CHAIR OF PRODUCTION MANAGEMENT
Prof. Dr. Raik Stolletz
http://stolletz.bwl.uni-mannheim.de

UNIVERSITY OF MANNHEIM

OPM 662 – Business Analytics : Modeling and Optimization (FSS 2022)

Assignment 4: Surgery Scheduling

Due Date: May 23rd 2022, 23:23 CET

An Operating Room (OR) is the unit of a hospital where surgical procedures are performed. A recent study by the Healthcare Financial Management Association (HFMA) estimated that ORs generate about 42% (if not more) of a hospital's revenues. Moreover, the same study states that improvements in the management of ORs can generate anywhere from \$4 million to \$7 million in additional annual revenue for an average-sized hospital organization. Reducing the downtime (idle time) of both ORs and surgeons is one of the ways in which the use of OR resources can be greatly improved. OR managers control these downtimes by developing appropriate schedules for surgeries and corresponding OR procedures. Besides the inherent complexity of scheduling problems, improving OR scheduling is further complicated by the uncertainty of the time required to perform OR procedures. The demand for operation is assumed to be known, *i.e.,* we do not consider demand changes, *e.g.* because of emergencies.

Abbildung 1: An operating room

In this case we will consider a particular instance of the OR scheduling and sequencing problem. The goal of your team is to develop tools to support the OR manager's scheduling and sequencing decisions.

Problem Description

The particular problem that your team is tasked to address is to recommend how to sequence a known set of surgeries for the next day with the objective of minimizing surgeon and OR idle times, as well as OR overtime. You should produce the recommended sequence in a reasonable amount of time of about one hour. This will allow the OR manager to make decisions about the next day's sequence of surgeries towards the end of the day. Assume you are in a situation in which a given set $\mathcal{I}$ of known surgeries must be sequenced to be performed by a **single** surgeon in **two parallel ORs**. That is, we want to decide in which order the surgeries should be done by the surgeon, and in which of the two (2) ORs each of them will be performed. Each surgery $i \in \mathcal{I}$ is characterized by a sequence of three (3) consecutive time spans:

tp_i preparation time (pre-incision time)

ts_i surgery time (incision time)

tc_i clean-up time (post-incision time)

We will assume that each OR has its own OR staff that handles preparation (pre-incision), clean-up (post-incision), and supports the surgeon during surgery (incision). Only the single surgeon might go from one OR to the other (as needed) after completing the incision time in a surgery. Also, the surgeon is required **only** during the surgery time span ts_i of any surgery $i \in \mathcal{I}$.

The OR staff in each of the two (2) ORs is scheduled to work in a *normal* shift from time $t = 0$ to time $t = T$, where the length of the OR staff normal shift T is given. If the OR staff is needed to work beyond the normal shift length of T hours, then this time is considered as **overtime**.

Furthermore, assume the OR manager has estimated the following parameters:

cv cost per hour of having an OR vacant (idle)

cw cost per hour of having the surgeon waiting (inactive)

co cost per hour of using OR staff in any of the ORs beyond their normal time shift of length T; that is, during overtime

In Figure 2, a sample sequencing of four (4) surgeries is given, and the corresponding OR vacant, surgeon waiting, and OR overtime is shown (Figure 2 is for illustrative purposes, and does not necessarily show the optimal sequencing of the surgeries or reflect real times for the surgeries). As Figure 2 illustrates, we will make the following assumptions when considering the solution of the problem:

