning of this department are challenging. This paper develops a mathematical model to address the integrated problem of the operating room and surgical member scheduling with the objective of makespan minimization. In the proposed model, several aspects, including the availability and necessity of surgical members and equipment, and lunch break consideration, are incorporated. Finally, a case study related to an OR department in a general hospital is provided to assess the applicability and performance of the proposed model.

Keywords: Operating room, Nurse scheduling, Mathematical modeling, Lunch break.

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1. Introduction

The Operating Room (OR) department is among the essential foundations of hospitals, which plays an irreplaceable role in healthcare systems [1-3]. Due to limited medical resources, efficient management and planning of ORs lead to high-quality services to patients, surgical member satisfaction, and cost reduction as well [4]. In this regard, the proper scheduling of ORs is a major concern of hospital managers. In the OR scheduling, the optimal time and sequence of surgeries are determined for human and material resource availability [5, 6]. The presence of several ORs, many patients with different surgical requirements, many surgical members with various qualifications and preferences, limited capacity of equipment, safety consideration and upstream regulatory highly increases the complexity of OR scheduling problems [2, 7, 8]. To simplify the problem, many researchers have neglected some real-world aspects. However, having a comprehensive approach for integrated OR planning and scheduling results in more effective solutions. Accordingly, Meskens et al. [5] and Wang et al. [9] incorporated the preferences of surgical team members and affinity among them. Monteiro et al. [8] considered the objectives related to team building and skill diversification of nurses besides other common objectives in the OR scheduling. Vancroonenburg et al. [7] took into consideration all human resources and equipment in multi-day OR scheduling and provided an efficient heuristic for the problem.

Xiang [10] developed a multi-objective Ant Colony Optimization (ACO) algorithm for the problem considering three stages in the scheduling, including the procedures before, during, and after surgery. Hamid et al. [4] investigated the impact of surgical member decision-making styles on the compatibility of surgical teams. To do this, they presented a comprehensive mathematical model considering various constraints related to human and material resources. A heuristic method based on column generation was 2 devised by Akbarzadeh et al. [11] for the OR planning and scheduling, considering the nurse rerostering to address the difference between expected and real demand. Regarding the uncertainty of surgery durations, Breuer et al. [12] presented a robust optimization model for the integrated staffing and scheduling problem incorporating the impact of variability in surgery durations, the availability of staff, and emergency arrivals. Effective utilization and planning of human resources are major priorities for healthcare systems [13]. A real-world requirement, which has mostly been neglected in human resource scheduling, is lunch break consideration. Considering this fact leads to more realistic and applicable schedules.

A limited number of studies incorporated the lunch break in human resource scheduling, i.e., Brunner and Bard [14] in postal personnel scheduling, and Liu et al. [15] in a home healthcare routing and scheduling problem. Lim et al. [16] addressed lunch break assignment in the scheduling of OR nurses. They provided a framework, in which the assignments of nurses to surgeries based on their skills and their lunch break assignments are determined. This study deals with an integrated daily OR and surgical member scheduling, considering the availability of required surgery members and equipment as well as lunch break assignment. To assign outpatients (surgeries) to ORs, form surgical teams, and determine lunch break time for each surgical member, a mathematical model is developed to minimize the makespan. The proposed model is applied to a case study related to an OR department in a general hospital.

2. Problem Definition

This paper addresses the daily scheduling problem of outpatient operating rooms. As an outpatient is selected to undergo an operation, an operating room must be assigned, and his/her surgery must be scheduled to be started at a specific time of the day. Also, an available and capable surgery team consists of at least two nurses, one surgeon, and an anesthesiologist is formed for this surgery. For this purpose, four decisions must be made: (1) assignment of the surgeries to ORs, (2) formation of surgical teams to perform them, (3) setting a start time for each surgery, and (4) determination of lunch break for surgical members. The assumptions of the considered problem are defined as follows:

- Before the planning, the list of outpatients (surgeries) for the day and their associated surgeons are provided.
- OR setup times are neither dependent on the type of surgeries nor their sequences.
- The duration of surgery is considered deterministic and determined according to the average time of the surgery in the past.
- Since urgent patients are assigned to some dedicated ORs, they are not incorporated in this study.
- ORs have specific working times.
- The working time of all surgeons and the other members of surgical teams are known in advance.
- Surgeries are not interrupted.
- Responsible surgeon of each surgery is already predetermined.
- Pre- and post-operative units are not considered in this problem.
- No member of surgery teams can participate in more than one surgery at the same time.
- Time is discretized into 30-minute time slots.
- Since there is no shortage regarding post-anesthesia care unit, it is neglected in the problem.

