14th AIMMS-MOPTA Optimization Modeling Competition

Surgery Scheduling in Flexible Operating Rooms Under Uncertainty

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 [1, 4]. 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. This competition focuses on an elective surgery planning problem (ESP) in flexible ORs, where emergency patients are accommodated in the existing elective surgery schedule [3]. Elective cases can be scheduled weeks or months in advance. In contrast, the arrival of emergency surgeries is random, and must be performed on the day of arrival. The goal is to construct a plan that specifies the assignments of a subset of elective cases from a waiting list to available OR surgery blocks and the scheduled start times of surgeries assigned to each block. The surgical blocks are typically designed to allow for multiple surgeries to be scheduled during the surgery block's time length. The plan's quality is a function of costs related to performing or delaying elective surgeries, costs related to OR overtime and idle time, costs related to surgery waiting times, and costs related to canceling scheduled surgeries to accommodate emergency surgeries. Your team's goal is to develop an efficient and implementable method to solve ESP that managers can use in practice.

Problem Description (based on [3])

This competition considers elective surgery planning at a hospital that has B available surgery blocks over an arbitrary planning horizon of T days (e.g., a week). Each surgery block $b \in [B] := \{1, \ldots, B\}$ is assigned to a particular OR, has a pre-allocated length of time L_b, and is dedicated to only one type of surgical specialty. For any $b \in [B]$, the time length L_b is typically long enough so that multiple surgeries can be performed during that time. Note that there can be multiple blocks for the same specialty during a cycle of the OR schedule. The OR capacity is shared among two competing surgery classes: a known number I of elective surgeries that are to be planned in advance, and random emergency surgeries that must be performed on the day of arrival.

Each elective surgery $i \in [I]$ has a surgery type and can be assigned to any of the blocks dedicated to the corresponding surgery type during the planning horizon. Associated with each elective case, there is a cost for performing/scheduling and for rejecting the surgery (i.e., cost of delaying surgery to the next planning horizon). Let's assume that patients who are not assigned to any surgery block during the current planning horizon are assigned to a dummy block $b' \notin [B]$. Further, let $c_{i,b}$ and $c_{i,b'}$ represent the costs of performing and postponing surgery $i \in [I]$, respectively. Then, it is reasonable to assume that $c_{i,b'} > c_{i,b}$, for all $b \in [B]$. Moreover, the cost of assigning a surgery to a block is block-dependent to take into account the surgery's waiting time on the list and clinical priority, among other potential factors. Elective surgery durations (d_i, $i \in [I]$) are random and depend on surgery type. Emergency surgeries arrive randomly, and their durations are also random. Note that when an emergency surgery arrives, the OR manager may: (1) cancel one or more pre-scheduled surgeries (which, for example, may generates cancellation costs), or (2) try to fit this emergency surgery within the schedule.

Given a waiting list of I elective surgeries and their types, we are interested in determining a plan that specifies: (a) the number (or subset) of elective surgeries to schedule in each surgery block (equivalently, surgery assignments to the available surgery blocks), and (b) the scheduled start times of surgeries assigned to each block. The plan's quality is a function of costs related to performing (scheduling) or not performing (rejecting) elective surgeries, costs related to OR overtime and total idle time, costs related to surgeries waiting times, and costs related to cancellation of scheduled surgeries to accommodate emergency surgeries. Overtime occurs when surgeries assigned to block b are not completed within $[0, L_b]$. Idle time is the time from the end of one surgery to the start of the next. Surgery waiting time is the time from the scheduled start of the surgery to its actual start time. Note that over time, idle time, waiting time, and the costs related to surgery cancellation are random (scenario-based) performance metrics; that is, they are observed after the realization of random parameters while the planned schedule is being executed. In contrast, costs related to scheduling or not scheduling an elective surgery are fixed planning costs incurred when the OR schedule is constructed.

Case Study

Your team should solve ESP instances with $I = 70, 100, 150, 200$ and $B = 32$ blocks. Also, you will consider six different elective surgical specialties; namely, general cardiology (CARD), gastroenterology (GASTRO), gynecology (GYN), medicine (MED), orthopedics (ORTH), and urology (URO). Assume that we have 10 available ORs and 32 surgery blocks . Table 1 presents the weekly assignments of surgery blocks to ORs. Each block is 8-hours long, and a surgery can be assigned to any of the blocks allocated to the corresponding surgery type during the planning horizon. It is worth to mention that the distribution of surgery blocks through OR rooms and the week is influenced by surgeons' and nurses' schedules, and the set up of the operating rooms, among other factors. Table 2 presents the mean and standard deviation of elective surgery duration based on surgery type. These values where computed from publicly available data that is referenced in [2].

