ELECTIVE SURGERY SCHEDULING

OPTIMIZATION PROJECT

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INTRODUCTION

Hospitals are complex and expensive systems to manage. One department of particular interest that poses major managerial challenges is the operating room (OR) department. The OR department generates about 40–70% of revenues and incurs 20–40% of operating costs in a hospital. It also demands significant hospital resources and directly influences patient flow and efficiency of care delivery. Thus, hospital managers are constantly seeking better OR and surgery scheduling approaches to improve OR utilization, surgical care, and quality, as well as to minimize operational costs. Stochasticity is an intrinsic characteristic of OR and surgery scheduling problems since surgical activities are subject to multiple sources of uncertainty.

WHY OPTIMIZATION IS REQUIRED

1. **Maximizing Resource Utilization**: Operating rooms (ORs) are valuable resources in healthcare facilities, and maximizing their utilization ensures efficient use of infrastructure and staff. However, overutilization can lead to increased wait times, staff fatigue, and compromised patient care.
2. **Minimizing Overtime and Postponements**: Overtime costs can escalate quickly if surgeries overrun their scheduled time slots. Similarly, postponing surgeries can disrupt patient schedules and lead to dissatisfaction. Optimization aims to minimize both overtime and postponements while ensuring all surgeries are accommodated within the available OR blocks.
3. **Balancing Surgeon and Patient Preferences**: Surgeons may have preferences for specific time slots or ORs based on their schedules and preferences. Patients may also prefer certain surgery times for personal reasons. Optimization seeks to balance these preferences while adhering to operational constraints and minimizing costs.
4. **Ensuring Patient Safety and Quality of Care**: Scheduling surgeries in a way that prevents fatigue among staff and maintains high standards of care is paramount. Optimization considers factors such as adequate recovery time between surgeries, staff workload, and adherence to safety protocols to ensure optimal patient outcomes.
5. **Managing Variability and Uncertainty:** Healthcare systems are inherently unpredictable, with variations in surgery durations, patient arrivals, and emergency cases. Optimization models must account for this variability and incorporate robustness to adapt to changing conditions while maintaining efficiency and effectiveness.

PROJECT OVERVIEW

Here, we aimed to devise and solve a problem regarding the efficient scheduling of elective surgeries. Our objective is to minimize the total cost associated with performing surgeries, postponing procedures, and managing overtime, while optimizing the utilization of limited operating room resources over a fixed planning horizon.

ASSUMPTIONS

1. The hospital has a known set of elective surgeries (I) that need to be scheduled.

2. There are a fixed number of available OR blocks (B), each with a predetermined duration (L).

3. Each elective surgery (i) has a deterministic duration (d_i).

4. Emergency surgeries are not considered in this scheduling process.

5. The hospital incurs a fixed cost (c_i) for performing each surgery, and a higher cost (c_i') for postponing surgeries to the next planning horizon.

6. Overtime costs (c_o) are incurred if the cumulative duration of surgeries in a block exceeds the block duration.

METHODOLOGY

PARAMETERS

I: the number of elective surgeries (20 in this case)
B: the number of available OR blocks (10 in this case)
L: the duration of each OR block (300 minutes)
d: the duration of each surgery (a list of 20 values)
c: the cost of each surgery (a list of 20 values)
c_p: the penalty cost for not scheduling a surgery (a list of 20 values)
c_o: the cost of overtime per minute(5 in this case)

DECISION VARIABLES

y[i, b, p]: a binary variable indicating whether surgery i is assigned to block b at time slot p

t[b, p]: the start time of the surgery scheduled in block b at time slot p

o[b]: the overtime for block b

OBJECTIVE FUNCTION

Objective Function:

The objective function combines three components:

1. **Minimize surgery assignment costs (obj1):**
   - It sums up the costs of assigning each surgery to a specific block and time slot.
   - $\sum_i \sum_b \sum_p c[i] \cdot y[i, b, p]$
2. **Minimize penalty costs for unassigned surgeries (obj2):**
   - It sums up the penalty costs for surgeries that are not assigned to any block or time slot.
   - $\sum_i c_p[i] \cdot (1 - \sum_b \sum_p y[i, b, p])$
3. **Minimize overtime costs (obj3):**
   - It sums up the overtime costs for each block.
   - $c_o \cdot \sum_b o[b]$

The total objective function is the sum of these three components.

