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Master surgery scheduling with nursing ward constraints

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Background

- Nurses experience **peaks of workload**, due to a high variability in bed occupancy.
- We optimize the **Master Surgical Schedule (MSS)** while accounting for **downstream bed occupancy**
- The MSS is **cyclic** and assigns **specialties** to a **day** and **operating room (OR).**

Objective

- To find the optimal Master Surgical Schedule while minimizing variability of nursing ward occupancy.

Process

- Close collaboration with practitioners to ensure practical implementability.

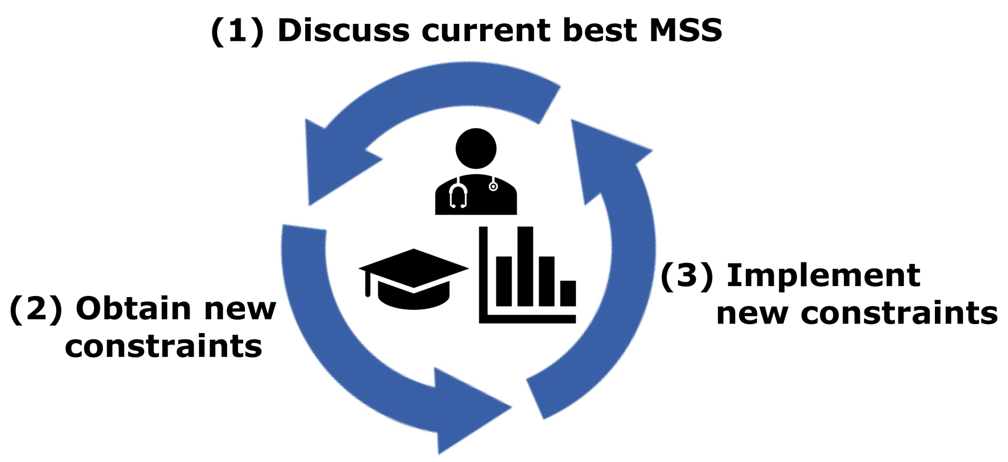

Figure 1: Graphical depiction of research process.

Models & Methods

(1) Master Surgical Schedule as Machine Scheduling Problem

- Each surgical session is a job.
- Each operating room (OR) is a machine.
- Not all schedules are possible due to numerous practical constraints.

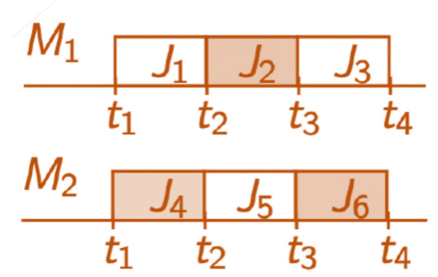

Figure 2: Machine schedule with two machines and six jobs.

(2) Nursing ward as Stochastic Knapsack

- The stochastic knapsack (SK) is a mathematical model, in which objects requiring resource units (RU) randomly arrive to the knapsack, and have to stay there a random amount of time.
- Objects, modelling patients, arrive to the resource, modelling the nursing ward.
- Patients require one bed, the resource unit (RU), and complete their length of stay, their holding time, and disappear from the system.

Figure 4: Graphical depiction of the stochastic knapsack..

(3) Master Surgery Scheduling Problem as Stochastic Knapsack with Periodic Scheduled Arrivals (SKPSA)

- MSS as cyclic schedule generating patient a random number of arrival to nursing wards.
- The patients arrive to the nursing ward, the knapsack, and complete their holding time, their length of stay (LOS).

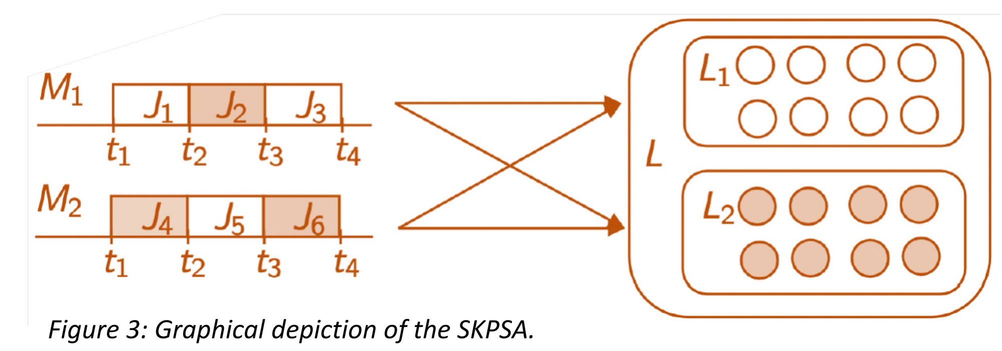

Figure 3: Graphical depiction of the SKPSA.

