Scheduling elective surgeries under uncertainty: a multi-objective stochastic approach

YAMC 2022

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Advisor: Davide Duma

2022-09-22

Overview

1. Introduction
2. Mathematical Models
3. Methodology
4. Computational Analysis
5. Conclusions

Introduction

Problem Statement

$\boxed{p_1}$

$\boxed{p_2}$

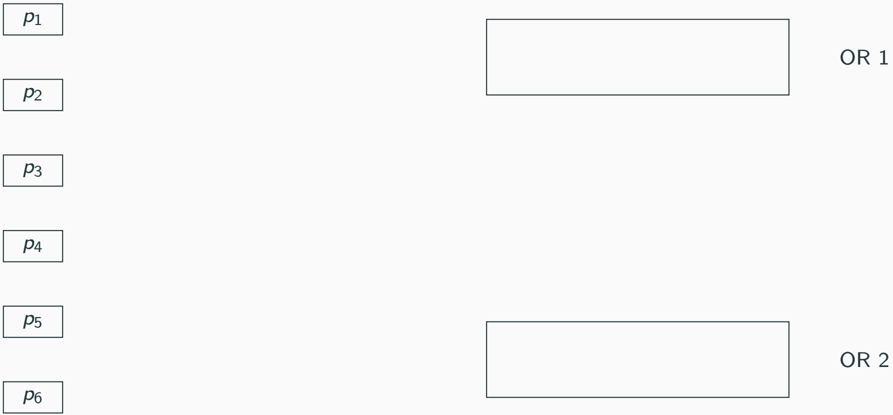
$\boxed{p_3}$

$\boxed{p_4}$

$\boxed{p_5}$

$\boxed{p_6}$

Problem Statement



Problem Statement

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p_2

p_3

p_4

p_5

p_6

OR 1

OR 2

Advance Scheduling:

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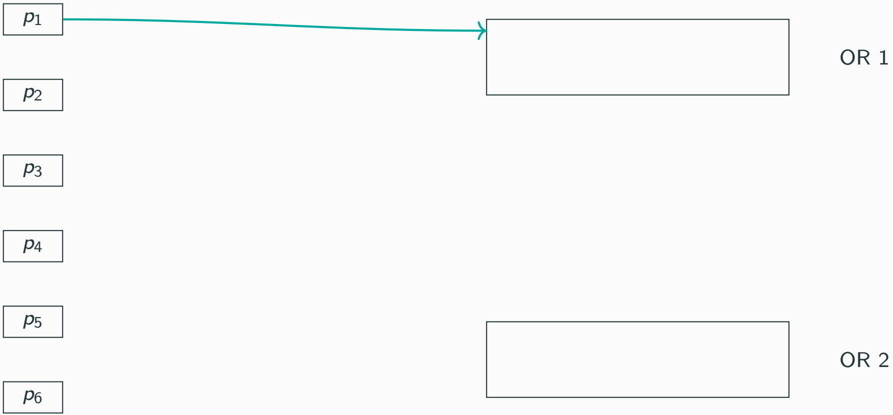

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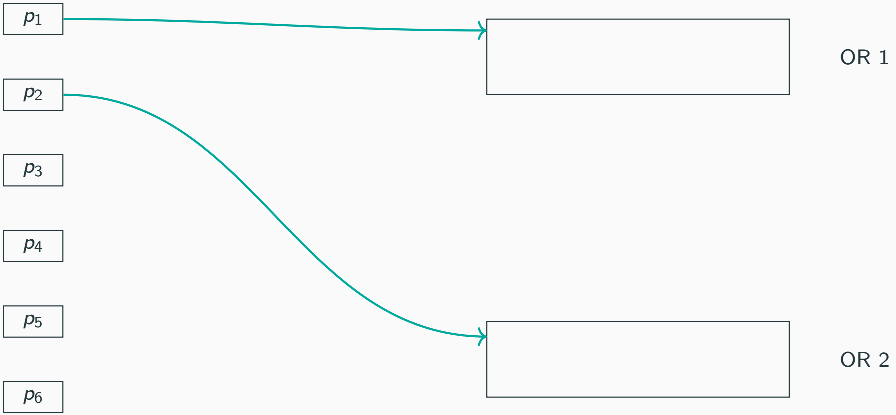

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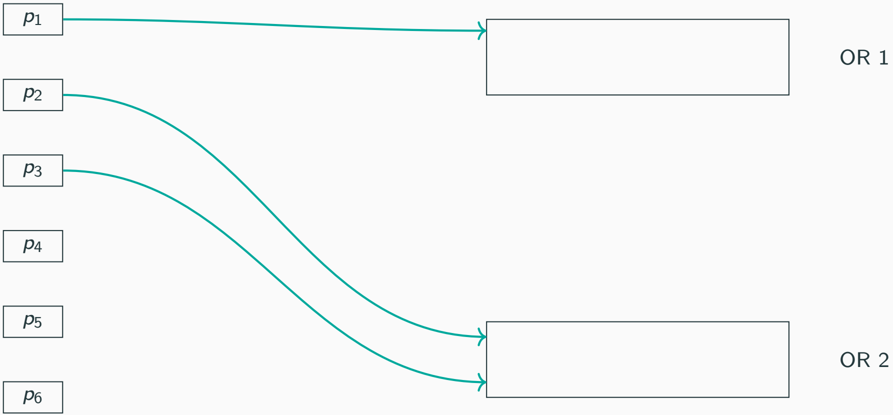

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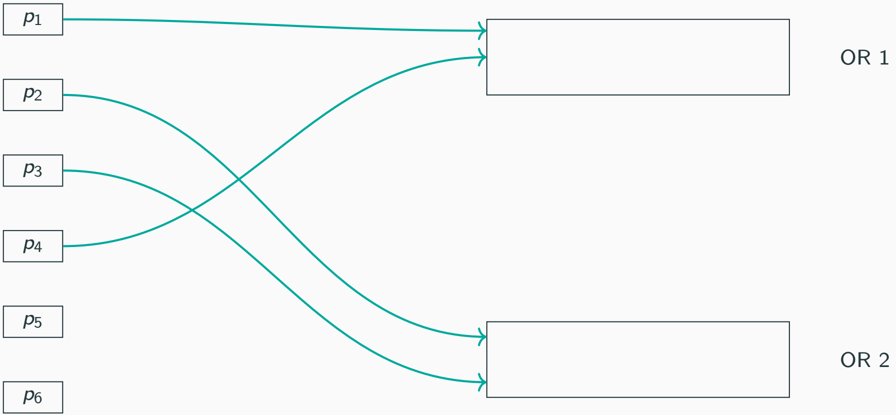

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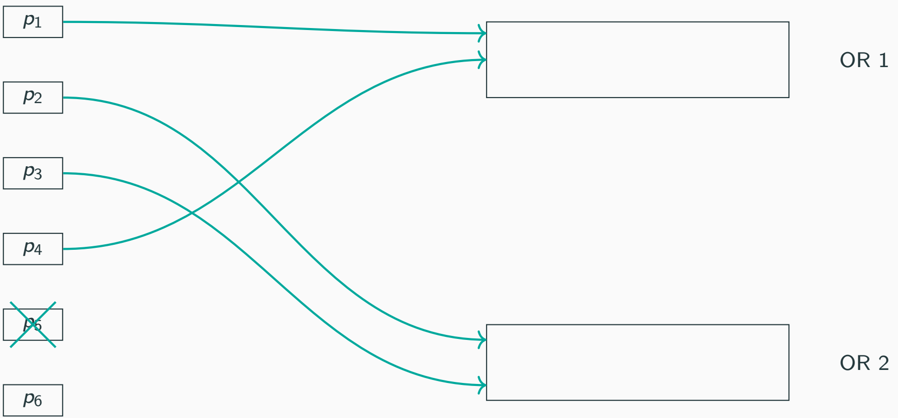

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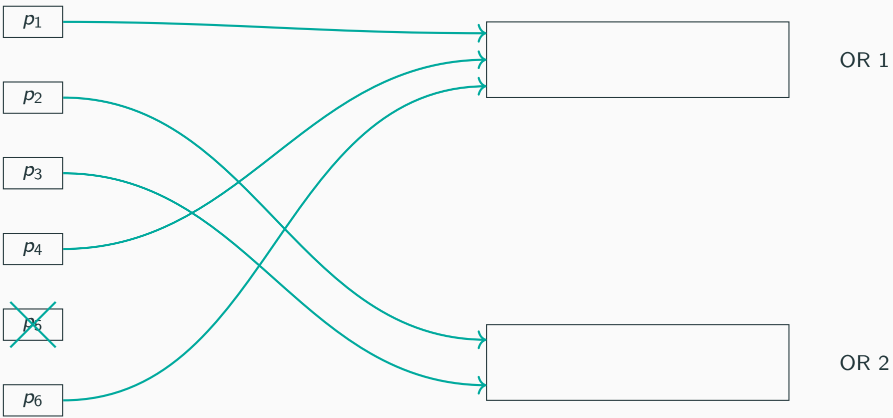

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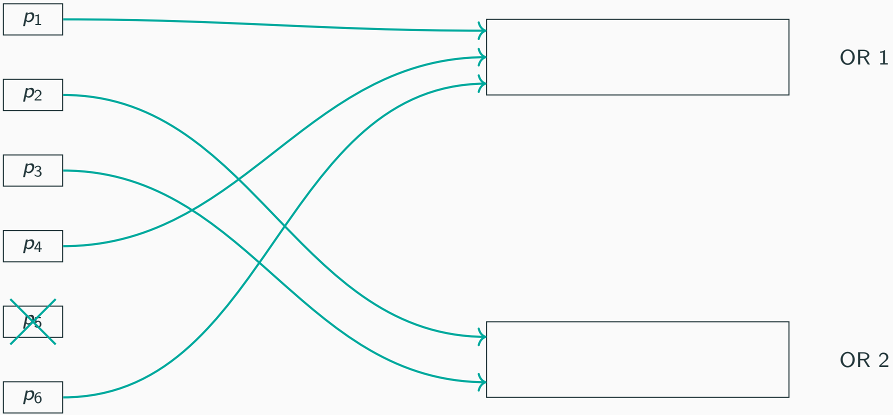

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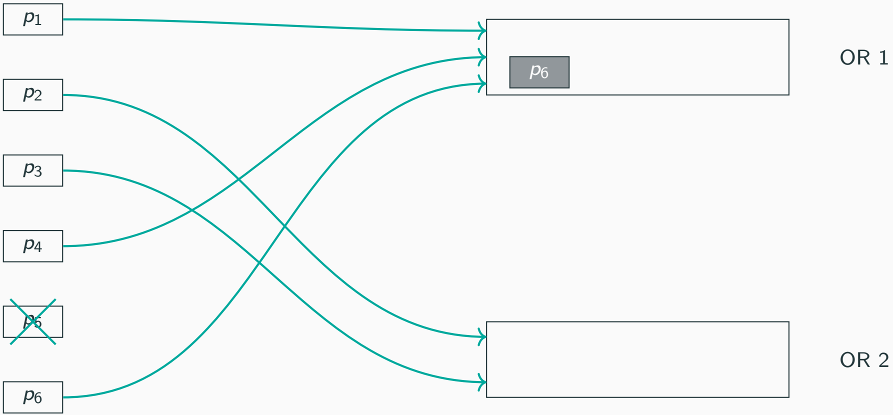