CONSTRAINTS

1. **Each surgery is assigned exactly once:**

$$\sum_{b=1}^{B} \sum_{p=1}^{B} y_{i,b,p} = \begin{cases} 1 & \text{if all surgeries must be scheduled without postponements} \\ \leq 1 & \text{if postponements are allowed} \end{cases}$$

   Explanation: For each surgery i, the sum of $y_{i,b,p}$ over all blocks b and time slots p should be equal to 1 if all surgeries must be scheduled without postponements. If postponements are allowed, the sum should be less than or equal to 1.

2. **At most one surgery per block per time slot:**

$$\sum_{i=1}^{I} y_{i,b,p} \leq 1 \quad \text{for } b = 1, 2, \ldots, B \text{ and } p = 1, 2, \ldots, B$$

   Explanation: For each block b and time slot p, the sum of $y_{i,b,p}$ over all surgeries i should be at most 1, indicating that at most one surgery can be assigned to block b at time slot p.

CONSTRAINTS

3. **Time scheduling constraint:**

$$t_{b,p} = \sum_{i=1}^{I} (t_{b,p-1} + d_i \cdot y_{i,b,p-1}) \quad \text{for } b = 1, 2, \ldots, B \text{ and } p = 2, 3, \ldots, B$$

   Explanation: For each block b and time slot p greater than 1, the start time $t_{b,p}$ is equal to the sum of the start time of the previous time slot $t_{b,p-1}$ and the duration of the surgery i assigned in the previous time slot multiplied by the binary variable $y_{i,b,p-1}$.

4. **Surgery start time must be non-negative:**

$$t_{b,p} \geq 0 \quad \text{for } b = 1, 2, \ldots, B \text{ and } p = 1, 2, \ldots, B$$

   Explanation: For each block b and time slot p, the start time $t_{b,p}$ should be non-negative, indicating that the surgery is scheduled to start at that time.

CONSTRAINTS

1. **Calculation of overtime for each block:**

$$o[b] = \left(\sum_{i=1}^{I} \sum_{p=1}^{B} (t_{b,p} + d_i \cdot y_{i,b,p}) \right) - L \quad \text{for } b = 1, 2, \ldots, B$$

Explanation: For each block b, the overtime $o[b]$ is calculated as the total time spent on surgeries in that block ($\sum_{i=1}^{I} \sum_{p=1}^{B} (t_{b,p} + d_i \cdot y_{i,b,p})$) minus the duration L of the block.

2. **Non-negative overtime for each block:**

$$o[b] \geq 0 \quad \text{for } b = 1, 2, \ldots, B$$

Explanation: The overtime $o[b]$ for each block b should be non-negative, ensuring that there is no negative overtime.

CONSTRAINTS

Surgery Start Time within Block Duration

$$t_{b,p} \leq L \quad \text{for } b = 1, 2, \ldots, B \text{ and } p = 1, 2, \ldots, B$$

For each block b and time slot p, the starting time $t_{b,p}$ of a surgery cannot exceed the duration of the block. This ensures that surgeries start within the specified block durations.

PARAMETER VALUES

```
I = 20  # Number of elective surgeries
B = 10  # Number of available OR blocks
L =150   # Duration of each OR block (in minutes)

# Surgery durations and costs
d = [140, 60, 150, 60, 120, 50, 170, 90, 100, 140, 100, 70, 150, 140, 160, 100, 60, 160, 80, 80]# duration of each surgery
c = [370, 360, 124, 720, 154, 147, 310, 720, 112, 520, 330, 100, 420, 190, 149, 103, 550, 690, 170, 100]# cost of each surgery
c_p = [500, 380, 390, 1800, 200, 340, 370, 1200, 210, 600, 400, 500, 500, 500, 340, 290, 600, 700, 310, 340]# cost of postponing
c_o = 5  # Cost of overtime per minute
```

RESULT 1(NOT CONSIDERING POSTPONMENT)