(4) Approximation by Distributionally Robust Optimization

- Distributionally Robust Optimization (DRO) optimizes with respect to the worst case distribution in a ball of distributions around a reference distribution.
- We apply this to the uncertain LOS and patient outflow per session.
- We reformulate the SKPSA as Mixed Integer Linear Program using tractability results from DRO.

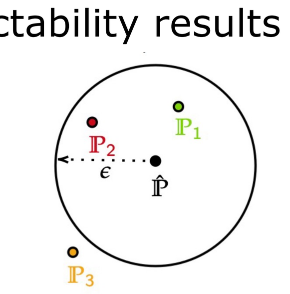

Figure 5: Ball of distributions around a reference distribution.

$$
\begin{aligned}
\min_{\mathbf{x},\mathbf{y}_1,\dots,\mathbf{y}_\ell} \sup_{\substack{\mathbb{Q}_\ell \in \mathcal{P}_\ell,\\ \ell\in\mathcal{L}}} \sum_{\ell=1}^{L} & \mathbb{E}_{\boldsymbol{\xi}_\ell\sim\mathbb{Q}_\ell}\left[\mathbf{y}_\ell^\intercal \mathbf{1}_T\right] \\
\text{s.t.}\quad & p_o\left(\mathbf{c}_\ell - \mathbf{G}_\ell(\mathbf{x})(\mathbf{b}_\ell \odot \boldsymbol{\xi}_\ell)\right) \le \mathbf{y}_\ell, && \ell\in\mathcal{L},\\
& p_u\left(\mathbf{G}_\ell(\mathbf{x})(\mathbf{b}_\ell \odot \boldsymbol{\xi}_\ell) - \mathbf{c}_\ell\right) \le \mathbf{y}_\ell, && \ell\in\mathcal{L},\\
& \mathbf{x}\in\mathcal{X}.
\end{aligned}
$$

Figure 6: Reformulated SKPSA as MILP.

Results

Fewer nurses, more levelled workload

- Optimizing the MSS results in saving one nurse.
- Besides, the occupancy is more flat, which results in less peaks in workload.
- The number of surgical sessions per specialty remains equal.

MSS A: before intervention

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
OK3_MID	NCH	NCH	NCH	KAA				NCH	NCH	NCH	GYN			
OK3_OCH	NCH	NCH	NCH	GYN				NCH	NCH	NCH	GYN			
OK4_MID	ORT	ORT	CHI	ORT	ORT			ORT	ORT	ORT	ORT	ORT		
OK4_OCH	ORT	ORT	PLA	ORT	ORT			ORT	ORT	ORT	ORT	ORT		
OK5_MID	CHI	CHI	CHI	CHI	CHI			CHI	CHI	CHI	CHI	CHI		
OK5_OCH	CHI	CHI	CHI	CHI	CHI			CHI	CHI	CHI	CHI	CHI		
OK7_MID	KNO	GYN	KNO	CHI	KNO			KNO	OOG	KNO	CHI	KNO		
OK7_OCH	CHI	PLA	KNO	CHI	CHI			CHI	CHI	PLA		CHI		
OK8_MID		CHI	CHI	OOG	URO			URO	PLA	CHI	KAA	URO		
OK8_OCH		CHI	CHI	URO	URO			URO	PLA	CHI	URO	URO		

MSS B: after intervention

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
OK3_MID	ORT	GYN	NCH	OOG	CHI			CHI	CHI	KNO	CHI	ORT		
OK3_OCH	ORT	GYN	NCH	OOG	CHI			CHI	CHI	KNO	CHI	ORT		
OK4_MID	NCH	OOG	KNO	CHI	CHI			NCH	GYN	PLA	CHI	CHI		
OK4_OCH	NCH	OOG	KNO	CHI	CHI			NCH	GYN	PLA	CHI	CHI		
OK5_MID	CHI	CHI	CHI	CHI	ORT			NCH	NCH	CHI	CHI	ORT		
OK5_OCH	CHI	CHI	CHI	CHI	ORT			NCH	NCH	CHI	CHI	ORT		
OK7_MID	ORT	PLA	KNO	CHI	ORT			ORT	OOG	KAA	ORT	CHI		
OK7_OCH	ORT		KNO	CHI	ORT			ORT	OOG	KAA	ORT	CHI		
OK8_MID	URO	NCH	PLA	ORT	URO			URO	KNO	URO	CHI	CHI		
OK8_OCH	URO	NCH	PLA	ORT	URO			URO		URO		CHI		

Figure 7: Depiction of saved nurses due to optimization of the MSS.