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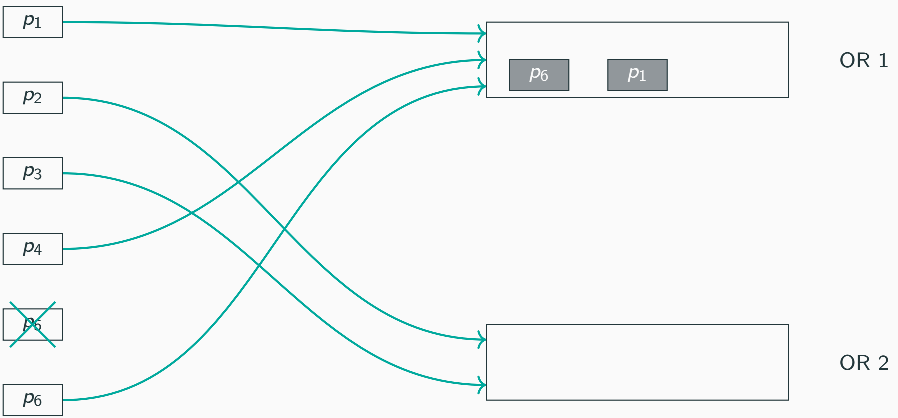

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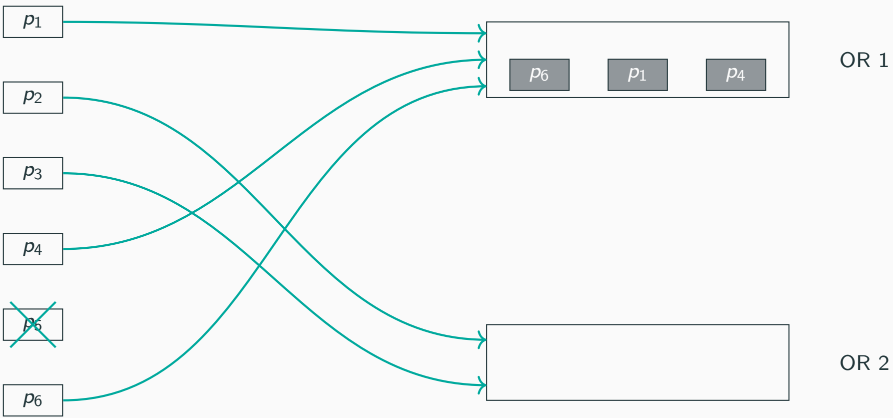

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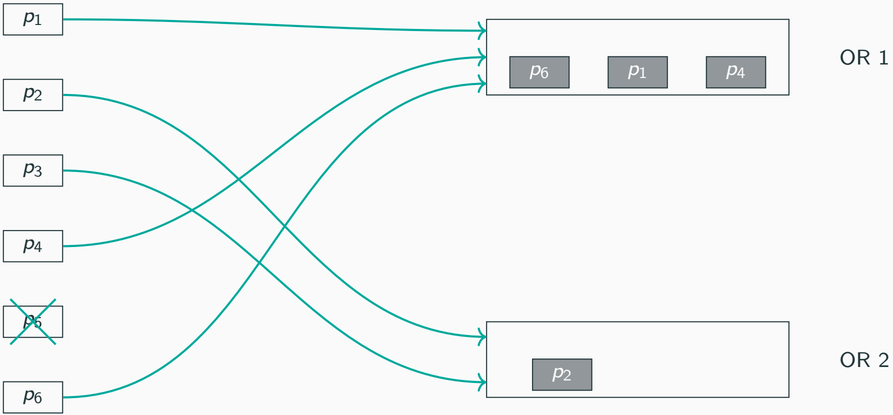

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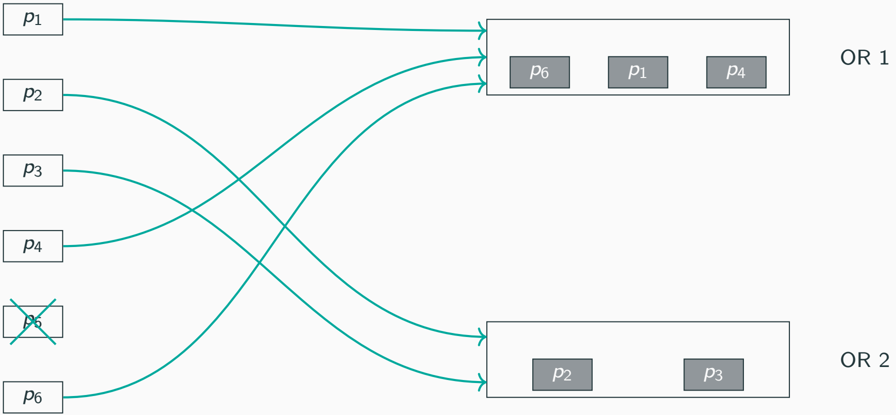

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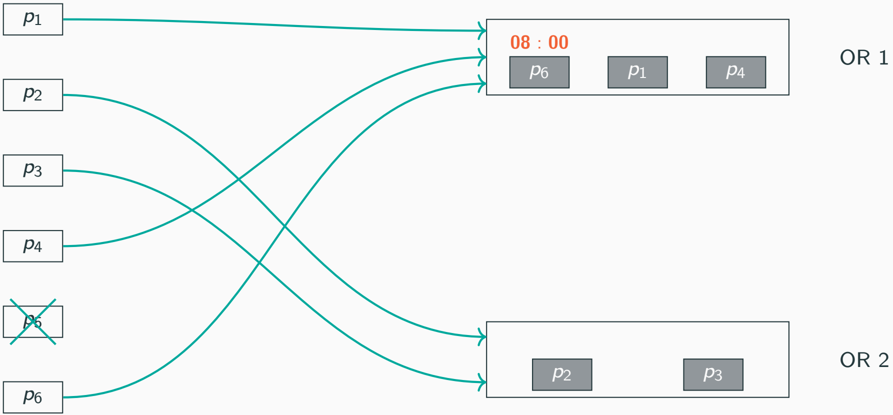

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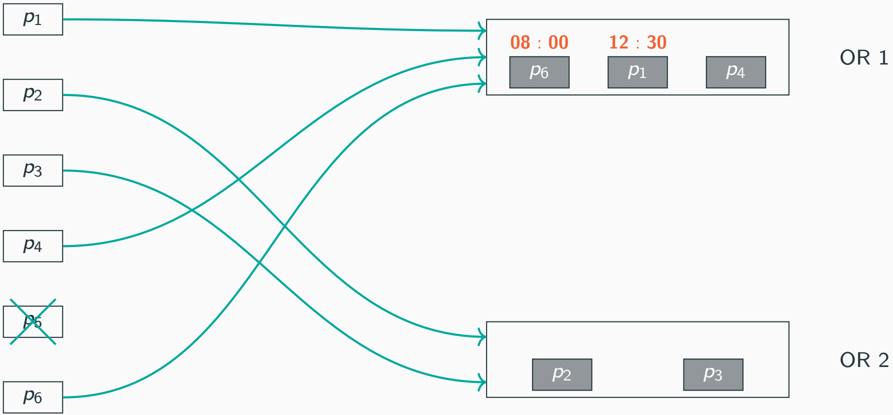

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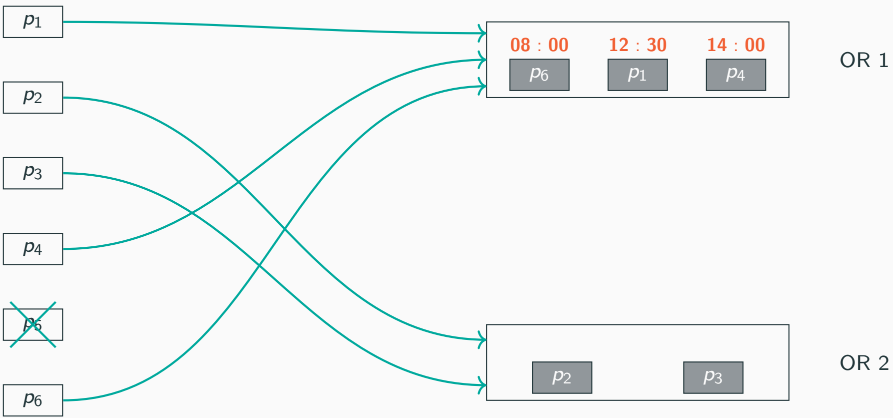

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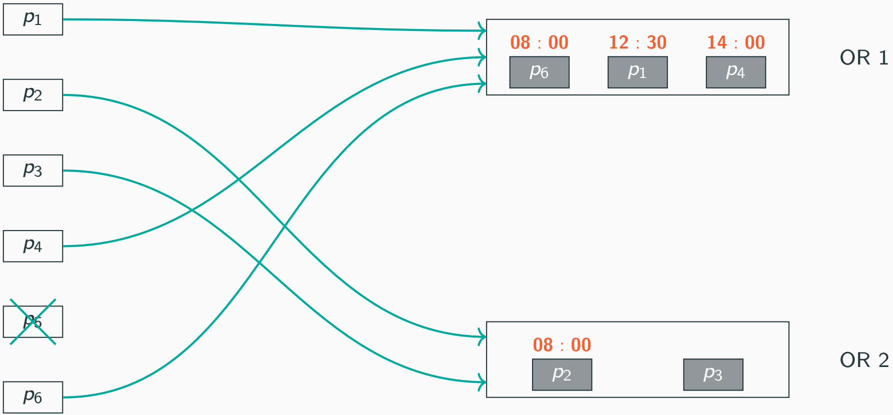

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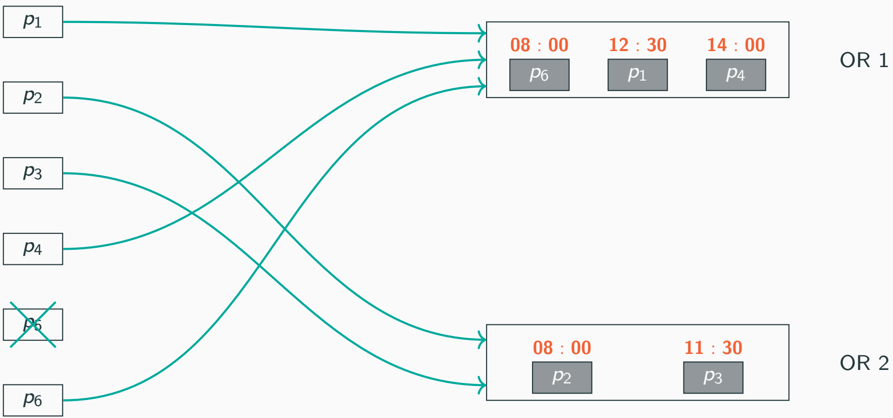

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Objectives

Cancellations	Indirect Waiting Time	Direct Waiting Time	Overtime	Idle Time

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Penalties associated to postponed surgeries

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Days spent waiting for the surgery scheduling

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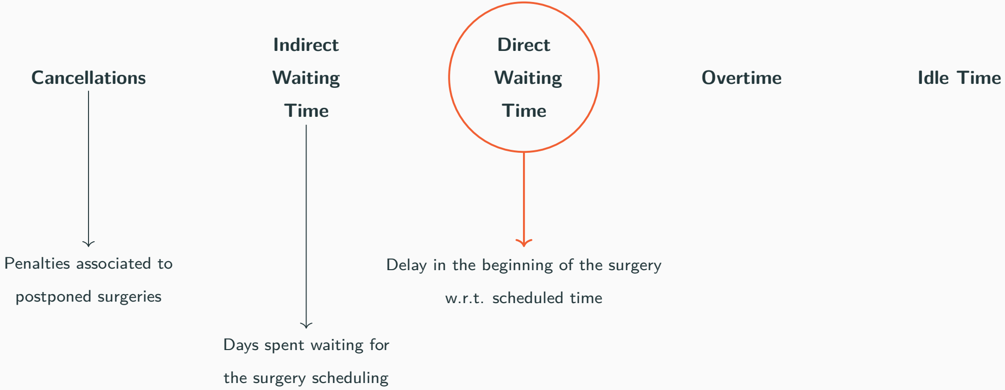

