# 5th AIMMS-MOPTA Optimization Modeling Competition (submit your solution by June 14, 2013 23:59 EDT)

## *Operating Room Management under Uncertainty*

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 the 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.

In this case we will consider a particular instance of the OR scheduling and sequencing problem. The goal of your team is to develop effective, quantitative, user-friendly tools to support the OR manager's scheduling and sequencing decisions by using the AIMMS modeling environment. AIMMS is an optimization modeling technology that is used by leading companies to support and improve decision-making in a wide range of industries. Further information about AIMMS is given below, and at `http://www.aimms.com`

## 1 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 reducing 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 (2) ORs** that function in parallel. 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:

$tp_i$ : **p**reparation **t**ime (pre-incision time)
$ts_i$ : **s**urgery **t**ime (incision time)
$tc_i$ : **c**lean-up **t**ime (post-incision time)

We will assume that each OR has *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:

$cv$ : **c**ost per hour of having an OR **v**acant (idle)
$cw$ : **c**ost per hour of having the surgeon **w**aiting (inactive)
$co$ : **c**ost per hour of using OR staff in any of the ORs beyond their normal time shift of length $T$; that is, during **o**vertime

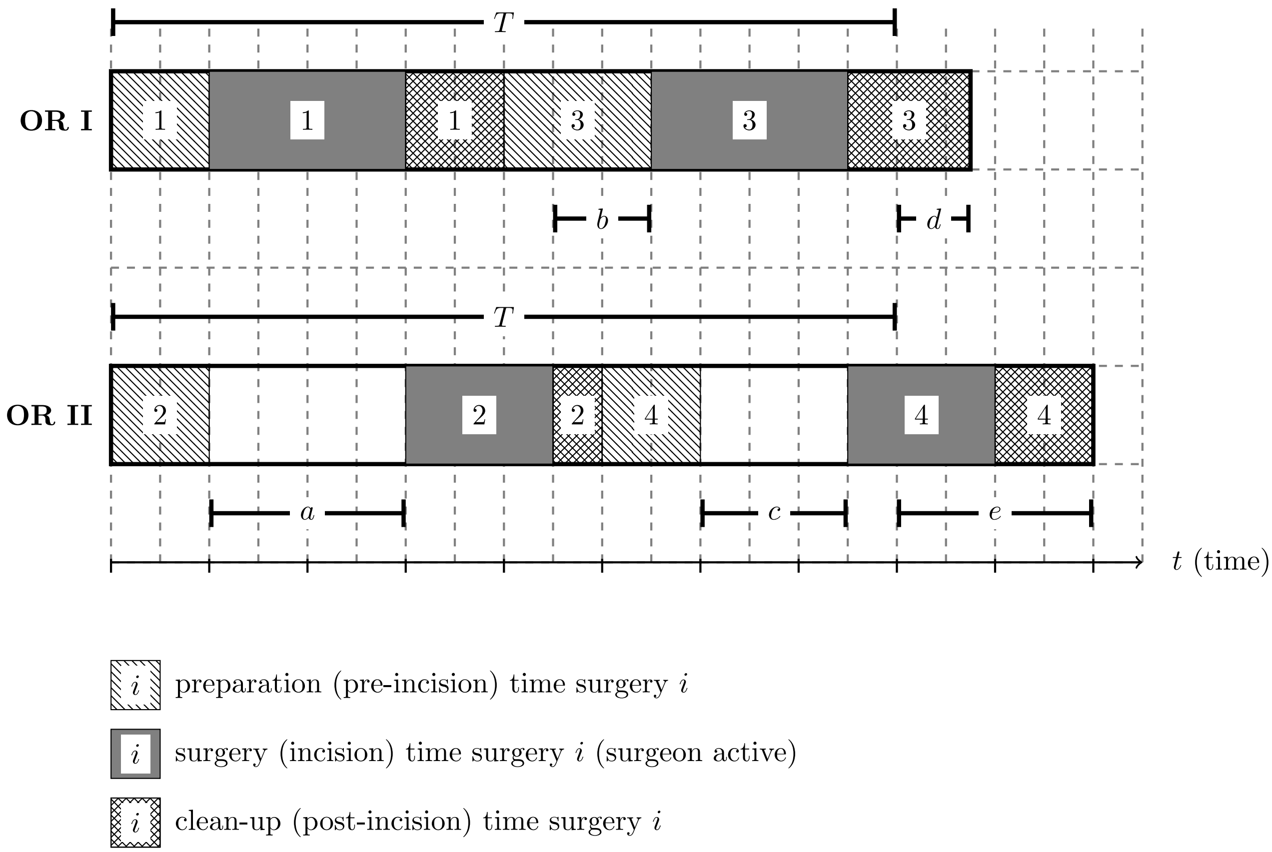


**Figure 1:** Sample sequencing of four (4) surgeries: [$a$], [$c$] OR II **v**acant time, [$b$] surgeon **w**aiting time, [$d$] OR I **o**vertime, [$e$] OR II **o**vertime.

In Figure 1, a sample sequencing of four (4) surgeries is given, and the corresponding OR **v**acant, surgeon **w**aiting, and OR **o**vertime is shown (Figure 1 is for explanation purposes, and does not show the optimal sequencing of the surgeries, or reflects real times for the surgeries). As Figure 1 illustrates, we will make the following assumptions when considering the solution of the problem:

(a) **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 until they are needed to perform the planned surgeries.

(b) Surgeon **waiting** time is defined as the time the surgeon is inactive **between** surgeries.

(c) We will assume that the surgeon can start a surgery in one OR right after finishing a surgery in the other OR.

(d) 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.

(e) Clean-up (post-incision) time for a surgery starts right after the corresponding surgery (incision) time has been finished.

(f) 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.

(g) 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.

(h) 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 **o**vertime (incurring a cost of $co$ per hour).

