Surgery Scheduling with Recovery Resources

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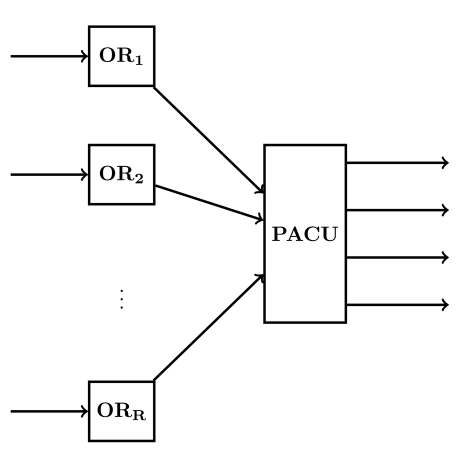
Motivation

- Elective surgery scheduling is a difficult and computationally challenging problem, especially when modeling both the surgical and recovery stages.
- Ignoring this coupling can result in resource overutilization, which can
  - delay consecutive surgeries
  - compromise patient safety
- The lack of sufficiently fast methods understandable by hospital personnel causes inefficiency for important an expensive resources.

Stages of the Surgical Process

1. Check-in
2. Pre-op
3. **Operating Room (OR)**
4. **Post-anesthesia care unit (PACU)**
5. Transfer

Our focus:



Problem Features

We formulated this problem as a mixed integer program (MIP) that we call MIP[OR,PACU] with the objective of minimizing the

- fixed cost of opening the ORs (c^f)
- variable cost of OR overtime (c^v)
- variable cost of surgeon elapsed time (c^s)

Constraints considered:

- OR availability
- PACU bed availability
- recovery starts in PACU right after surgery
- patient-surgeon assignment respected
- surgeons perform all their cases consecutively

Solution Methods

We solve the problem using a novel 2-phase heuristic that first assigns surgeons to ORs, and then sequences surgeries and surgeons. To provide a solvable and near optimal benchmark, we simplify MIP[OR,PACU] by decomposing it into two steps similar to the phases of the 2-phase heuristic. We refer to this as the decomposition heuristic.

2-Phase Heuristic: Theoretical Analysis

Phase 1 - longest processing time first heuristic (LPT): surgeon-to-OR assignments.

- Use LPT with respect to surgeon block durations (i.e., group of surgeries that are performed by the same surgeon), for fixed number of ORs.
- Exhaustive search through the number of ORs available.

Theorem 1. *For any instance where the planned session length of each OR is S, we have*

$$\frac{C^{LPT}}{C^*} \leq 1 + \frac{Sc^v}{12c^f},$$

where C^{LPT} is the cost of the schedule given by LPT, and C^* is the cost of the optimal solution. Moreover, this bound is tight for every even number of ORs.

Phase 2 - difference heuristic (DH): surgery & surgeon sequencing.

- Pick the surgery to be first that would cause the most potential blocking.
- Comparing the current patient's recovery duration (r_i) to potential next patients' surgery duration (d_j), pick patient that will cause the least blocking.

Theorem 2. *Letting*

$$D_i = \max_{j:i\neq j}\{(r_i - d_j)^+\} - \min_{j:i\neq j}\{(r_i - d_j)^+\},$$

then for any instance we have

$$C^{DH} - C^* \leq c^s \left(\sum_{i=1}^{I} D_i - \min_i D_i \right),$$

where C^{DH} is the cost of the schedule given by DH, and C^* is the cost of the optimal solution. Moreover, this bound is tight.

Theorem 3. *The DH gives an optimal schedule for any instance where the number of cases assigned to a single surgeon is two.*