Cancellations
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Days spent waiting for the surgery scheduling
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Idle Time

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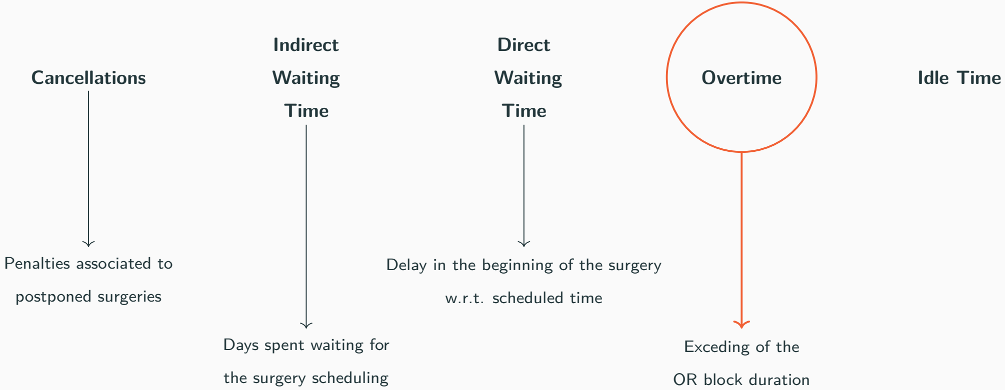

Cancellations
Indirect Waiting Time
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Idle Time
Penalties associated to postponed surgeries
Delay in the beginning of the surgery w.r.t. scheduled time
Days spent waiting for the surgery scheduling
Exceding of the OR block duration

Objectives

Cancellations

Penalties associated to postponed surgeries

Indirect Waiting Time

Days spent waiting for the surgery scheduling

Direct Waiting Time

Delay in the beginning of the surgery w.r.t. scheduled time

Overtime

Exceding of the OR block duration

Idle Time

Unused OR time between surgeries

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Cancellations → Penalties associated to postponed surgeries

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Direct Waiting Time → Delay in the beginning of the surgery w.r.t. scheduled time

Overtime → Exceding of the OR block duration

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Cardoen et al. (2009). Optimizing a multiple objective surgical case sequencing problem. Int. J. Prod. Econ 119(2) pp. 354-366.
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Surgery Duration: the Real Operating Time (ROT) differs from the Estimated Operating Time (EOT).

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No-shows: some patients do not showing up the day of surgery.

Prior Papers

Few prior studies deal with at least two of the three defined **procedures** (AP, SP, and TP) under uncertainty.

Paper	AP	SP	TP	Other decisions	Uncertainty	Objectives	Methodologies
Testi et al. (2007)	✓	✓	✗	MSS	surgery duration	overtime, OR utilization, throughput, bed utilization	DES, ILP, heuristics
Batun et al. (2011)	✓	✓	✗	ORs to be opened, physician-patient assignment	surgery duration	overtime, idle time, financial costs	SMIP
Landa et al. (2016)	✓	✓	✗	overtime allocation	surgery duration	OR utilization, cancellations	SMIP, metaheuristics
Aringhieri et al. (2016)	✓	✓	✗	real-time management	surgery duration	overtime, OR utilization, throughput, cancellations, indirect waiting time, % patient within due date	DES, online algorithms
Duma et al. (2019)	✓	✓	✗	OR policy, real-time management	surgery duration, non-elective patients	overtime, OR utilization, throughput, cancellations, indirect waiting time, % patient within due date	DES, online algorithms
Wang et al. (2022)	✓	✓	✗	partitioning	surgery duration, non-elective patients	overtime, idle time, OR utilization, throughput, cancellations, indirect waiting time, % patient within due date	DES

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This work	✓	✓	✓	-	surgery duration, non-elective patients, no-shows	overtime, idle time, cancellations, direct and indirect waiting time	SMIP, metaheuristics

Mathematical Models

Assumptions

Emergencies: at most one emergency per OR block, arrival with fixed probability and uniform distribution over the OR block duration (= overall Poisson process), duration has lognormal distribution, emergency surgery starts as soon as possible.

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Strum et al. (2003). Estimating times of surgeries with two components procedures comparison of the lognormal and normal models. Anesthesiology 98(1) pp. 232-240.

Cardoen et al. (2009). Optimizing a multiple objective surgical case sequencing problem. Int. J. Prod. Econ 119(2) pp. 354-366.

Denton et al. (2007). Optimizing of surgery sequencing and scheduling decisions under uncertainty. Health Care Manag. Sci. 10(1) pp. 13-24.

Our Approach

MSS, elective
waiting list

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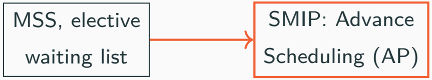

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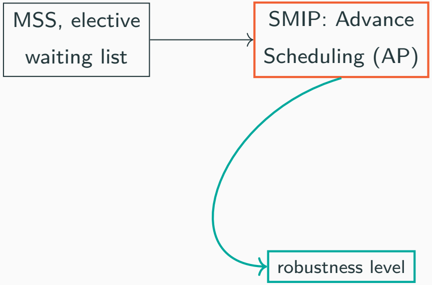

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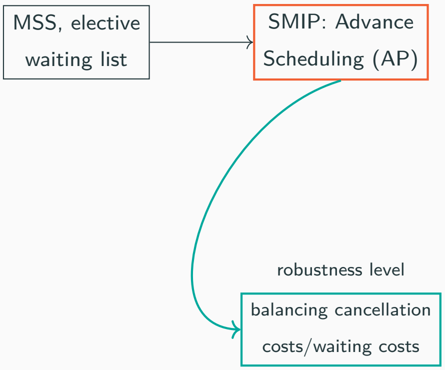

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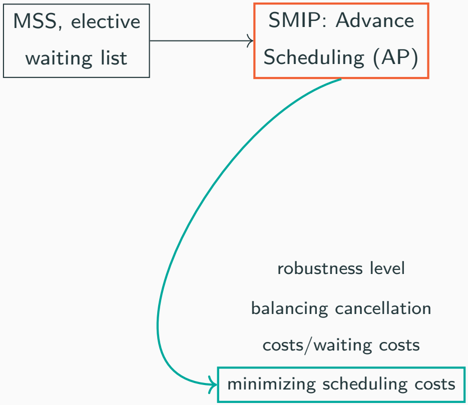

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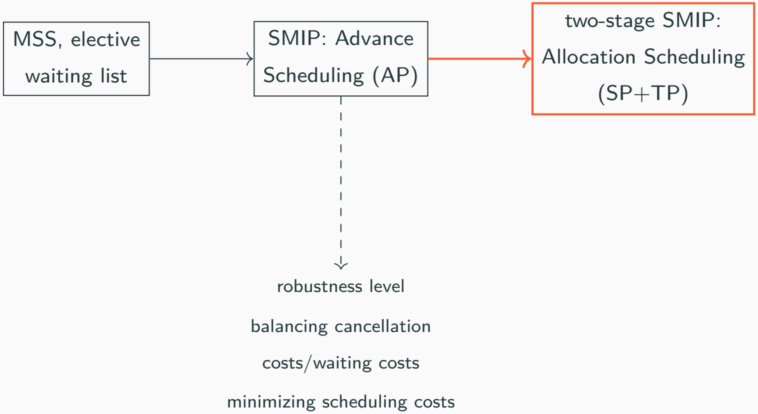

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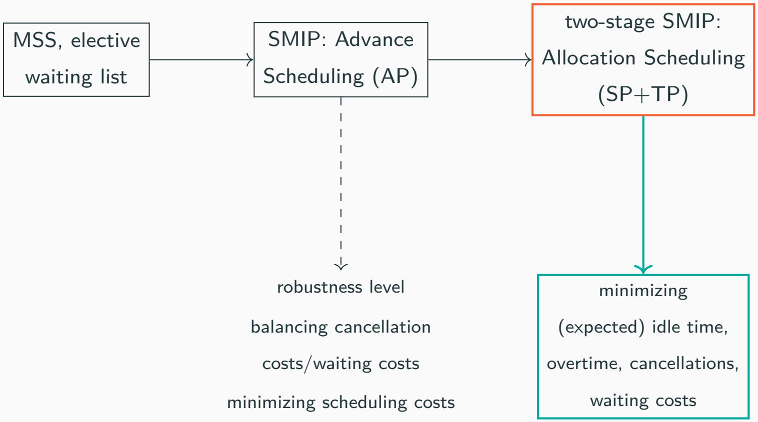

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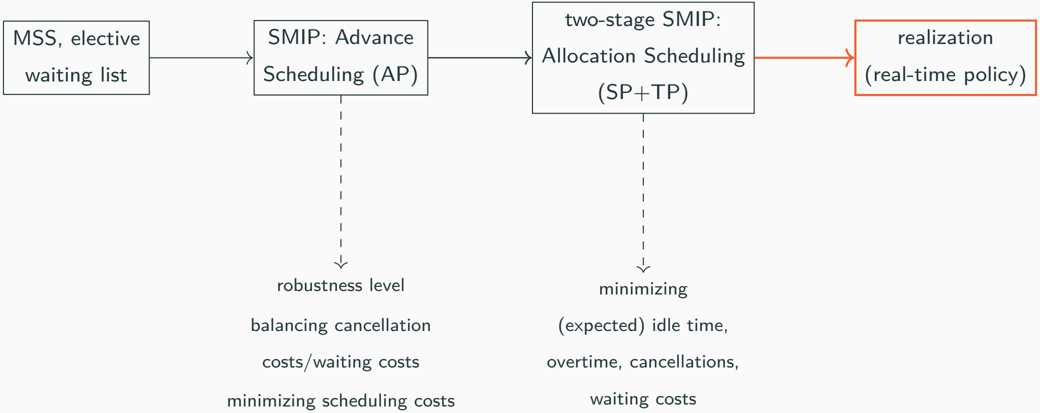

Advance Scheduling - First Model

$$\mathcal{A}_s(\alpha): \qquad \min_{\mathbf{x}} \sum_{i \in W_s} c_i^{sched} \left(1 - \sum_{(j,k) \in B_s} x_{ijk} \right) \tag{1a}$$

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$$\text{s.t.} \sum_{(j,k) \in B_s} x_{ijk} \leq 1, \qquad \forall i \in W_s, \tag{1b}$$

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$$\sum_{i \in W_s} \mu_i x_{ijk} \leq L, \qquad \forall (j,k) \in B_s, \tag{1c}$$

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\mathcal{A}_s(\alpha): \qquad & \min_{\mathbf{x}} \sum_{i \in W_s} c_i^{sched} \left(1 - \sum_{(j,k) \in B_s} x_{ijk} \right) && && \text{(1a)} \\
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& \sum_{i \in W_s} \mu_i x_{ijk} \leq L, && \forall (j,k) \in B_s, && \text{(1c)} \\
& \mathbb{P}_\xi \left[\delta_{jk}(\omega) + \sum_{i \in W_s} \rho_i(\omega) x_{ijk} \leq L + H \right] \geq 1 - \alpha, && \forall (j,k) \in B_s, && \text{(1d)}
\end{aligned}
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& \sum_{i \in W_s} q_i x_{ijk} \leq 1, && \forall (j,k) \in B_s, && \text{(1e)} \\
& \sum_{i \in W_s} u_i x_{ijk} \leq 1, && \forall (j,k) \in B_s, && \text{(1f)}
\end{aligned}
$$