(i) Surgeries in the two (2) ORs can overlap, **except** during the surgery (incision) time (since there is a 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.

    Notice that having two (2) ORs 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.

(j) For simplicity, we will consider 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.

### 1.1 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 tasks are to:

1. Develop a "rule of thumb" (quick heuristic) to decide a *good* sequence of the surgeries $i \in \mathcal{I}$, together with the OR in which they should be performed. *Good* is measured in terms of the total vacant and overtime costs of the ORs, plus the total waiting time cost of the surgeon.

2. Develop an optimization model or algorithm that, in a *reasonable* time, finds the best or approximately best sequence and the OR in which each of the surgeries $i \in \mathcal{I}$ should be planned in order to minimize the total vacant and overtime costs of the ORs, plus the total waiting time cost of the surgeon.

3. Analyze the pros and cons of the two approaches proposed in item 1 and item 2. In particular, make sure you compare the two approaches in terms of total costs (objective) and time required to obtain the recommended surgery sequence.

4. Discuss whether or not it is "useful" to have the two (2) ORs available. What change to the problem or the problem parameters will switch your previous answer (i.e., from useful to not useful or viceversa)?

## 1.2 Uncertain Case

In reality, the times $tp_i, ts_i, tc_i$ of a planned surgery $i \in \mathcal{I}$ can vary a lot depending on the patient, complications, uncertain diagnosis, etc. Thus, they are likely not known exactly before surgeries are sequenced. In this section of the case, you are asked to assume that the times $tp_i, ts_i, tc_i$ are uncertain; that is, not known exactly before the surgeries have to be **sequenced**.

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

4. Given that the times associated with the completion of a given surgery are now uncertain, **choose or propose** a quantitative form of characterizing the *optimal* sequence of surgeries, and the OR in which each of the surgeries $i \in \mathcal{I}$ should be planned. This task will require you to also choose or propose the way in which the uncertainty is taken into account in your quantitative approach to characterize the *optimal* solution of the problem. As an **example**, one can characterize the *optimal* sequence of surgeries as the one that minimizes the expected value of the total vacant, overtime, and waiting costs. In order to compute the expected value, one can consider that the distribution of the preparation, surgery, and clean-up times is given by equiprobable samples of these times. However, a number of alternative approaches to define the optimal solution and model the uncertainty can be used, as long as the optimal decision is driven by OR vacant costs, OR overtime costs, and surgeon waiting time costs.