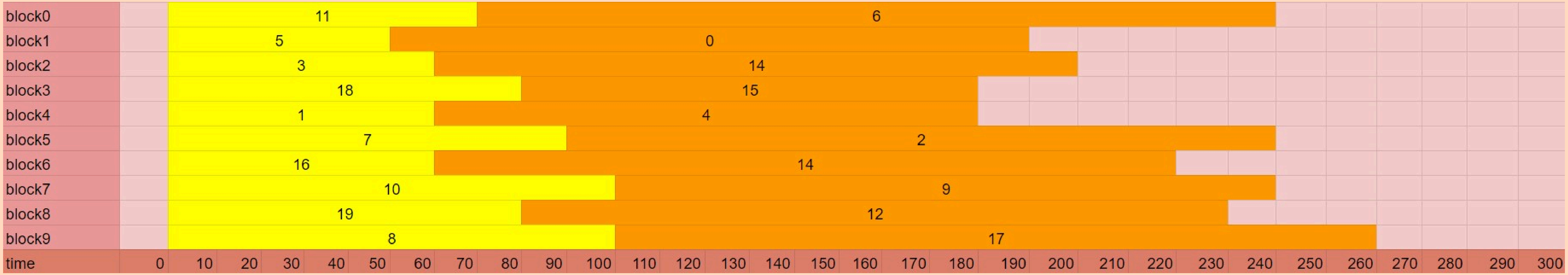
Here idea is that no surgery is postponed and all the surgeries are considered for the scheduling. Taking I=20 surgeries, B=10 OR blocks, and 300 minutes as the length of each block with 5 as the overtime cost and same rest parameters ::

```
Surgery 0 is assigned to block 1,  at time 50.0
Surgery 1 is assigned to block 4,  at time 0.0
Surgery 2 is assigned to block 5,  at time 90.0
Surgery 3 is assigned to block 2,  at time 0.0
Surgery 4 is assigned to block 4,  at time 60.0
Surgery 5 is assigned to block 1,  at time 0.0
Surgery 6 is assigned to block 0,  at time 70.0
Surgery 7 is assigned to block 5,  at time 0.0
Surgery 8 is assigned to block 9,  at time 0.0
Surgery 9 is assigned to block 7,  at time 100.0
Surgery 10 is assigned to block 7,  at time 0.0
Surgery 11 is assigned to block 0,  at time 0.0
Surgery 12 is assigned to block 8,  at time 80.0
Surgery 13 is assigned to block 2,  at time 60.0
Surgery 14 is assigned to block 6,  at time 60.0
Surgery 15 is assigned to block 3,  at time 80.0
Surgery 16 is assigned to block 6,  at time 0.0
Surgery 17 is assigned to block 9,  at time 100.0
Surgery 18 is assigned to block 3,  at time 0.0
Surgery 19 is assigned to block 8,  at time 0.0
```

Here each surgery is scheduled and given a slot and adding the cost of each surgery and the overtime for each block we get our objective function.

RESULT 1(NOT CONSIDERING POSTPONMENT)

Here idea is that no surgery is postponed and all the surgeries are considered for the scheduling. Taking I=20 surgeries, B=10 OR blocks, and 300 minutes as the length of each block with 5 as the overtime cost and same rest parameters ::



RESULT 2(CONSIDERING POSTPONMENT)

Taking I=20 surgeries, B=10 OR blocks, and 150 minutes as the length of each block with 5 as the overtime cost and same rest parameters ::

```
Surgery 1 is assigned to block 8,  at time 0.0
Surgery 2 is assigned to block 6,  at time 0.0
Surgery 3 is assigned to block 7,  at time 0.0
Surgery 5 is assigned to block 9,  at time 0.0
Surgery 7 is assigned to block 1,  at time 0.0
Surgery 11 is assigned to block 2,  at time 0.0
Surgery 12 is assigned to block 0,  at time 0.0
Surgery 16 is assigned to block 3,  at time 0.0
Surgery 18 is assigned to block 4,  at time 0.0
Surgery 19 is assigned to block 5,  at time 0.0
```

As the duration of the surgeries are defined to be from 60-170 minutes , 2-3 surgeries can't fit depending upon the block into its length and is postponed because of the extra overtime cost incurred would be much more than its postponement cost. Thus, reducing the overtime cost per minute may reduce chances of postponing.

CONCLUSION

Elective surgery scheduling optimization plays a critical role in managing surgery, postponement, and overtime costs. By minimizing these expenses through efficient resource allocation, while ensuring patient satisfaction and safety, healthcare facilities can achieve significant cost savings and enhance overall operational performance and patient outcomes.

THANK YOU SO MUCH