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& \sum_{i\in W_s} u_i x_{ijk} \le 1, && \forall (j,k)\in B_s, && \text{(1f)}\\
& x_{ijk}\in\{0,1\}, && \forall i\in W_s, \forall (j,k)\in B_s. && \text{(1g)}
\end{aligned}
$$

Advance Scheduling - Second Model

Hierarchy and balance constants

$$C_1 = \frac{c_{min}^{sched}}{1 + \sum_{i \in W_s} c_i^{sched}}, \qquad C_2 = \frac{c_{min}^{canc}}{c_{min}^{wait}}.$$

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The Model

$$\mathcal{B}_s(\alpha, \beta, \nu): \quad \min_{\mathbf{x}, \Gamma^{canc}, \Gamma^{wait}} \sum_{i \in W_s} c_i^{sched} \left(1 - \sum_{(j,k) \in B_s} x_{ijk}\right) + \boxed{C_1 \left(\beta \Gamma^{canc} + \nu C_2 \Gamma^{wait}\right)} \tag{2a}$$

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$$\text{s.t.} \quad (1b) - (1g),$$

$$\Gamma^{canc} = \max_{(j,k) \in B_s} \left\{ \sum_{i \in W_s} c_i^{canc} x_{ijk} \right\}, \tag{2b}$$

$$\Gamma^{wait} = \max_{(j,k) \in B_s} \left\{ \sum_{i \in W_s} c_i^{wait} x_{ijk} \right\}. \tag{2c}$$

Allocation Scheduling Model - First Stage

$$\mathcal{C}^{I}_{jk}: \qquad \min_{\mathbf{o},\mathbf{t}} \; \mathbb{E}_{\xi}\left[Q(\mathbf{o},\mathbf{t};\xi(\omega))\right] \tag{3a}$$

Allocation Scheduling Model - First Stage

$$\mathcal{C}^{I}_{jk}: \quad \min_{\mathbf{o},\mathbf{t}} \ \mathbb{E}_{\xi}\left[Q(\mathbf{o},\mathbf{t};\xi(\omega))\right] \tag{3a}$$

$$\text{s.t.} \quad t_i \leq (L-\mu_i) \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i}, \qquad \forall i \in I_{jk}, \tag{3b}$$

Allocation Scheduling Model - First Stage

$$
\begin{aligned}
\mathcal{C}^{I}_{jk}: \qquad & \min_{\mathbf{o},\mathbf{t}} \ \mathbb{E}_{\xi}\left[Q(\mathbf{o},\mathbf{t};\xi(\omega))\right] && && \text{(3a)}\\
& \text{s.t.} \ t_i \le (L-\mu_i)\sum_{i'\in I_{jk}\setminus\{i\}} o_{i'i}, && \forall i \in I_{jk}, && \text{(3b)}\\
& \qquad t_i + \mu_i \le t_{i'} + (1-o_{i'i})M_{i'i}, && \forall i, i' \in I_{jk}, i \neq i', && \text{(3c)}
\end{aligned}
$$

Allocation Scheduling Model - First Stage

$$
\begin{aligned}
\mathcal{C}^I_{jk}: \quad & \min_{\mathbf{o},\mathbf{t}} \ \mathbb{E}_\xi\left[Q(\mathbf{o},\mathbf{t};\xi(\omega))\right] && && \text{(3a)}\\
& \text{s.t.} \ t_i \le (L-\mu_i) \sum_{i' \in I_{jk}\setminus\{i\}} o_{i'i}, && \forall i \in I_{jk}, && \text{(3b)}\\
& t_i + \mu_i \le t_{i'} + (1 - o_{i'i}) M_{i'i}, && \forall i, i' \in I_{jk}, i \neq i', && \text{(3c)}\\
& \sum_{i \in I_{jk}\setminus\{i'\}} o_{i'i} \le 1 - q_{i'}, && \forall i' \in I_{jk}, && \text{(3d)}\\
& \sum_{i' \in I_{jk}\setminus\{i\}} o_{i'i} \le 1 - u_i, && \forall i \in I_{jk}, && \text{(3e)}
\end{aligned}
$$

Allocation Scheduling Model - First Stage

$$
\begin{aligned}
\mathcal{C}^{I}_{jk}: \quad & \min_{\mathbf{o},\mathbf{t}} \ \mathbb{E}_{\xi}\left[Q(\mathbf{o},\mathbf{t};\xi(\omega))\right] && && \text{(3a)} \\
\text{s.t.} \quad & t_i \leq (L-\mu_i) \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i}, && \forall i \in I_{jk}, && \text{(3b)} \\
& t_i + \mu_i \leq t_{i'} + (1 - o_{i'i}) M_{i'i}, && \forall i, i' \in I_{jk}, i \neq i', && \text{(3c)} \\
& \sum_{i \in I_{jk} \setminus \{i'\}} o_{i'i} \leq 1 - q_{i'}, && \forall i' \in I_{jk}, && \text{(3d)} \\
& \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i} \leq 1 - u_i, && \forall i \in I_{jk}, && \text{(3e)} \\
& \sum_{i \in I_{jk}} \sum_{i' \in I_{jk} \setminus \{i\}} = |I_{jk}| - 1, && && \text{(3f)}
\end{aligned}
$$

Allocation Scheduling Model - First Stage

$$\mathcal{C}^{I}_{jk}: \quad \min_{\mathbf{o},\mathbf{t}} \ \mathbb{E}_{\xi}\left[Q(\mathbf{o},\mathbf{t};\xi(\omega))\right] \tag{3a}$$

$$\text{s.t.} \quad t_i \leq (L-\mu_i) \sum_{i' \in I_{jk}\setminus\{i\}} o_{i'i}, \qquad \forall i \in I_{jk}, \tag{3b}$$

$$t_i + \mu_i \leq t_{i'} + (1 - o_{i'i})M_{i'i}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{3c}$$

$$\sum_{i \in I_{jk}\setminus\{i'\}} o_{i'i} \leq 1 - q_{i'}, \qquad \forall i' \in I_{jk}, \tag{3d}$$

$$\sum_{i' \in I_{jk}\setminus\{i\}} o_{i'i} \leq 1 - u_i, \qquad \forall i \in I_{jk}, \tag{3e}$$

$$\sum_{i \in I_{jk}} \sum_{i' \in I_{jk}\setminus\{i\}} = |I_{jk}| - 1, \tag{3f}$$

$$o_{ii'} \in \{0,1\}, t_i \geq 0, \qquad \forall i, i' \in I_{jk}, i \neq i'. \tag{3g}$$

Allocation Scheduling Model - Second Stage

$$\mathcal{C}^{II}_{jk}(\omega): \qquad \min_{\mathbf{o},\mathbf{t}} \; c^h h_{jk} + c^g g_{jk} + \sum_{i \in I_{jk}} c_i^{canc}(1 - y_i) + \sum_{i \in I_{jk}} c_i^{wait} a_i \tag{4a}$$

Allocation Scheduling Model - Second Stage

$$
\begin{aligned}
\mathcal{C}^{II}_{jk}(\omega): \qquad & \min_{\mathbf{o},\mathbf{t}} \; c^h h_{jk} + c^g g_{jk} + \sum_{i \in I_{jk}} c_i^{canc}(1 - y_i) + \sum_{i \in I_{jk}} c_i^{wait} a_i && && \text{(4a)} \\
& \text{s.t.} \; o_{ii'} = 1 \implies q_{i'} = \max\{c_i, t_{i'}\} \wedge \hat{q}_{i'} = \max\{\hat{c}_i, t_{i'}\}, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4b)} \\
& \qquad q_i, \hat{q}_i \leq M \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i}, && \forall i \in I_{jk}, && \text{(4c)}
\end{aligned}
$$

Allocation Scheduling Model - Second Stage

$$
\begin{aligned}
\mathcal{C}^{II}_{jk}(\omega): \qquad & \min_{\mathbf{o},\mathbf{t}} \; c^h h_{jk} + c^g g_{jk} + \sum_{i \in I_{jk}} c_i^{canc}(1 - y_i) + \sum_{i \in I_{jk}} c_i^{wait} a_i && && \text{(4a)} \\
& \text{s.t.} \; o_{ii'} = 1 \implies q_{i'} = \max\{c_i, t_{i'}\} \wedge \hat{q}_{i'} = \max\{\hat{c}_i, t_{i'}\}, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4b)} \\
& q_i, \hat{q}_i \leq M \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i}, && \forall i \in I_{jk}, && \text{(4c)} \\
& c_i = q_i + \rho_i(\omega)\theta_i(\omega) y_i + z_i + \delta_{jk}(\omega) e_i, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4d)} \\
& \hat{c}_i = \hat{q}_i + \rho_i(\omega)\theta_i(\omega) y_i, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4e)}
\end{aligned}
$$

Allocation Scheduling Model - Second Stage

$$
\begin{aligned}
\mathcal{C}^{II}_{jk}(\omega): \quad & \min_{\mathbf{o},\mathbf{t}} \; c^h h_{jk} + c^g g_{jk} + \sum_{i \in I_{jk}} c_i^{canc}(1 - y_i) + \sum_{i \in I_{jk}} c_i^{wait} a_i && && (4a) \\
\text{s.t. } & o_{ii'} = 1 \implies q_{i'} = \max\{c_i, t_{i'}\} \wedge \hat{q}_{i'} = \max\{\hat{c}_i, t_{i'}\}, && \forall i, i' \in I_{jk}, i \neq i', && (4b) \\
& q_i, \hat{q}_i \leq M \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i}, && \forall i \in I_{jk}, && (4c) \\
& c_i = q_i + \rho_i(\omega)\theta_i(\omega)y_i + z_i + \delta_{jk}(\omega)e_i, && \forall i, i' \in I_{jk}, i \neq i', && (4d) \\
& \hat{c}_i = \hat{q}_i + \rho_i(\omega)\theta_i(\omega)y_i, && \forall i, i' \in I_{jk}, i \neq i', && (4e) \\
& C \geq \theta_i(\omega)(q_i + \rho_i(\omega)y_i) + z_i + \delta_{jk}(\omega)e_i - (1 - y_i)M, && \forall i \in I_{jk}, && (4f) \\
& C \geq \tau_{jk}(\omega) + \delta_{jk}(\omega), && \forall i \in I_{jk}, && (4g)
\end{aligned}
$$