To formulate the problem, the following notations are defined.

Indices and Sets.

r	Index of operating rooms, $r \epsilon \{1,2,\dots,R\}$.
s	Index of skills, $s \epsilon \{\text{surgeon}, \text{nurse}, \text{anesthesiologist}\}$.
n	Index of surgical members.
$N(s)$	Set of surgical members with skill s.
t	Index of time slots, $t \epsilon \{1,2,\dots,T\}$, where T is the number of time slots of an OR per day.
o	Index of outpatients (surgeries).
e	Index of equipment.
LT_{sn}	Set of time slots, in which surgical member n with skill s presents in the OR department and can have lunch.

Parameters.

B_o^s	Required number of surgical members with skill s for surgery o.
$dur(o)$	Duration of surgery o.
$A(s,n,t)$	If surgical member n with skill s is available in time slot t, it takes 1; otherwise, 0.
β_o^e	Required number of equipment e for surgery o.
A_t^e	Available number of equipment e in time slot t.
E_{ns}	1 if surgical member n with skill s is required to have lunch during the lunch break window (e.g., three-time slots from 12:00 to 13:30); 0, otherwise.
G	A large positive number.
λ_o^{sn}	1 if surgical member n who is a surgeon is determined for surgery o in advance; 0, otherwise.

Decision Variables.

X_{or}	1 if surgery o assigned to operating room r; 0, otherwise.
M_{ort}	1 if surgery o is being performed in operating room r within time slot t; 0, otherwise.
R_o^{sn}	If surgical member n with skill s is employed for surgery o.
Z_{otsn}	If surgical member n with skill s is employed for surgery o in time slot t.
S_o	Start time of surgery o.
C_o	Completion time of surgery o.
C_{max}	Completion time of the latest surgery in the day called the makespan.
N_{snt}	1 if surgical member n with skill s has lunch in time slot t; 0, otherwise.

According to the before-mentioned assumptions and notations, the problem is formulated below.

$$\text{Min } C_{max}. \tag{1}$$

s.t.

$$\sum_r M_{ort} \leq 1; \quad \forall t, \forall o. \tag{2}$$

$$\sum_o M_{ort} \leq 1; \quad \forall t, \forall r \tag{3}$$

$$\sum_r X_{or} = 1; \quad \forall o. \tag{4}$$

$$B_o^s = \sum_{n \in N(s)} R_o^{sn}; \quad \forall o, \forall \frac{s}{\text{surgeon}}. \tag{5}$$

$$\lambda_o^{sn} = R_o^{sn}; \quad \forall o, s = \text{surgeon}, \forall n \in N(s). \tag{6}$$

$$\sum_t M_{ort} = X_{or} \times dur_o; \quad \forall o, \forall r. \tag{7}$$

$$B_o^s \sum_r M_{ort} = \sum_{n \in N(s)} Z_{otsn}; \quad \forall o, \forall s, \forall t. \tag{8}$$

$$\sum_t Z_{otsn} \leq G \times R_o^{sn}; \quad \forall o, \forall s, \forall n \in N(s). \tag{9}$$

$$\sum_o Z_{otsn} \leq A(s, n, t); \quad \forall s, \forall t, \forall n \in N(s). \tag{10}$$

$$S_o \leq t \sum_r M_{ort} + G\left(1 - \sum_r M_{ort}\right); \quad \forall o, \forall t. \tag{11}$$