Table 1. Block schedule from [3].

OR room	Monday	Tuesday	Wednesday	Thursday	Friday
1	GASTRO	GASTRO	GASTRO		
2			GASTRO	GASTRO	GASTRO
3	CARD		CARD		CARD
4	ORTH	ORTH		ORTH	ORTH
5		ORTH	MED		
6	GYN	GYN	GYN	GYN	
7		GYN	GYN	GYN	GYN
8	URO	URO		URO	URO
9	CARD		URO		CARD
10	URO		ORTH		

Table 2. Mean and standard deviation (STDEV) of elective surgery duration (in minutes) based on surgery type [2].

Surgery type	Mean	STDEV
CARD	99	53
GASTRO	132	76
GYN	78	52
MED	75	72
ORTH	142	58
URO	72	38

Each list of $I = 70, 100, 140, 200$ surgeries should consists of: 18% GASTRO, 14% CARD, 17% ORTH, 28% GYN, 18% URO, and 5% MED surgeries. You can propose any cost parameters for the performance metrics (i.e., overtime, idle time, waiting, cancellation, $c_{i,b}$, $c_{i,b'}$) in the objective **supported by appropriate references or a logical argument**. We expect to see solutions and insights under different cost structures. You should solve problem instances with various rates of (daily) emergency surgeries arrival, e.g., $\{1,2,3,..\}$ emergency surgeries per day. For simplicity, you can assume that emergency surgeries can be performed in any of the available OR blocks (on the day the emergency surgery arrives). Moreover, assume that the average duration of each emergency surgery is between 1-3 hours. You can make other assumptions on the duration of emergency surgeries that are supported by appropriate references or logical arguments. **Finally, you are free to choose appropriate probability distributions for each of the random problem parameters.**

Deliverables

Your team has to deliver a complete solution to the ESP case study problem. Specifically, your submission should include:

- The development of an optimization model and corresponding solution approach that, in a reasonable time, finds the optimal or near-optimal solution to ESP for the given case study.
- A user interface for your model(s) that can be used to run different scenarios in order to visualize results and make scheduling decisions.
- A report (max. 15 pages) describing the application and modeling approach, the solution techniques used, the results and insights obtained, and your team's final recommendations. **In order to judge your numerical results, it is key that all mathematical programming, and algorithms you used are clearly presented in the report.** The 15 pages limit includes references.

You are allowed and strongly encouraged to use related literature. Please cite properly all information sources and references used and carefully distinguish your ideas from ideas found in the literature.

Strongly encouraged: mathematical curiosity, passion for learning, and enthusiasm for applying optimization techniques.

Deadline and Questions

The **deadline** for submission is **May 15, 2022, 23:59 EDT**. If you have any question about the problem or the competition, please contact **MOPTA Competition Chairs** **Dr. Karmel S. Shehadeh** (kshehadeh[AT]lehigh.edu; kas720[AT]Lehigh.edu) and **Dr. Luis F. Zuluaga** (luis.zuluaga[AT]lehigh.edu). Please start the subject line of your email with [MOPTA Competition 2022] (otherwise your email may be overlooked) and send it to both Dr. Shehadeh and Dr. Zuluaga.

Software & Data

You are free to use any software of your choice, but it is recommended to use AIMMS for your submission. **All source code and data must be included, properly documented, and results must be reproducible.**

About AIMMS: AIMMS is an industry leading rapid model building and deployment platform perfected for over 30 years. AIMMS is an enjoyable and robust way to not only build optimization models but to deploy them as optimization applications to be used by business professionals. You can develop analytical models and highly interactive end user interfaces all within the same environment. Learn more and request the free academic license from here: AIMMS Academic License.

References

[1] Brecht Cardoen, Erik Demeulemeester, and Jeroen Beliën. Operating room planning and scheduling: A literature review. *European journal of operational research*, 201(3):921–932, 2010.

[2] Carlo Mannino, Eivind J Nilssen, and Tomas Eric Nordlander. Sintef ict: Mss-adjusts surgery data. *[WWW] Available from:* `https://www.sintef.no/Projectweb/Health-care-optimization/Testbed/`, 2010.

[3] Karmel S Shehadeh. Data-driven distributionally robust surgery planning in flexible operating rooms over a wasserstein ambiguity. *arXiv preprint arXiv:2103.15221*, 2021.

[4] Karmel S Shehadeh and Rema Padman. Stochastic optimization approaches for elective surgery scheduling with downstream capacity constraints: Models, challenges, and opportunities. *Computers & Operations Research*, page 105523, 2021.