Allocation Scheduling Model - Second Stage

$$
\begin{aligned}
\mathcal{C}^{II}_{jk}(\omega): \quad & \min_{\mathbf{o},\mathbf{t}} \; c^h h_{jk} + c^g g_{jk} + \sum_{i \in I_{jk}} c_i^{canc}(1 - y_i) + \sum_{i \in I_{jk}} c_i^{wait} a_i && && \text{(4a)} \\
\text{s.t.} \quad & o_{ii'} = 1 \implies q_{i'} = \max\{c_i, t_{i'}\} \wedge \hat{q}_{i'} = \max\{\hat{c}_i, t_{i'}\}, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4b)} \\
& q_i, \hat{q}_i \leq M \sum_{i' \in I_{jk} \setminus \{i\}} o_{i'i}, && \forall i \in I_{jk}, && \text{(4c)} \\
& c_i = q_i + \rho_i(\omega)\theta_i(\omega)y_i + z_i + \delta_{jk}(\omega)e_i, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4d)} \\
& \hat{c}_i = \hat{q}_i + \rho_i(\omega)\theta_i(\omega)y_i, && \forall i, i' \in I_{jk}, i \neq i', && \text{(4e)} \\
& C \geq \theta_i(\omega)(q_i + \rho_i(\omega)y_i) + z_i + \delta_{jk}(\omega)e_i - (1 - y_i)M, && \forall i \in I_{jk}, && \text{(4f)} \\
& C \geq \tau_{jk}(\omega) + \delta_{jk}(\omega), && \forall i \in I_{jk}, && \text{(4g)} \\
& z_i \leq M e_i, && \forall i \in I_{jk}, && \text{(4h)} \\
& \sum_{i \in I_{jk}} e_i = 1, && \forall i \in I_{jk}, && \text{(4i)}
\end{aligned}
$$

Allocation Scheduling Model - Second Stage

$$e_i = 1 \wedge o_{ii'} = 1 \iff \hat{q}_i \leq \tau_{jk}(\omega) < \hat{q}_{i'}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{4j}$$

Allocation Scheduling Model - Second Stage

$$e_i = 1 \land o_{ii'} = 1 \iff \hat{q}_i \leq \tau_{jk}(\omega) < \hat{q}_{i'}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{4j}$$

$$\begin{cases} e_i = 1, \\ \tau_{jk}(\omega) > q_i + \rho_i(\omega)\theta_i(\omega)y_i \end{cases} \implies z_i = \tau_{jk}(\omega) - (q_i + \rho_i(\omega)\theta_i(\omega)y_i), \qquad \forall i \in I_{jk}, \tag{4k}$$

Allocation Scheduling Model - Second Stage

$$e_i = 1 \wedge o_{ii'} = 1 \iff \hat{q}_i \leq \tau_{jk}(\omega) < \hat{q}_{i'}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{4j}$$

$$\begin{cases} e_i = 1, \\ \tau_{jk}(\omega) > q_i + \rho_i(\omega)\theta_i(\omega)y_i \end{cases} \implies z_i = \tau_{jk}(\omega) - (q_i + \rho_i(\omega)\theta_i(\omega)y_i), \qquad \forall i \in I_{jk}, \tag{4k}$$

$$\theta_i(\omega)(q_i + \mu_i) \leq L + H \iff y_i = 1, \qquad \forall i \in I_{jk}, \tag{4l}$$

Allocation Scheduling Model - Second Stage

$$e_i = 1 \land o_{ii'} = 1 \iff \hat{q}_i \le \tau_{jk}(\omega) < \hat{q}_{i'}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{4j}$$

$$\begin{cases} e_i = 1, \\ \tau_{jk}(\omega) > q_i + \rho_i(\omega)\theta_i(\omega)y_i \end{cases} \implies z_i = \tau_{jk}(\omega) - (q_i + \rho_i(\omega)\theta_i(\omega)y_i), \qquad \forall i \in I_{jk}, \tag{4k}$$

$$\theta_i(\omega)(q_i + \mu_i) \le L + H \iff y_i = 1, \qquad \forall i \in I_{jk}, \tag{4l}$$

$$y_i \ge 1 - \theta_i(\omega), \qquad \forall i \in I_{jk}, \tag{4m}$$

Allocation Scheduling Model - Second Stage

$$e_i = 1 \wedge o_{ii'} = 1 \iff \hat{q}_i \leq \tau_{jk}(\omega) < \hat{q}_{i'}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{4j}$$

$$\begin{cases} e_i = 1, \\ \tau_{jk}(\omega) > q_i + \rho_i(\omega)\theta_i(\omega)y_i \end{cases} \implies z_i = \tau_{jk}(\omega) - (q_i + \rho_i(\omega)\theta_i(\omega)y_i), \qquad \forall i \in I_{jk}, \tag{4k}$$

$$\theta_i(\omega)(q_i + \mu_i) \leq L + H \iff y_i = 1, \qquad \forall i \in I_{jk}, \tag{4l}$$

$$y_i \geq 1 - \theta_i(\omega), \qquad \forall i \in I_{jk}, \tag{4m}$$

$$a_i \geq q_i - t_i - M(1 - y_i\theta_i(\omega)), \qquad \forall i \in I_{jk}, \tag{4n}$$

$$h_{jk} \geq C - L, \qquad \forall i \in I_{jk}, \tag{4o}$$

$$g_{jk} \geq \max\{L, C\} - \sum_{i \in I_{jk}} \rho_i(\omega)\theta_i(\omega)y_i - \delta_{jk}(\omega), \qquad \forall i \in I_{jk}, \tag{4p}$$

Allocation Scheduling Model - Second Stage

$$e_i = 1 \wedge o_{ii'} = 1 \iff \hat{q}_i \leq \tau_{jk}(\omega) < \hat{q}_{i'}, \qquad \forall i, i' \in I_{jk}, i \neq i', \tag{4j}$$

$$\begin{cases} e_i = 1, \\ \tau_{jk}(\omega) > q_i + \rho_i(\omega)\theta_i(\omega)y_i \end{cases} \implies z_i = \tau_{jk}(\omega) - (q_i + \rho_i(\omega)\theta_i(\omega)y_i), \qquad \forall i \in I_{jk}, \tag{4k}$$

$$\theta_i(\omega)(q_i + \mu_i) \leq L + H \iff y_i = 1, \qquad \forall i \in I_{jk}, \tag{4l}$$

$$y_i \geq 1 - \theta_i(\omega), \qquad \forall i \in I_{jk}, \tag{4m}$$

$$a_i \geq q_i - t_i - M(1 - y_i\theta_i(\omega)), \qquad \forall i \in I_{jk}, \tag{4n}$$

$$h_{jk} \geq C - L, \qquad \forall i \in I_{jk}, \tag{4o}$$

$$g_{jk} \geq \max\{L, C\} - \sum_{i \in I_{jk}} \rho_i(\omega)\theta_i(\omega)y_i - \delta_{jk}(\omega), \qquad \forall i \in I_{jk}, \tag{4p}$$

$$h_{jk}, g_{jk}, q_i, \hat{q}_i, c_i, \hat{c}_i, C, z_i, a_i \geq 0, \quad y_i, e_i \in \{0, 1\}, \qquad \forall i \in I_{jk}. \tag{4q}$$