$$C_o \geq (t+1) \sum_r M_{ort}; \quad \forall o, \forall t. \tag{12}$$

$$\sum_{t}\sum_{r} M_{ort} = C_o - S_o; \quad \forall o. \tag{13}$$

$$\sum_{o}\sum_{r} \beta_o^e \times M_{ort} \le A_t^e; \quad \forall t, \forall e. \tag{14}$$

$$1 - G(1 - R_o^{sn}) \le \sum_{t \in LT_{sn}} N_{snt} \le 1 + G(1 - R_o^{sn}); \quad \forall s, \forall o, \forall n \in N(s) | E_{ns} = 1. \tag{15}$$

$$\sum_{o} Z_{otsn} \le 1 - N_{snt}; \quad \forall s, \forall t, \forall n \in N(s). \tag{16}$$

$$C_{max} \ge C_o; \quad \forall o. \tag{17}$$

$$R_o^{sn}, M_{ort}, X_{or}, Z_{otsn}, N_{snt} \in \{0,1\}; \quad S_o \ge 0, C_o \ge 0, C_{max} \ge 0. \tag{18}$$

Objective Function (1) minimizes the makespan. ***Constraints (2)*** ensures that in each time slot, for each surgery at most one OR is assigned. ***Constraint (3)*** indicates that in each time slot, in each OR, maximum one surgery is performed. ***Constraint (4)*** guarantees that exactly one OR is utilized for each surgery. If surgery is started in a specific OR and time slot, its required human resources, including nurses and anesthesiologist, must be determined and assigned (its surgeon is predetermined). This restriction is observed in ***Constraint (5)***. ***Constraint (6)*** assigns the 5 predetermined surgeons to their associated surgery. ***Constraint (7)*** shows that if a surgery is started in an OR, it occupies the required number of time slots of that OR.

Constraint (8) makes sure that the required surgical members of each surgery in each time slot are provided. ***Constraint (9)*** indicates that if a surgical member with a specific skill is not assigned to surgery, he/she will not be employed in any time slot for the respected surgery. ***Constraint (10)*** shows that if a surgical member with a specific skill is not available in a particular time slot, she cannot be employed for any surgery within the time slot. The start time and completion time of each surgery are determined in ***Constraints (11)*** and ***(12)***, respectively.

The number of occupied time slots for surgery is calculated based on the difference of its completion time and start time. ***Constraint (13)*** guarantees that these time slots are consecutive without interruption. The limitation of each equipment in each time slot is represented in ***Constraint (14)***. ***Constraint (15)*** determines the time slot for a lunch break for each surgical member who is required to have lunch. ***Constraint (16)*** relates that a surgical member cannot be employed in any OR during his or her lunch break. ***Constrain (17)*** calculates the makespan. ***Constraint (18)*** defines the variables of the model.

3. Case Study and the Numerical Result

To validate and implement the proposed model in a real-world problem, the surgery data related to a general hospital in a specific day was considered. For each surgery, two nurses, including one scrub and one circular nurse, one anesthesiologist, and one surgeon, are required. Also, some equipment like CARM and microscope might be needed. In this case, six surgeries must be done in Two ORs. The list of surgeries, their associated surgeons, and required equipment are provided in ***Table 1***. The working time of the operating department is from 8 to 16, which is equivalent to 16-30 minute slots. One CARM, four nurses, two anesthesiologists, and three surgeons are available. The availability times of surgical members are listed in ***Table 2***. Lunch break time is presumed from 12:00 to 13:30. The case is solved by coding the proposed model in GAMS software (solver CPLEX) on a system with Intel Hexa-Core i7-9750H 4.5 GHz CPU and 16 GB of RAM.

The Gantt chart of the optimal solution using GAMS is depicted in ***Figure 1***. For example, in ***Figure 1***, "3, Nu1, Nu4, An6, Su7" indicates that surgery No. 3 was done on OR1 with Nurse No. 1 and Nurse No. 4, anesthesiologist No. 6, and surgeon No. 7 from 12:30 to 15. Also, the Gantt chart of the proposed schedule by the OR director is presented in ***Figure 2***. It is noteworthy that the computation time for GAMS is 13.6 seconds, while the OR director spends about 5 minutes for planning. As shown in ***Figures 1*** and ***2***, the performance of the proposed model is superior to manual planning based on the makespan objective. Regarding the favorable solution quality and short computational time of the proposed model, it can be employed in OR management and scheduling as a useful and efficient tool.