2-Phase Heuristic: Empirical Analysis

To evaluate heuristic performance, the following formula was used:

$$\frac{C^{Heuristic} - C^*}{C^*} \cdot 100\%$$

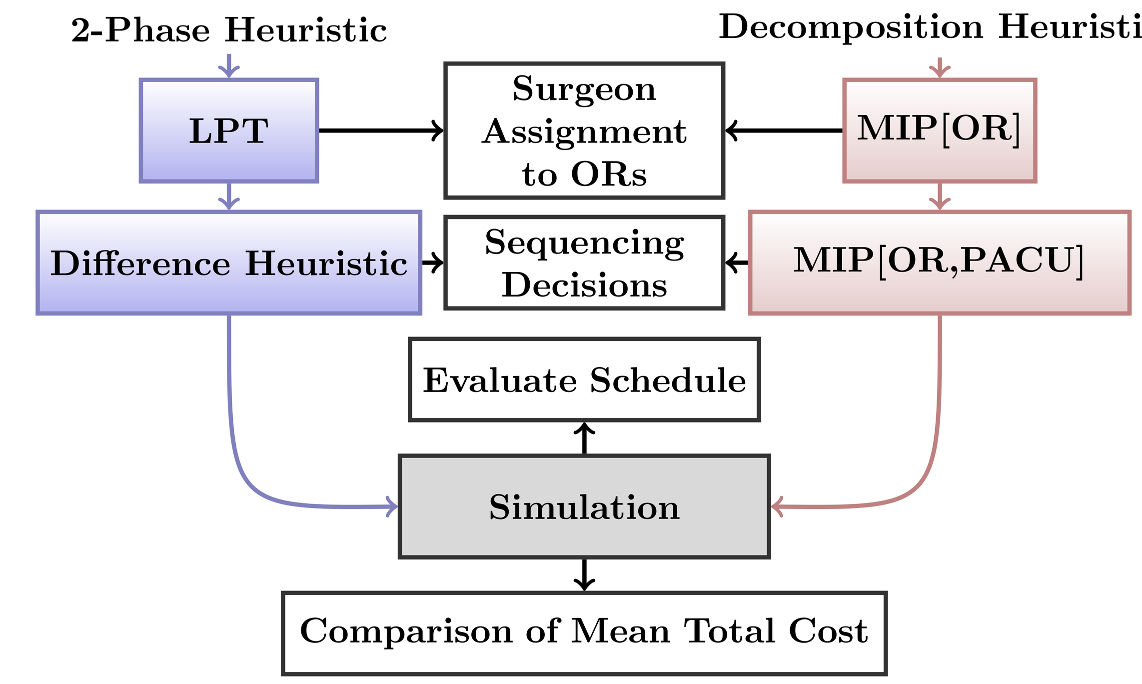
	LPT	DH
Average performance	0.42%	0.70%
Worst-case performance	6.99%	30.30%
% of time optimal	77.41%	95.19%

Comparison of the 2-Phase & Decomposition Heuristics Via Simulation

Similarly to the 2-phase heuristic, the decomposition heuristic has two steps:

1. Assign surgeons to ORs ignoring the PACU using a MIP we call MIP[OR].
2. Fixing the decisions made in step 1, sequence surgeries and surgeons considering PACU resources using MIP[OR,PACU].

Moreover we obtain a lower bound for MIP[OR,PACU] from step 1 and the data. Deterministic schedules are evaluated under uncertainty using a discrete event simulation model, where surgery and recovery duration distributions are surgeon and case specific.