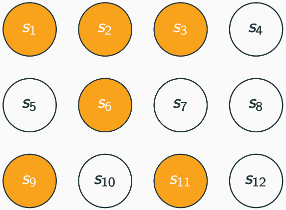
Methodology

SAA and SAA_N

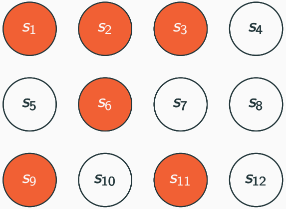
SAA

SAA and SAA_N

SAA

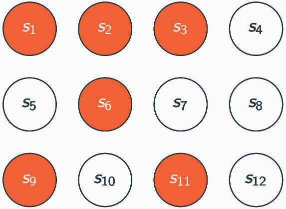


SAA



SAA and $\mathrm{SAA_N}$

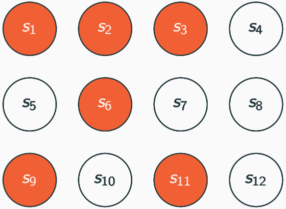
SAA



$\mathrm{SAA_N}$

SAA and SAA$_N$

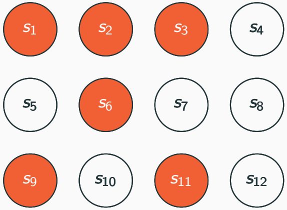
SAA



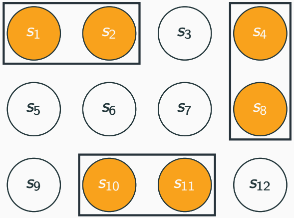
SAA$_N$

SAA and SAA_N

SAA

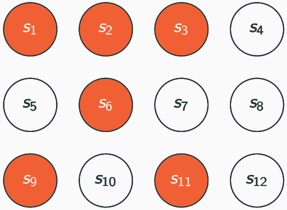


SAA_N

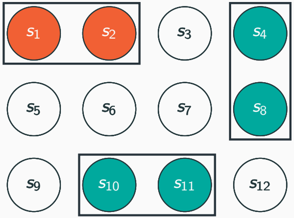


SAA and SAA_N

SAA

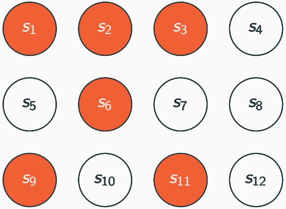


SAA_N

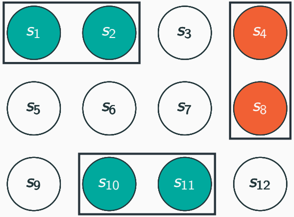


SAA and SAA_N

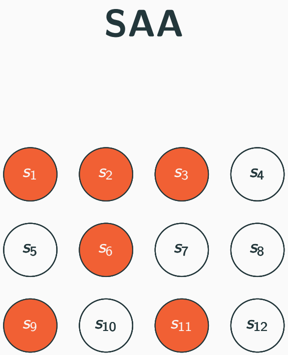
SAA

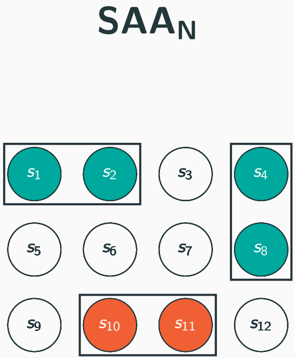


SAA_N



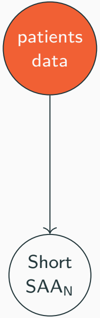
SAA and SAA_N


SAA
s_1 s_2 s_3 s_4
s_5 s_6 s_7 s_8
s_9 s_{10} s_{11} s_{12}

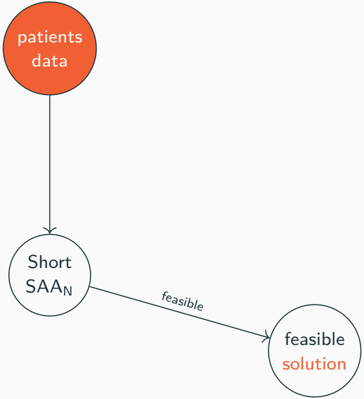

SAA_N
s_1 s_2 s_3 s_4
s_5 s_6 s_7 s_8
s_9 s_{10} s_{11} s_{12}

Advance Scheduling - SCI

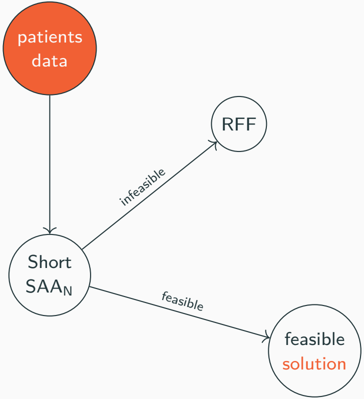
Advance Scheduling - SCI



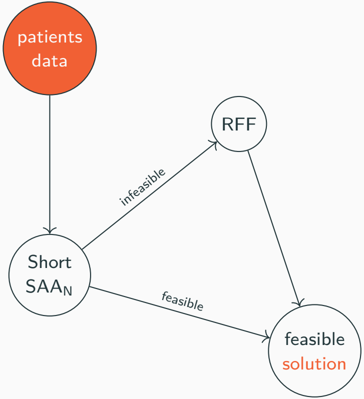
Advance Scheduling - SCI



Advance Scheduling - SCI



Advance Scheduling - SCI



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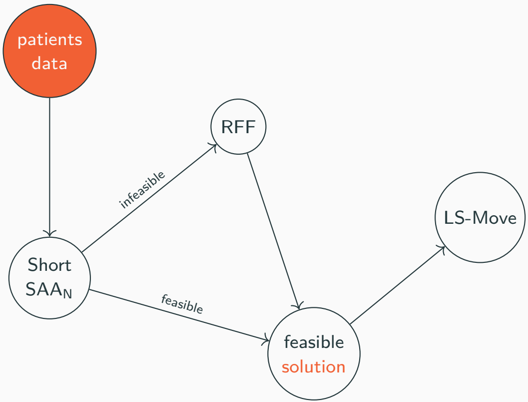
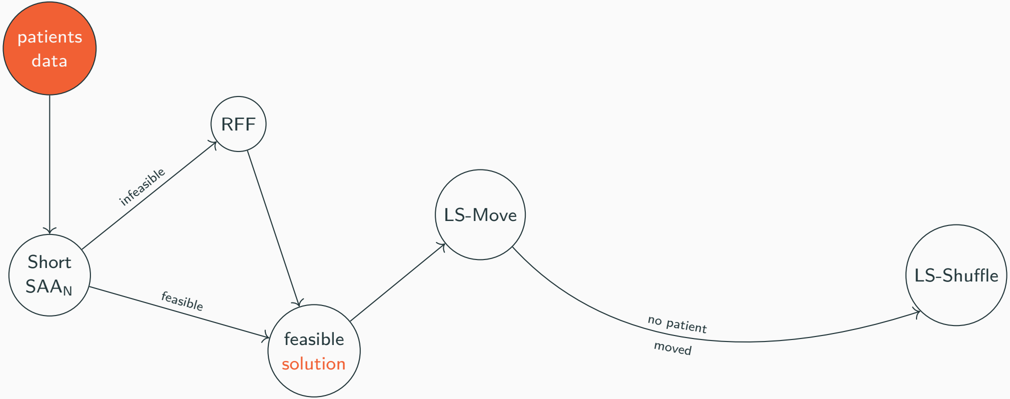
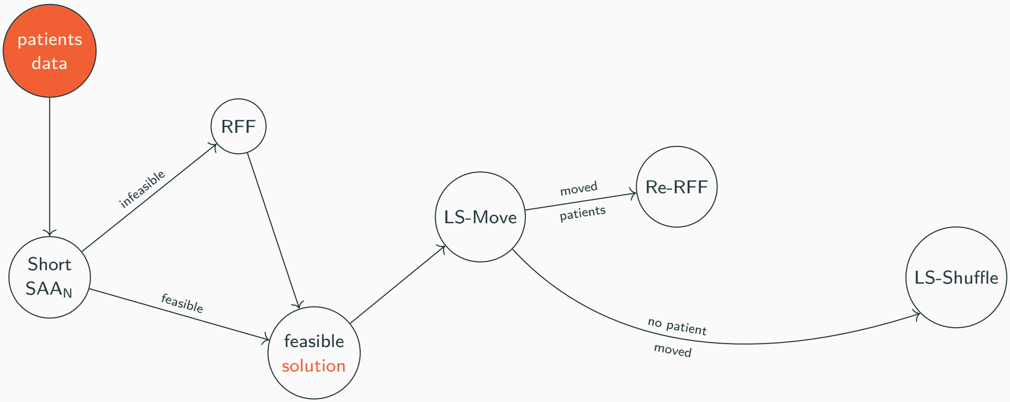