Table 1. List of surgeries, their associated surgeons, and required equipment.

Surgery No.	Type of surgery	Duration of surgery (time slot)	Associated surgeon	Equipment
1	Osteoplasty tibia/fibula.	4	No. 7	CARM
2	Repair of shoulder rotator cuff tears.	4	No. 7	CARM
3	Treatment of distal fibula fractures.	5	No. 8	---
4	Treatment of distal fibula fractures.	5	No. 8	---
5	Thyroidectomy.	5	No. 9	---
6	Adjacent tissue transfer.	4	No. 9	---

Table 2. Availability times of surgical members.

No.	Skill	Availability time
1	Nurse	[8:00, 16:00]
2	Nurse	[8:00, 16:00]
3	Nurse	[8:00, 16:00]
4	Nurse	[8:00, 16:00]
5	anesthetist	[8:00, 16:00]
6	anesthetist	[8:00, 16:00]
7	Surgeon	[9:00, 16:00]
8	Surgeon	[8:00, 15:00]
9	Surgeon	[8:00, 16:00]

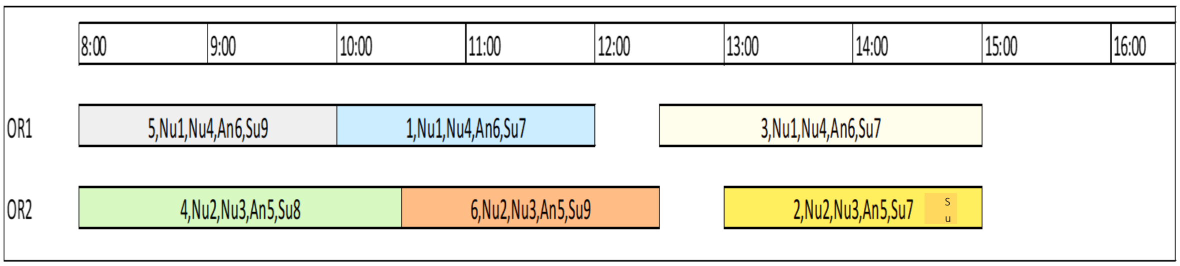

Figure 1. Gantt chart of the optimal solution using GAMS.

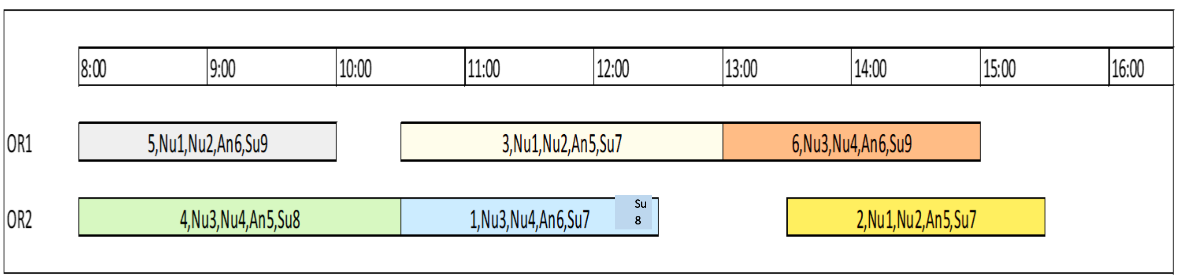

Figure 2. Gantt chart of the proposed schedule by the OR director.

4. Conclusion

This paper investigated an integrated OR and surgical member scheduling considering the limitation of human resources, equipment, and lunch break necessity. A mathematical model was devised to formulate the problem. The proposed model was applied to the scheduling of a surgical department in a general hospital. According to the result, the superiority of the model to manual scheduling both in the quality of the solution and computation time is evident. So, this model as a fruitful tool can aid OR directors for OR scheduling. For future research, the proposed daily model can be extended to a weekly model, considering some of the constraints affecting weekly models such as availability of ICU and ward beds. Also, as future work, we plan to provide some scenarios to gain more managerial insights regarding this problem. Another direction for extending this study can be considering uncertainties regarding surgery and recovery times, unavailability of human resources, and the arrival of emergency patients and using robust optimization approaches to tackle these uncertainties.