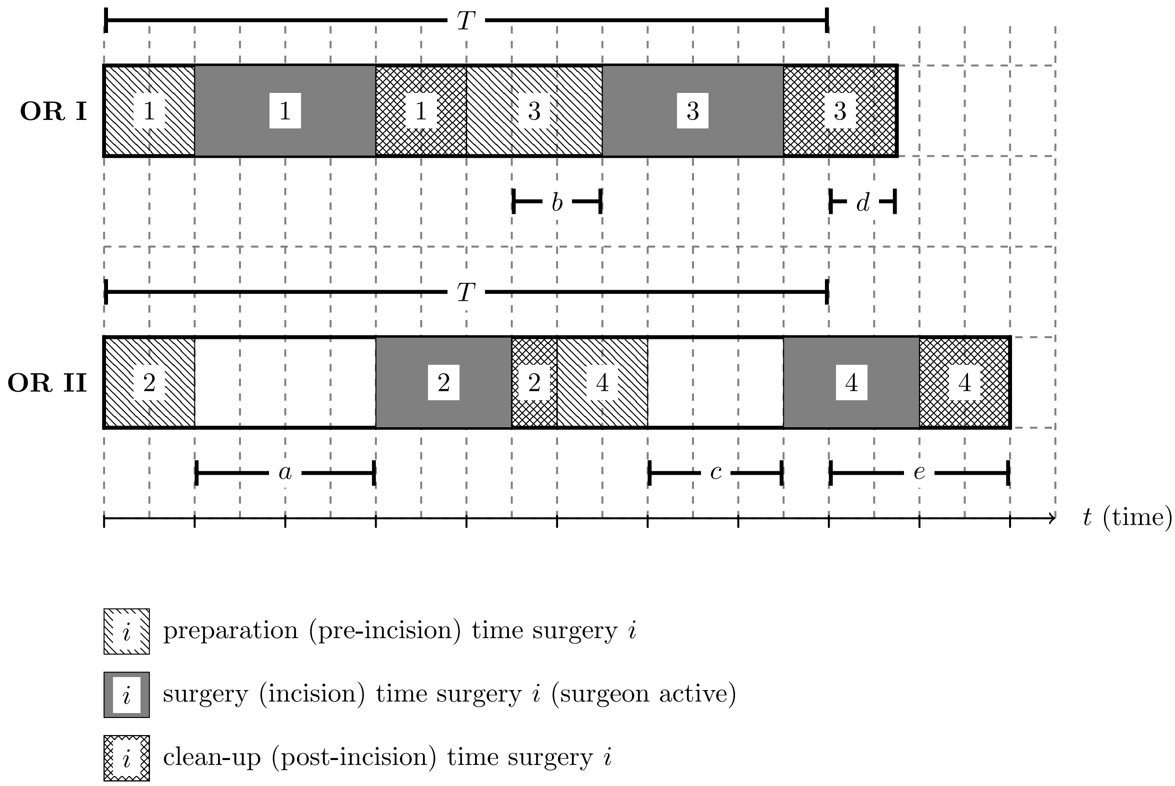

Abbildung 2: Sample sequencing of four (4) surgeries: [a], [c] OR II vacant time, [b] surgeon waiting time, [d] OR I overtime, [e] OR II overtime.

- All planned surgeries must be performed the next day. In particular, assume that both the surgeon and the OR staff in each of the two (2) ORs would work as long as they are needed to perform the planned surgeries.
- Surgeon waiting time is defined as the time the surgeon is inactive between surgeries.
- We will assume that the surgeon can start a surgery in one OR right after finishing a surgery in the other OR.
- Although having patients at the hospital ready to start a surgical procedure (which includes the pre-incision, incision, and post-incision time) is in itself a challenging part of OR management; here, we will assume that patients are always ready to start the surgical procedure.
- Clean-up (post-incision) time for a surgery starts right after the corresponding surgery (incision) time has been finished.
- Preparation (pre-incision) time for a surgery is always done as soon as possible. In particular, preparation (pre-incision) time for the next surgery in an OR will be started right after the clean-up (post-incision) time of the previous surgery has been finished.
- For simplicity, assume that neither surgeons or OR staff take any predetermined breaks during the day (i.e., during normal shift time as well as potential overtime). That is, they are available to work anytime as needed.
- OR staff in both ORs is scheduled to work for a normal shift of T hours of length, beginning at time $t = 0$, where T is given. Any work by the OR staff in any of the ORs

after completion of their T hours shift is considered as overtime (incurring a cost of co per hour).