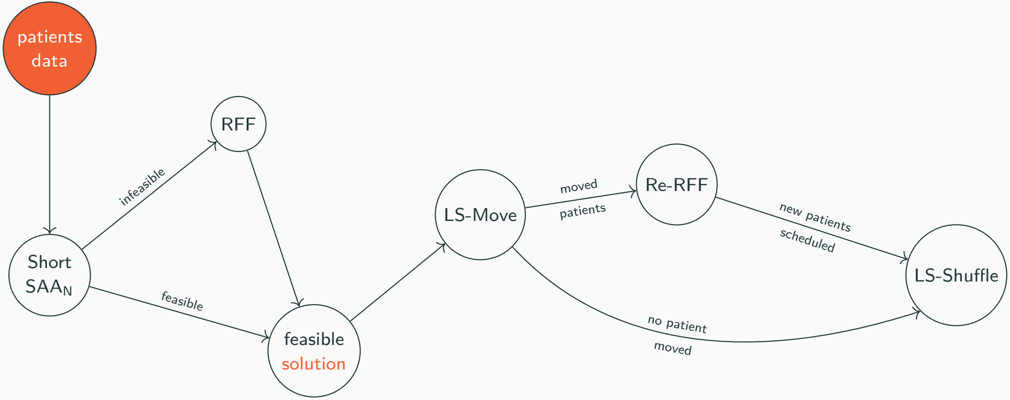
Advance Scheduling - SCI



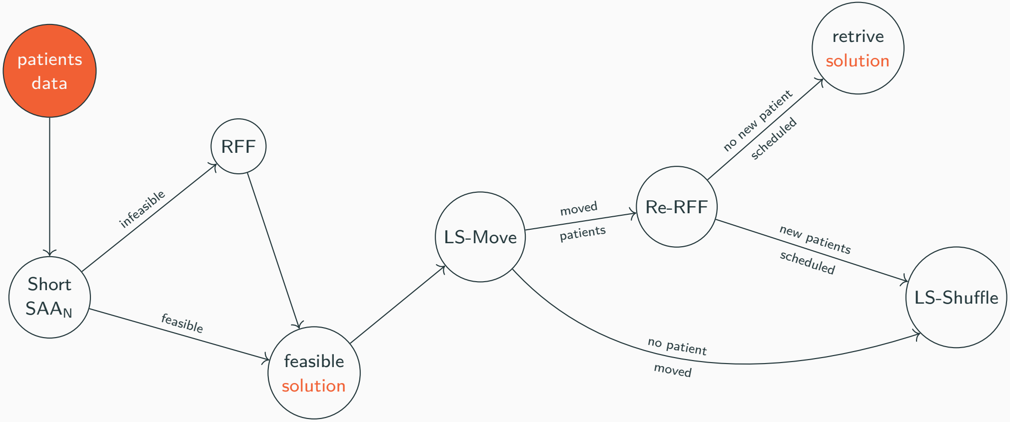
Advance Scheduling - SCI



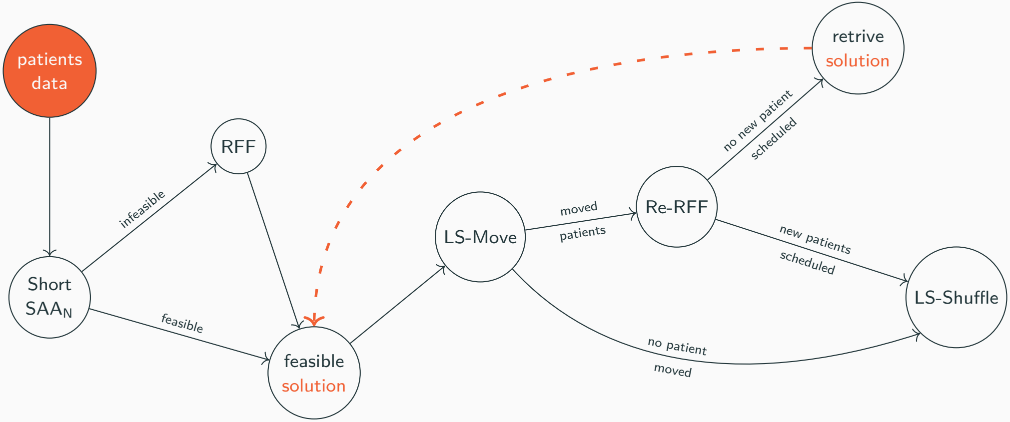
Advance Scheduling - SCI



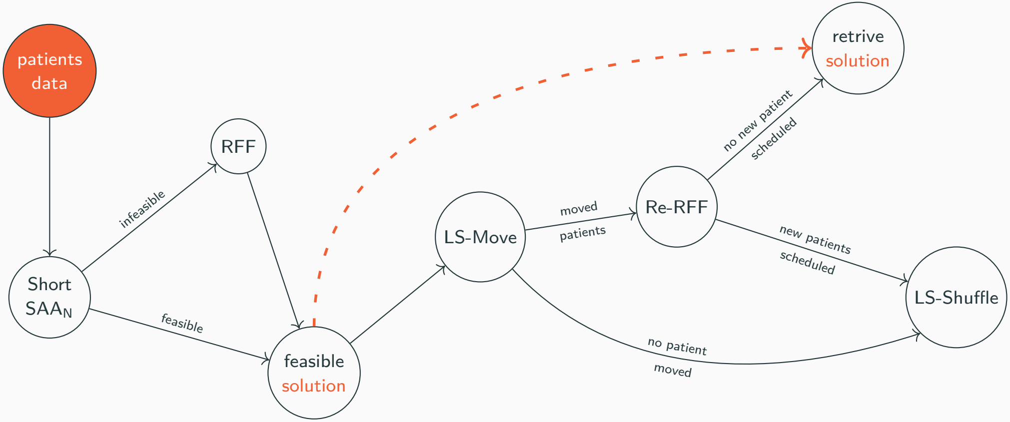
Advance Scheduling - SCI



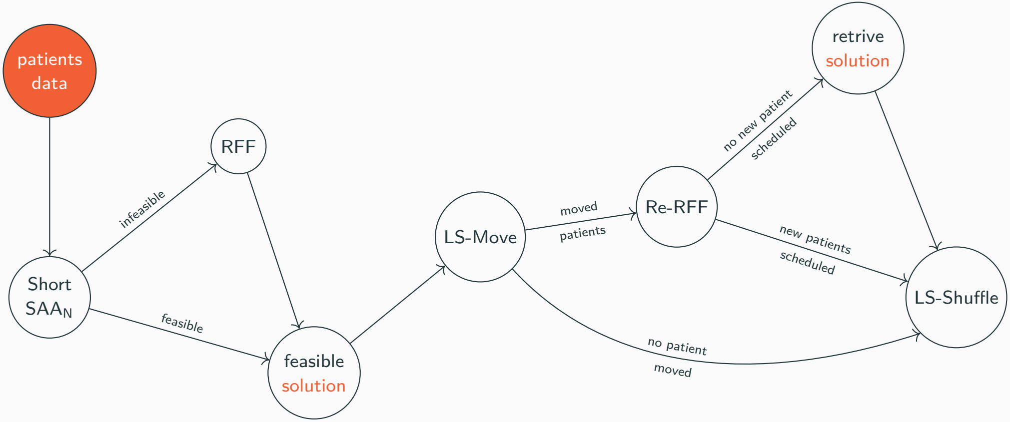
Advance Scheduling - SCI



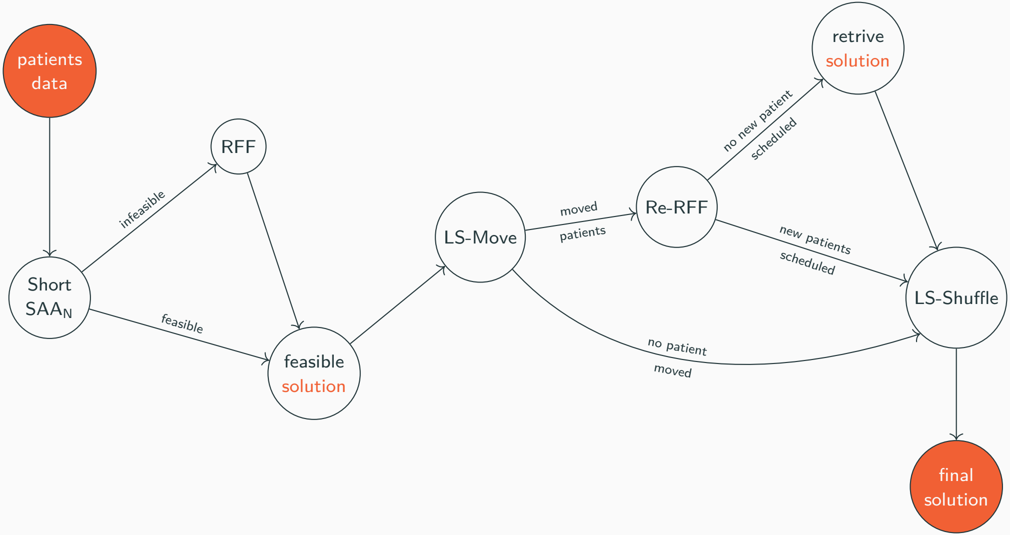
Advance Scheduling - SCI



Advance Scheduling - SCI



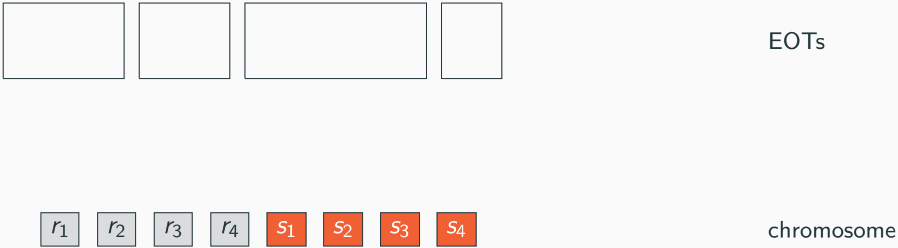
Advance Scheduling - SCI



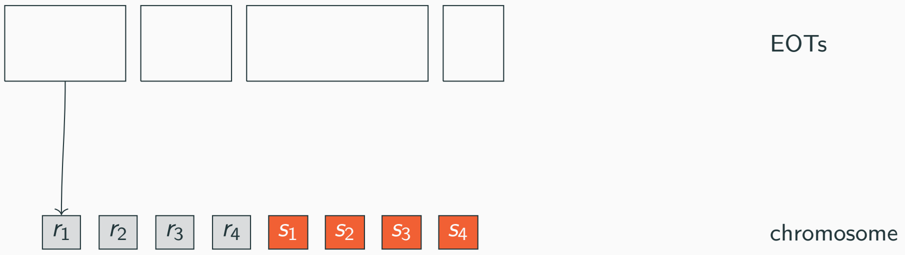
Allocation Scheduling - BRKGA

EOTs

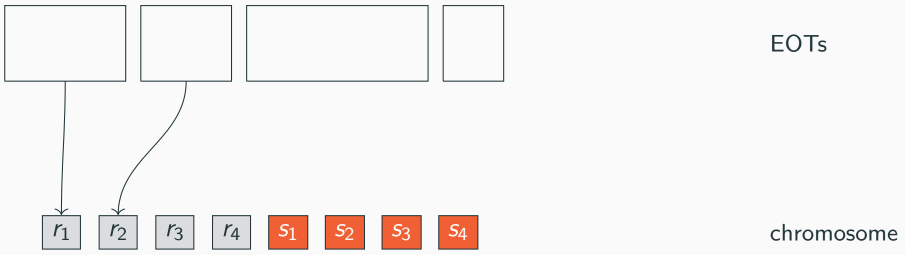
Allocation Scheduling - BRKGA



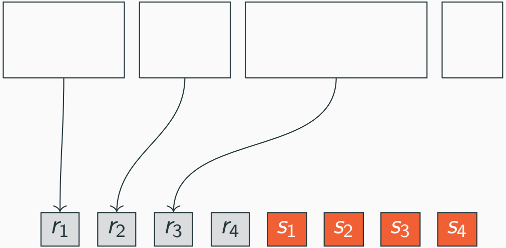
Allocation Scheduling - BRKGA



Allocation Scheduling - BRKGA



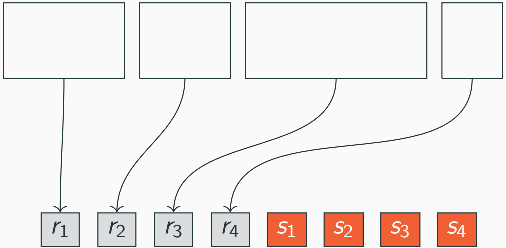
Allocation Scheduling - BRKGA



EOTs

chromosome

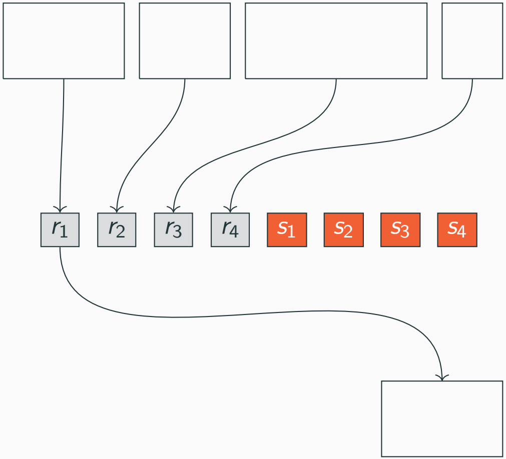
Allocation Scheduling - BRKGA



EOTs

chromosome

Allocation Scheduling - BRKGA

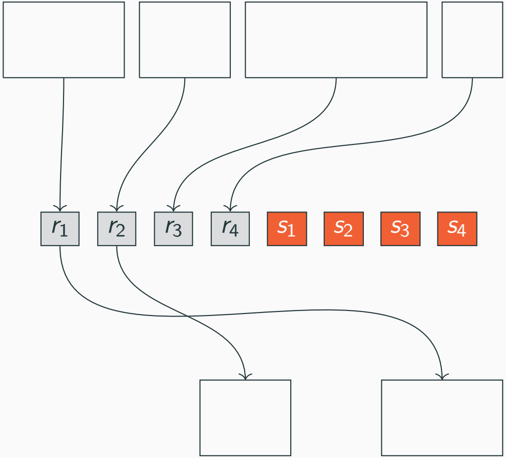


EOTs

chromosome

sequencing and starting times

Allocation Scheduling - BRKGA

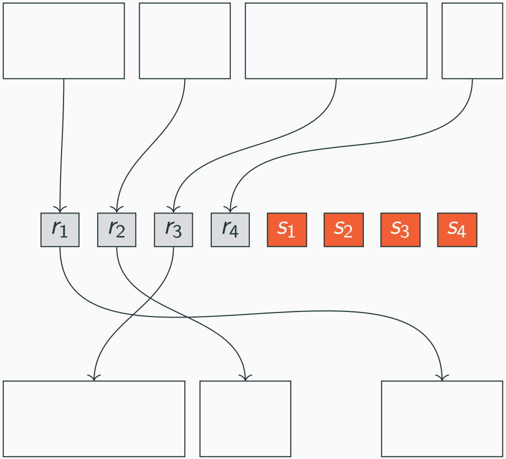


EOTs

chromosome

sequencing and starting times

Allocation Scheduling - BRKGA

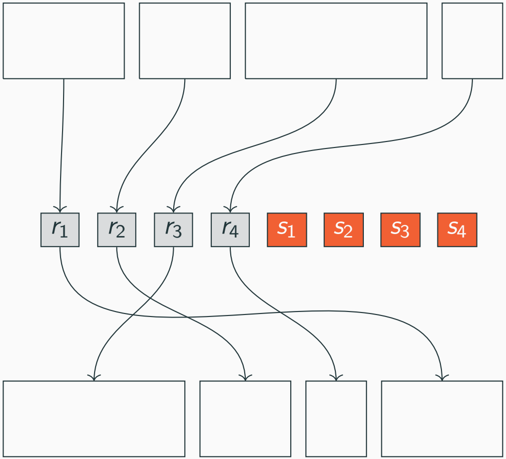


EOTs

chromosome

sequencing and
starting times

Allocation Scheduling - BRKGA



EOTs

chromosome

sequencing and
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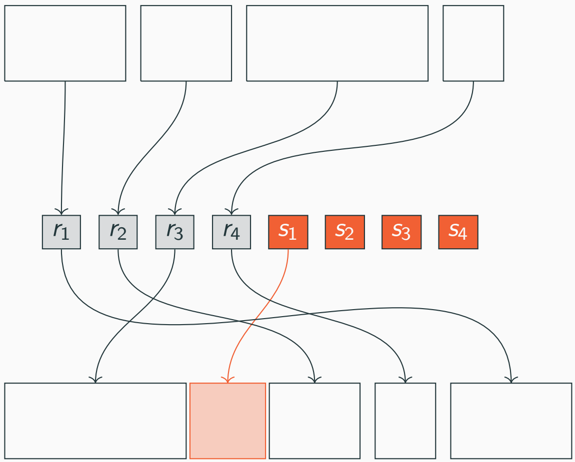
Allocation Scheduling - BRKGA



EOTs

chromosome

sequencing and starting times

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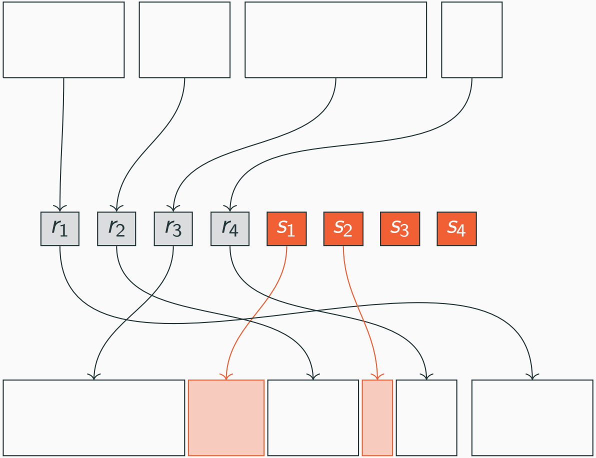

EOTs

chromosome

sequencing and starting times

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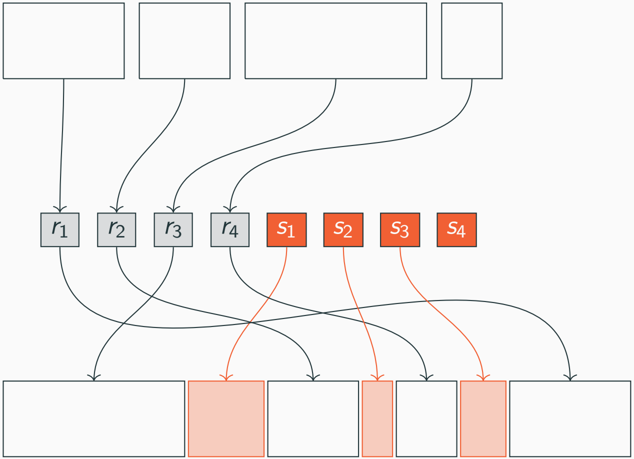