5. Develop a "rule of thumb" (quick heuristic) to decide a *good* sequence and the OR in which each of the surgeries $i \in \mathcal{I}$ should be planned. Here, *good* refers to the characterization made by your team in item 4.

6. Develop an optimization model or algorithm that, in a *reasonable* time, finds the *optimal* or approximately *optimal* sequence and the OR in which each of the surgeries $i \in \mathcal{I}$ should be planned. Here, *optimal* refers to the characterization made by your team in item 4.

7. Analyze the pros and cons of the two approaches proposed in item 5 and item 6. In particular, if your solutions are approximate either from an optimization and/or probabilistic point of view, propose a way to test the "actual" performance of your solutions. For example, this can be done by using some of the sample data given as "training" (or in sample) data, and some of the sample data as "testing" (or out of sample) data. Also, make sure you compare the two approaches in terms of objective (which you defined in item 4) and time required to obtain the recommended surgery sequence.

8. Discuss whether or not it is "useful" to have the two (2) ORs available. What change to the problem or the problem parameters will switch your previous answer (i.e., from useful to not useful or viceversa)?

## 1.3 Generating problem instances

The data to generate the problem instances for the questions in Sections 1.1, and Section 1.2 is contained in the file `OR_data.xlsx` that can be downloaded at `http://coral.ie.lehigh.edu/~mopta/competition`. The first tab of the file ("Costs") provides de values of $cv, cw, co$ in dollars per hour that should be used for all the instances. The second tab of the file ("Sequencing Instances") defines ten (10) 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 $A, B, C, D, E, F, G, H, I, J$ 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 $A$ through $J$. 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 Section 1.1, 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 tab "Surgery Times" to generate deterministic instances of the OR sequencing problem.

# 2 The Tools

The following tools will be available to your team to address the case problem.

## 2.1 Software

A full version of the AIMMS modeling platform along with solvers `CPLEX`, `GUROBI`, `MOSEK`, `XA`, `CONOPT`, `MINOS`, `SNOPT`, `LGO`, `AOA`, `PATH`, `CP Optimizer` and, through `COIN-OR`, `CBC`, and `IPOPT` are provided to the teams free of charge. You may use any combination of these to solve your models. In particular, `CP Optimizer` is a new addition to the available solvers in AIMMS that allows the user to use Constraint Programming techniques to solve optimization problems.

We encourage all teams to take advantage of the procedural aspect of the AIMMS modeling system and solve the problems in multiple stages. Please study the documentation about the features and capabilities of these solvers.

If you have any questions about the software please contact support@aimms.com.

## 2.2 Data sets

As mentioned in Section 1.3, the file `OR_data.xlsx` that contains the necessary data to generate the problem instances is is available at `http://coral.ie.lehigh.edu/~mopta/competition`.

## 2.3 Relevant literature

You are free to browse and use the relevant literature for inspiration. Please cite all sources and carefully distinguish your ideas from those obtained in the literature.

# 3 Deliverables

Your team needs to deliver a solution to the problem described in this case study. In particular, your submission should include:

- implementation of your models in AIMMS, including a user interface, providing the user graphical and textual output. An AIMMS Gantt chart like in Figure 1 would really help the OR manager.
- solutions of the instances provided in the data file (the more the better), as well as summary tables or graphs addressing the performance of your developed methodologies.

- a no more than 15 page report that discusses your models, the mathematical background of your techniques, the solutions that you obtained, and further 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**.

Teams that only develop partial solutions to the case are still encouraged to submit their solution. Teams are also encouraged to address additional or alternative “realistic” factors, variants, or modifications of the underlying problem considered in the case. If data beyond the one provided with the case is necessary to consider these factors, variants, or modifications, you’re asked to generate additional corresponding data either from relevant literature or sensible assumptions. Be sure to reference the literature or assumptions you used to generate the additional data.

The **deadline** for submission is **June 14, 2013 23:59 EDT**. If you have questions about the problem or the competition in general, please contact Luis F. Zuluaga at luis.zuluaga@lehigh.edu.