Case Study: General, Orthopedic & Urology Services

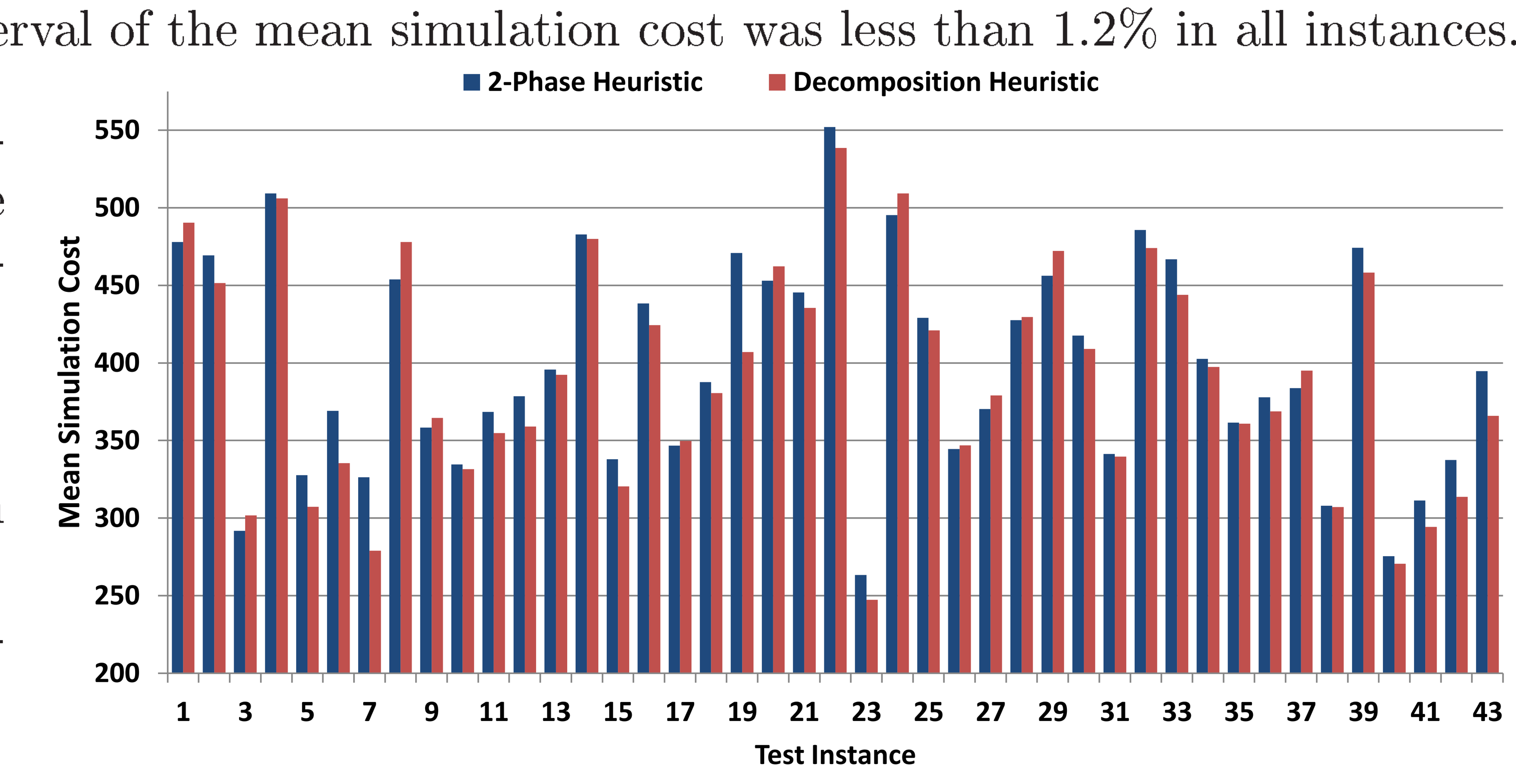
We sampled from 14 months of data. The number of surgeries per instance day varied from 15 to 20 with a mean of 18, the number of ORs used varied from 4 to 7 with a mean of 6, and the number of surgeons varied from 6 to 11 with a mean of 8. Surgery durations varied from 60 to 375 minutes with a mean of 166 minutes (including turnover). Recovery durations varied from 75 to 210 minutes with a mean of 133 minutes.

The half width of the 95% confidence interval of the mean simulation cost was less than 1.2% in all instances.

- Based on our results, surgery and recovery duration percentiles used in the deterministic setting were 60 and 70, respectively.

The 2-phase heuristic was

- within 10% of the decomposition heuristic in 93% of the test instances;
- within 5% of the decomposition heuristic in 74% of the test instances.



Comparison based on the lower bound:

	2-Phase Heuristic	Decomposition Heuristic
Average performance	6%	1%
Worst-case performance	27%	9%
% of time optimal solution found	26%	86%

Comparison based on OR blocking:

	2-Phase Heuristic	Decomposition Heuristic
Avg OR time used for blocking	0.05%	0.27%
Max OR time used for blocking	0.34%	3.16%

Conclusions

1. The 2-phase heuristic has a tight worst-case performance bound for each of its phases.
2. The 2-phase heuristic performs very well both in the deterministic and stochastic settings in terms of cost, when compared to the decomposition heuristic.
3. Under uncertainty the 2-phase heuristic performs well when compared to the decomposition heuristic in terms of OR blocking.
4. Hospitals can realize substantial benefits without sophisticated optimization software implementations.