References

[1] Hamid, M., Hamid, M., Nasiri, M. M., & Talebi, A. (2017, February). A comprehensive mathematical model for the scheduling problem of the elective patients considering all resources and the capacity of the postoperative care unit: A case study. *13th international conference on industrial engineering.* https://civilica.com/doc/648708/

[2] Hamid, M., Hamid, M., Nasiri, M. M., & Ebrahimnia, M. (2018). Improvement of operating room performance using a multi-objective mathematical model and data envelopment analysis: A case study. *International journal of industrial engineering and production research*, *29*(2), 117-132.

[3] Hamid, M., Hamid, M., Nasiri, M. M., & Ebrahimnia, M. (2017). Improving surgical theater performance using an integrated and multi-objective mathematical model and data envelopment analysis: A case study. *3th international conference on industrial engineering.* Babolsar, Iran. https://civilica.com/doc/648715/

[4] Hamid, M., Nasiri, M. M., Werner, F., Sheikhahmadi, F., & Zhalechian, M. (2019). Operating room scheduling by considering the decision-making styles of surgical team members: a comprehensive approach. *Computers and operations research, 108*, 166-181.

[5] Meskens, N., Duvivier, D., & Hanset, A. (2013). Multi-objective operating room scheduling considering desiderata of the surgical team. *Decision support systems*, *55*(2), 650-659.

[6] Hamid, M., Hamid, M., Musavi, M., & Azadeh, A. (2019). Scheduling elective patients based on sequence-dependent setup times in an open-heart surgical department using an optimization and simulation approach. *Simulation*, *95*(12), 1141-1164.

[7] Vancroonenburg, W., Smet, P., & Berghe, G. V. (2015). A two-phase heuristic approach to multi-day surgical case scheduling considering generalized resource constraints. *Operations research for health care, 7*, 27-39.

[8] Monteiro, T., Meskens, N., & Wang, T. (2015). Surgical scheduling with antagonistic human resource objectives. *International journal of production research, 53*(24), 7434-7449.

[9] Wang, T., Meskens, N., & Duvivier, D. (2015). Scheduling operating theatres: Mixed integer programming vs. constraint programming. *European journal of operational research, 247*(2), 401-413.

[10] Xiang, W. (2017). A multi-objective ACO for operating room scheduling optimization. *Natural computing*, *16*(4), 607-617.

[11] Akbarzadeh, B., Moslehi, G., Reisi-Nafchi, M., & Maenhout, B. (2020). A diving heuristic for planning and scheduling surgical cases in the operating room department with nurse re-rostering. *Journal of scheduling*, 1-24.

[12] Breuer, D. J., Lahrichi, N., Clark, D. E., & Benneyan, J. C. (2020). Robust combined operating room planning and personnel scheduling under uncertainty. *Operations research for health care, 27*, 100276. https://doi.org/10.1016/j.orhc.2020.100276

[13] Hamid, M., Tavakkoli-Moghaddam, R., Golpaygani, F., & Vahedi-Nouri, B. (2020). A multi-objective model for a nurse scheduling problem by emphasizing human factors. *Proceedings of the institution of mechanical engineers, part h: journal of engineering in medicine*, *234*(2), 179-199.

[14] Brunner, J. O., & Bard, J. F. (2013). Flexible weekly tour scheduling for postal service workers using a branch and price. *Journal of scheduling, 16*(1), 129-149.

[15] Liu, R., Yuan, B., & Jiang, Z. (2017). Mathematical model and exact algorithm for the home care worker scheduling and routing problem with lunch break requirements. *International journal of production research, 55*(2), 558-575.

[16] Lim, G. J., Mobasher, A., Bard, J. F., & Najjarbashi, A. (2016). Nurse scheduling with lunch break assignments in operating suites. *Operations research for health care, 10*, 35-48. https://doi.org/10.1016/j.orhc.2016.07.001