Partial Day Operating Room Block Scheduling

An Mixed Integer Programming Approach

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Outline

Problem Motivation

Non-HMO hospitals face specific OR scheduling challenges:

- Compete against other surgical centers for surgeons
  - Negotiate over allocation of OR time
  - Need to account for preferences of non-employee surgeons
- Balance profit generated directly or indirectly by surgeries against resource constraints
  - Limited time available in OR
    - Overtime in OR after end of nursing shift incurs costs and leads to higher turnover
  - Post-surgical hospital ward capacities
- Goal is to set time allocations to maximize profitability
- We have observed hospitals struggle with these decisions

Problem Backdrop

- Lower insurance payouts in recent years encourage shorter hospital stays
- Hospitals have responded by downsizing hospital wards
- Need to schedule OR more carefully to keep hospital ward occupancy more stable
- Lack of available beds in downstream wards can lead to delay of surgeries

Past Research

Previous research has considered:

- Allocate entire day blocks to smooth ward bed occupancy (Belien and Demeulemeester 2007)
- Generalize the above model to allow for multiple wards and half day blocks (Belien et al. 2009)
- Maximize OR utilization and smooth bed occupancy while accounting for uncertainty in surgery length (van Oostrum et al. 2008)
- Allocate full day blocks to different specialties while accounting for step-function nursing costs and smoothing bed occupancy (Benchoff, Yano and Newman 2017)

Problem Setting

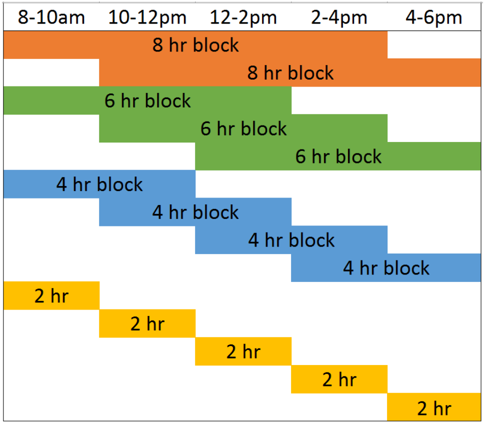
Assign physicians to partial day surgical blocks over a four-week horizon to maximize profit considering the following:

- Profit accruing from each surgeon is concave function of hours assigned
- Costs for overtime in the ORs
- Hospital ward capacities and adverse consequences for patients beyond capacity of preferred ward
- Schedule must repeat after four-week cycle
- Individual physician requirements and preferences

Negative Outcomes from Exceeding Ward Capacity

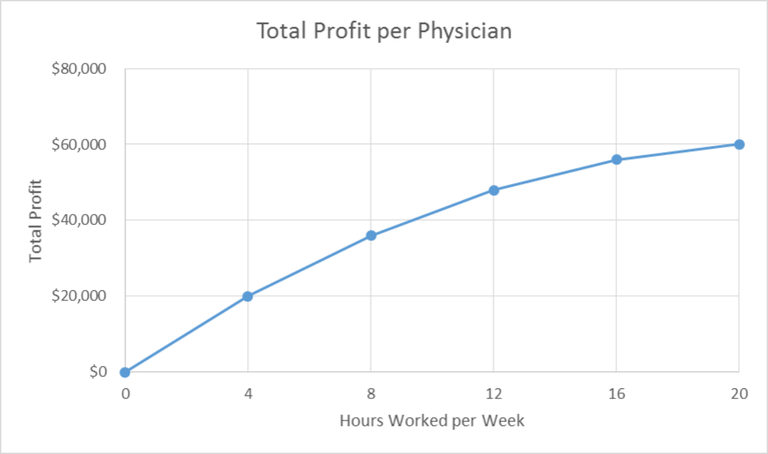
- Patients placed in the “wrong” ward with nurses who have less experience with the patient’s medical condition
  - more likely to have complications
  - more likely to be readmitted later
  - both are costly to hospital (and patient)
- Patients may need to be released earlier than desired to accommodate the “excess” patient

What's a Block?



We use multiples of 2 hours for illustrative purposes.

Profit per Physician



Objective Function

Profit accruing due to each physician modeled as a piece-wise linear function of the number of hours assigned to each physician:

α_{hp} = hourly profit in hour band h for physician p

z_{pwh} = hours assigned to physician p in week w in hour band h

β = overtime cost for 2 hours beyond 8-hour shift

γ = penalty per patient-day over capacity in preferred ward

$$\max \sum_{p \in P} \sum_{w \in W} \sum_{h \in H} \alpha_{hp} z_{pwh} - \sum_{r \in R} \sum_{d \in D} \beta y_{rd} - \sum_{f \in F} \sum_{d \in D} \gamma o_{fd}$$

Block Assignment Constraints

For sets physicians P, surgery blocks B, OR Rooms R, and days D:

$$x_{pbrd} = \begin{cases} 1 \text{ if physician } p \text{ is assigned block } b \text{ in room } r \text{ on day } d \\ 0 \text{ otherwise} \end{cases}$$

Each block can only be given to one physician at a time:

$$\sum_{p \in P} x_{pbrd} \leq 1 \quad \forall b \in B, r \in R, b \in B$$

Each physician can only be in one room at a time:

$$\sum_{r \in R} x_{pbrd} \leq 1 \quad \forall p \in P, b \in B, d \in D$$

Physician-Related Requirements

Each physician can specify a set of requirements:

- Feasible blocks
- Min/max total hours needed for a given day
- Min/max total hours needed for a given week
- Min/max number of blocks needed for a given week

Example constraint:

ℓ_b is the length of block b

δ_{pd} is the minimum hours needed by physician p on day d

$$\sum_{b \in B} \sum_{r \in R} \ell_b x_{pbrd} \geq \delta_{pd} \quad \forall p \in P, d \in D$$

OR Overtime

Our numerical examples have 10 hours of OR time each day, 8-hour surgical nurse shifts and blocks that are multiples of 2 hours, so overtime is a binary decision here, but could be a continuous variable or (say) a multiple of an hour.

$$y_{rd} = \begin{cases} 1 \text{ if room } r \text{ has more than 8 hrs assigned on day } d \\ 0 \text{ otherwise} \end{cases}$$

Penalty is incurred for exceeding 8 hours:

$$\sum_{p \in P} \sum_{b \in B} \ell_b x_{pbrd} \leq 8 + 2y_{rd} \quad \forall r \in R, d \in D$$

Hospital Ward Occupancy

P_f = set of physicians whose patients go to floor (ward) f

μ_{pi} = expected number of patients recovering from physician p's surgeries i days after surgery per hour of OR time assigned to physician p

u_{pd} = number of hours assigned to physician p on day d

s_{fd} = number of patients on floor (ward) f on day d

Hospital ward occupancy is:

$$\sum_{p \in P_f} \sum_{i=1}^{d} \mu_{p(d-i)} u_{pi} = s_{fd} \quad \forall f \in F, d \in D$$

Depends on surgeries by all physicians within the past l days, where l is the longest length of stay

Penalty due to Excess Patients

s_{fd} = actual occupancy in floor (ward) f on day d

κ_f = capacity allocated to surgical patients in floor (ward) f

$o_{fd} = (s_{fd} - \kappa_f)^+$ representing the number of patients over capacity in floor (ward) f on day d

Penalty for exceeding beds allocated to surgical patients:

$$\gamma \sum_{fd} o_{fd}$$

Steady State Condition

Each 4-week cycle must start in the same state, defined by number of patients who will stay an additional 1, 2, 3,... days in each ward

v_{fd} = the number of patients in floor (ward) f on day d remaining from previous month's surgeries

Initial floor occupancy:

$$v_{fd} + \sum_{p \in P_f} \sum_{i=1}^{d} \mu_{p(d-i)} u_{pi} = s_{fd} \quad \forall f \in F, d \in D$$

Constraint to ensure that the next 4-week cycle has the same initial condition:

$$v_{fd} = s_{f(d+28)} \quad \forall f \in F, d \in D$$

Problem Parameters

Problem Dimensions:

P	B	R	D	# of x variables
50	14	10	28	196000

Cost parameters:

α_{hp} = \$5000/hr dropping by \$500 for every 4 hours assigned

e.g. 7 hours $\Rightarrow$ Profit $= 4(5000) + 3(4500)$

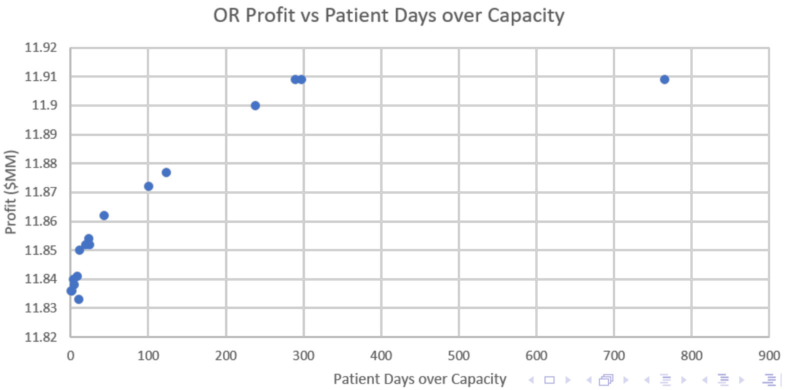
β = \$1000 per instance of OR overtime (for 2 hours)

γ = \$1000 per patient-day over capacity in ward

CPLEX can solve to optimality in 10 minutes

Tradeoff between Profit and Patient-Days in Excess of Ward Capacity

Curve generated by different penalty costs for excess ward patients



Observations from Numerical Example

- Profit changes very little with the penalty
- Even imposing a small penalty can significantly reduce patient-days in excess of capacity
- Reducing patient-days in excess of capacity can help to reduce costs due to readmission, etc., that are not accounted for in the model

Summary

- Mixed integer programs can effectively allocate partial day OR blocks among physicians
- Problems of reasonable size can be solved even when using piece-wise linear profits and linear costs incorporating various interconnected and communal hospital resources

Future Work

- Step-function nursing costs
- Physician preferences for repeatable weekly or bi-weekly schedules
- Longer OR days and shorter blocks
- Block type constraints (e.g., morning vs evening)

Thank you

Any questions?

For Further Reading I

Belien J, Demeulemeester E (2007)
Building cyclic master surgery schedules with leveled resulting bed occupancy. Eur. J. Oper. Res. 176(2):11851204

Belien J, Demeulemeester E, Cardoen B (2009)
A decision support system for cyclic master surgery scheduling with multiple objectives. J. Scheduling 12(2):147161.

van Oostrum JM, Van Houdenhoven M, Hurink JL, Hans EW, Wullink G, Kazemier G (2008)
A master surgical scheduling approach for cyclic scheduling in operating room departments. OR Spectrum 30(2):355374.

For Further Reading II

Brittney Benchoff, Candace Arai Yano, Alexandra Newman (2017)
Kaiser Permanente Oakland Medical Center Optimizes Operating Room Block Schedule for New Hospital. Interfaces