By simulation we show that we can save up to four beds

- Results obtained by Monte-Carlo Simulation.
- The graph shows lower bed usage and flattened bed occupancy.

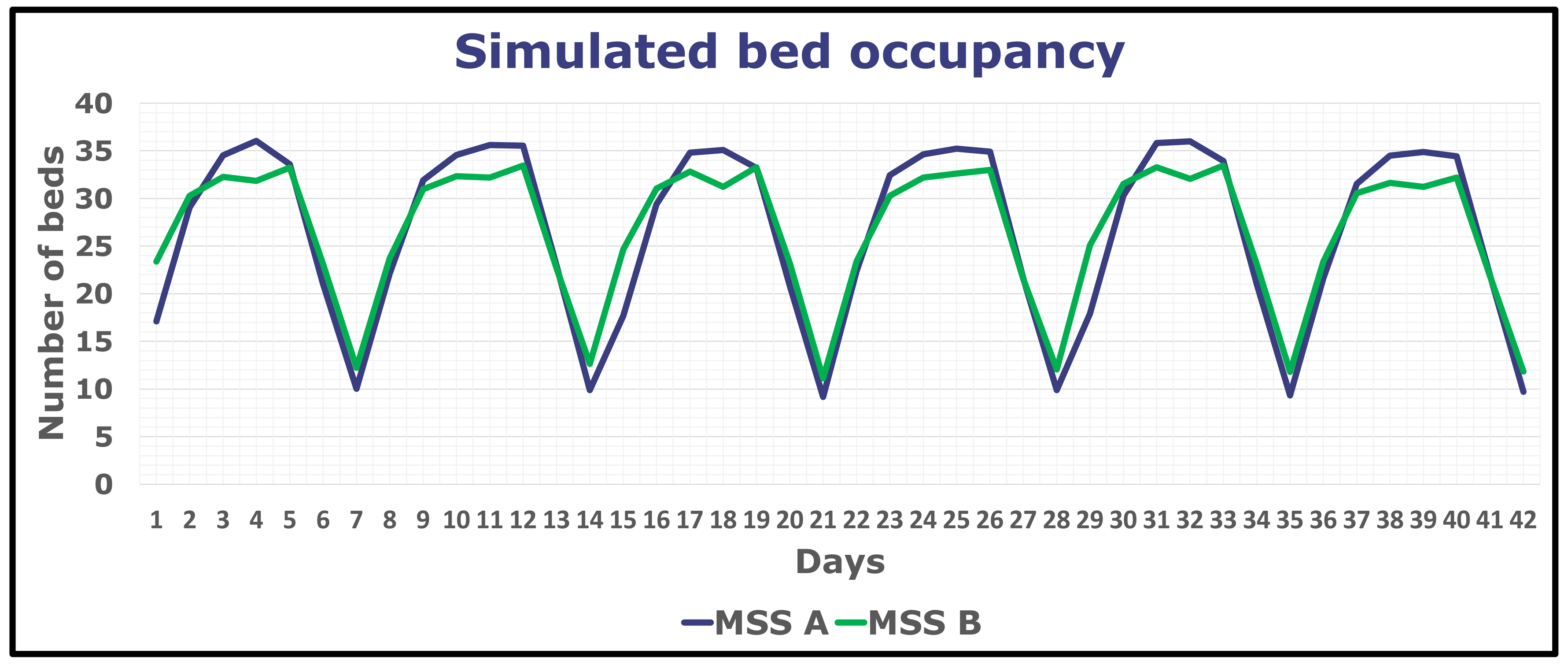

Figure 8: Simulated bed occupancy for current MSS A and optimized MSS B.

Conclusions

- It requires a thorough collaboration between researchers and practitioners to come up with the full set of constraints.
- Our model provides MSSs that make better use of available resources, by saving four beds which means one nurse.

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Based on: H. Bos, R. J. Boucherie, E. W. Hans, and A. G. Leeftink, “Distributionally robust scheduling of stochastic knapsack arrivals,” *Working Paper*, 2023.