- Surgeries in the two (2) ORs can overlap, except during the surgery (incision) time (since there is only one single surgeon). In particular, this allows the OR manager to possibly start the preparation of a surgery in one of the ORs, while the (single) surgeon is performing a surgery in the other OR. Also, the OR manager can possibly start preparation of a surgery in one of the ORs, while clean-up is being performed in the other OR after a surgery (incision) time has been completed.
- For simplicity, we will assume that there is no limit in the time the surgeon can work, or in the amount of overtime possibly incurred by OR staff in any of the ORs.

Instructions

Deterministic Case

In this section of the case, assume (unrealistically) that $tp_i,\ ts_i,\ tc_i$ for all $i \in \mathcal{I}$ are deterministic; that is, they are known before the surgeries have to be sequenced. With this assumption, your task is to:

1. Formulate and solve the decision problem to find the best sequence and the OR assignment for each of the surgeries $i \in \mathcal{I}$ in order to minimize the total vacant and overtime costs of the ORs, plus the total waiting time cost of the surgeon. In particular:

    a. Structure and describe the decision problem in terms of input, decisions, objective and constraints.

    b. Define an optimization model in algebraic notation.

    c. Implement the model in Python.

    d. Find the optimal solution of the four (4) problem instances provided in the attached Excel file and report the optimal objective value as well as the optimal sequence and OR assignment for each surgery. **(20 P.)**

Stochastic Case

In reality, the times $tp_i,\ ts_i,\ tc_i$ of a planned surgery $i \in \mathcal{I}$ are affected by stochastic variability because people are involved in the steps, complications may occur, etc. Therefore, in this section of the case, you are asked to assume that the times $tp_i,\ ts_i,\ tc_i$ are stochastic and not known exactly before the surgeries have to be sequenced. The information on the theoretical distributions is not available, however, the sample (historical) data about the times $tp_i,\ ts_i,\ tc_i$ for all the surgeries types are provided and can be used directly in the optimization.

Notice that when stochastic variability is added to the problem, the best or optimal sequence can be defined in different ways. In this section of the case, your tasks are:

2. Extend your deterministic optimization model from task 1 (algebraic and Python) to create **robust** solutions. Propose a measure how to evaluate the quality of your model, *e.g.,* expected costs, worst-case costs, etc. **(10 P.)**

3. Please discuss the following:
   - Please explain what type of robustness you are forcing and elaborate on why you are using certain measures or constraints in your model.
   - Please overview and discuss the numerical results compared to the deterministic solutions for both the solution behaviour of the standard solver for the four cases[1] and the observed differences in the structure of the solutions.

(5 P.)

Please limit the report to a maximum of 9 pages.

Problem Data
The data to generate the problem instances is contained in the file `Surgery_scheduling.xlsx` (to be found in ILIAS). The first worksheet of the file ("Costs") provides the values of $cv,\ cw,\ co$ in dollars per hour that should be used for all the instances. The second worksheet ("Sequencing Instances") defines four (4) instances of the surgery sequencing problem by providing for each instance, the normal OR staff shift time T in hours, and the number of surgeries of type A to J that should be sequenced in each instance. Finally, the third tab of the file ("Surgery Times") provides sample (historical) data about the times $tp_i,\ ts_i,\ tc_i$ (in minutes) for all the surgeries types A to J. The fact that the instances have the value of T equal to either 4, 8, or 12 hours is related to the fact that surgeons might be scheduled for "block times" of 4, 8, or 12 hours. Note that as T increases, more surgeries are required to be sequenced which increases the difficulty of the problem.

For task 1, where the times $tp_i,\ ts_i,\ tc_i$ are assumed to be deterministic, you should use the sample mean values of the times given in the third worksheet ("Surgery Times") to generate deterministic instances of the OR sequencing problem. Feel free to re-arrange the input data in the Excel file and/or move it to another data format in order make it readable for your model.

Send your complete solutions (report, Python files) as a zipped archive to **opm662@bwl.uni-mannheim.de**. To obtain full score, your models and results must have proper documentation and it must be possible for us to re-create the results using your Python models.

[1] If the computation times becomes prohibitively large, use a limit on the computation time or on the gap to the optimal solution. In case this is necessary, please elaborate on this.