EOTs

chromosome

sequencing and starting times

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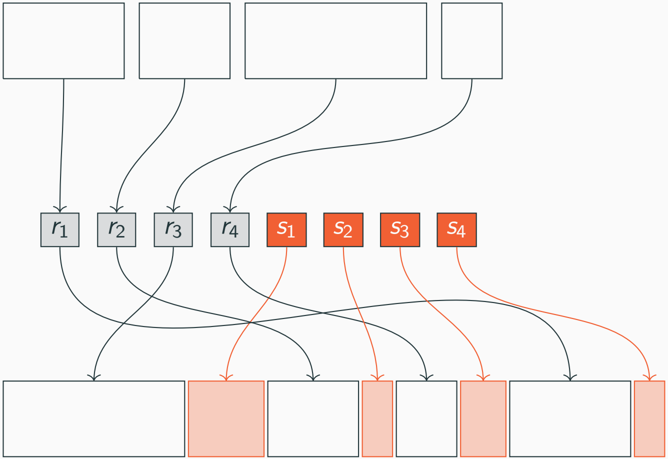

EOTs

chromosome

sequencing and
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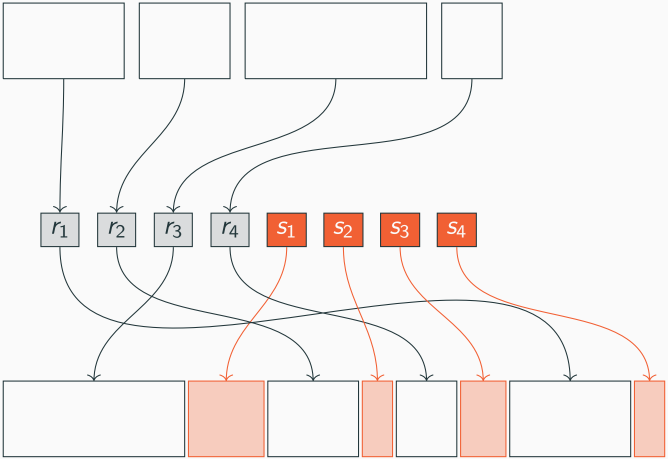

EOTs

chromosome

sequencing and starting times

Gonçalves & Resende (2011). Biased random-key genetic algorithms for combinatorial optimization. J. Heuristics 17(5) pp. 487–525.

Computational Analysis

Data - Sykehuset Asker og Bærum HF

OR room	Monday	Tuesday	Wednesday	Thursday	Friday
1	GASTRO	GASTRO	GASTRO		
2			GASTRO	GASTRO	GASTRO
3	CARD		CARD		CARD
4	ORTH	ORTH		ORTH	ORTH
5		ORTH	MED		
6	GYN	GYN	GYN	GYN	
7		GYN	GYN	GYN	GYN
8	URO	URO		URO	URO
9	CARD		URO		CARD
10	URO		ORTH		

Data - Sykehuset Asker og Bærum HF

OR room	Monday	Tuesday	Wednesday	Thursday	Friday
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2			GASTRO	GASTRO	GASTRO
3	CARD		CARD		CARD
4	ORTH	ORTH		ORTH	ORTH
5		ORTH	MED		
6	GYN	GYN	GYN	GYN	
7		GYN	GYN	GYN	GYN
8	URO	URO		URO	URO
9	CARD		URO		CARD
10	URO		ORTH		

Surgery type	Mean	STDEV
CARD	99	53
GASTRO	132	76
GYN	78	52
MED	75	72
ORTH	142	58
URO	72	38

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OR room	Monday	Tuesday	Wednesday	Thursday	Friday
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2			GASTRO	GASTRO	GASTRO
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4	ORTH	ORTH		ORTH	ORTH
5		ORTH	MED		
6	GYN	GYN	GYN	GYN	
7		GYN	GYN	GYN	GYN
8	URO	URO		URO	URO
9	CARD		URO		CARD
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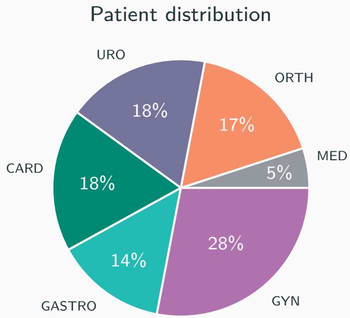

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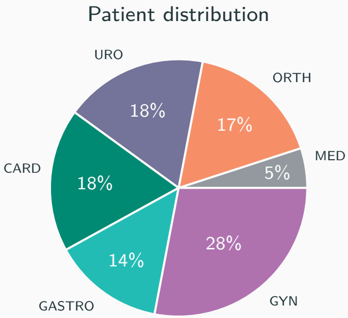
OR room	Monday	Tuesday	Wednesday	Thursday	Friday
1	GASTRO	GASTRO	GASTRO		
2			GASTRO	GASTRO	GASTRO
3	CARD		CARD		CARD
4	ORTH	ORTH		ORTH	ORTH
5		ORTH	MED		
6	GYN	GYN	GYN	GYN	
7		GYN	GYN	GYN	GYN
8	URO	URO		URO	URO
9	CARD		URO		CARD
10	URO		ORTH		

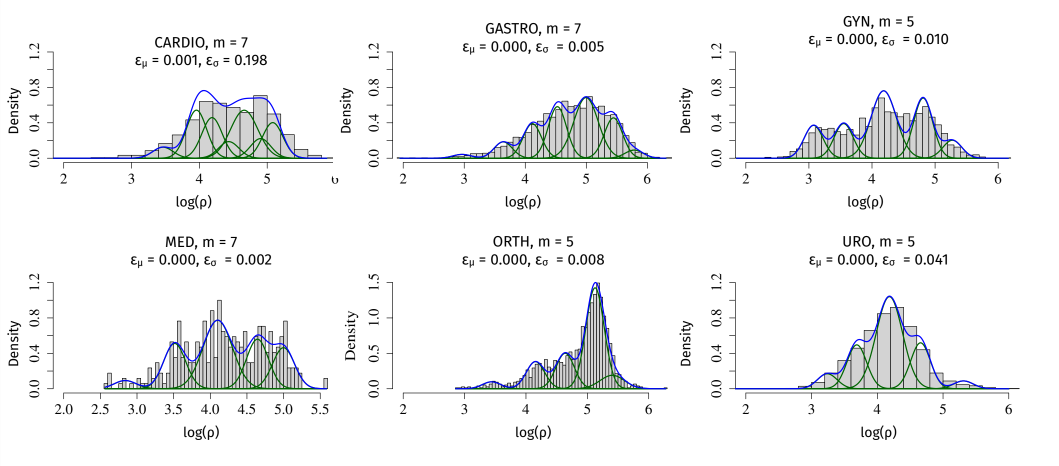


Surgery type	Mean	STDEV
CARD	99	53
GASTRO	132	76
GYN	78	52
MED	75	72
ORTH	142	58
URO	72	38

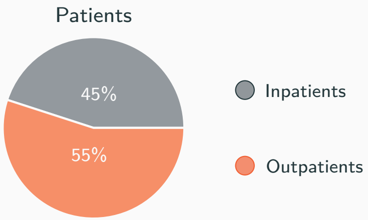
2 emergency surgeries per day. ROTs $\sim$ Lognormal(93, 60) min.

Mannino et al. (2010). SINTEF ICT: MSS adjusts surgery data. URL: https://www.sintef.no/Projectweb/Health-care-optimization/Testbed/
Karmel S. Shehadeh and Luis F. Zuluaga (2022). "14th AIMMS-MOPTA Optimization Modeling Competition. Surgery Scheduling in Flexible Operating Rooms Under Uncertainty", Modeling and Optimization: Theory and Application (MOPTA)

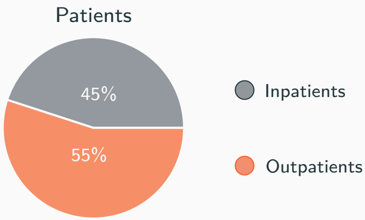
Instance Generation

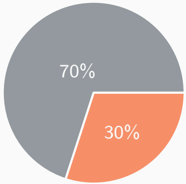


Instance Generation

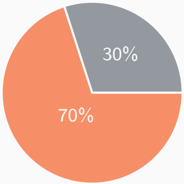


Instance Generation





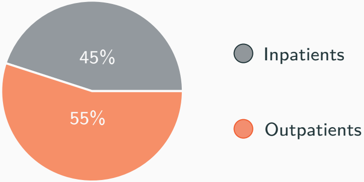
Patients with
higher CoV

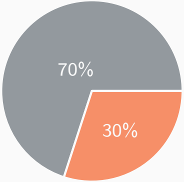


Patients with
lower CoV

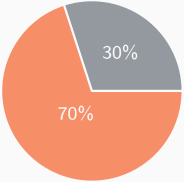
Instance Generation

Patients





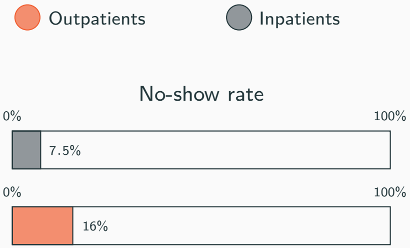
Patients with
higher CoV



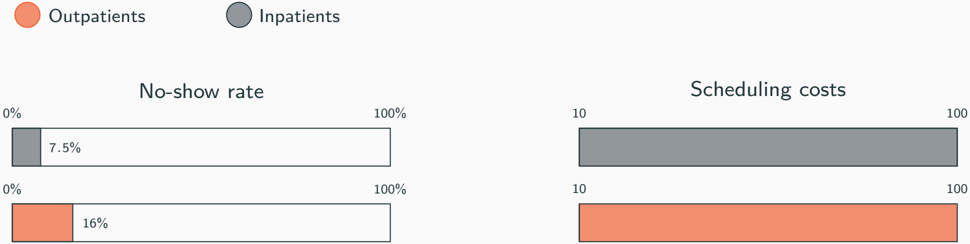
Patients with
lower CoV

$\text{CoV}_i = \sigma_i / \mu_i \in \{0.1518, 0.202\}$

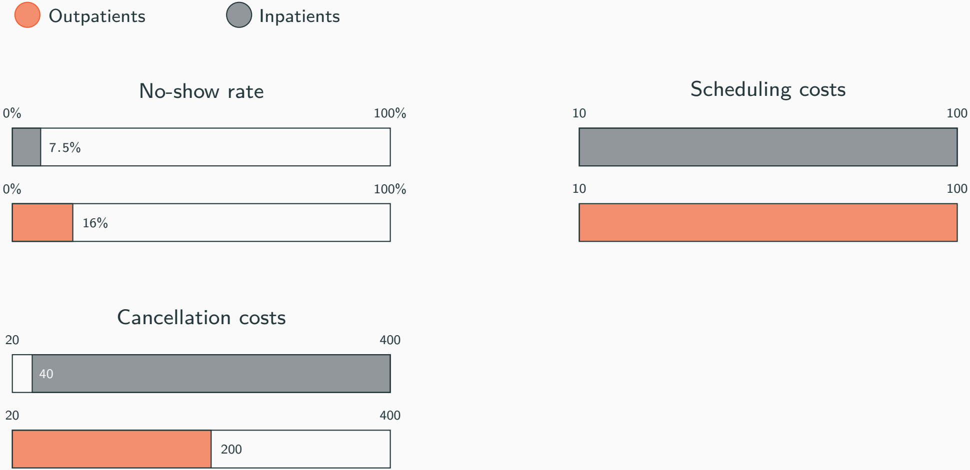
Instance Generation



Instance Generation



Instance Generation



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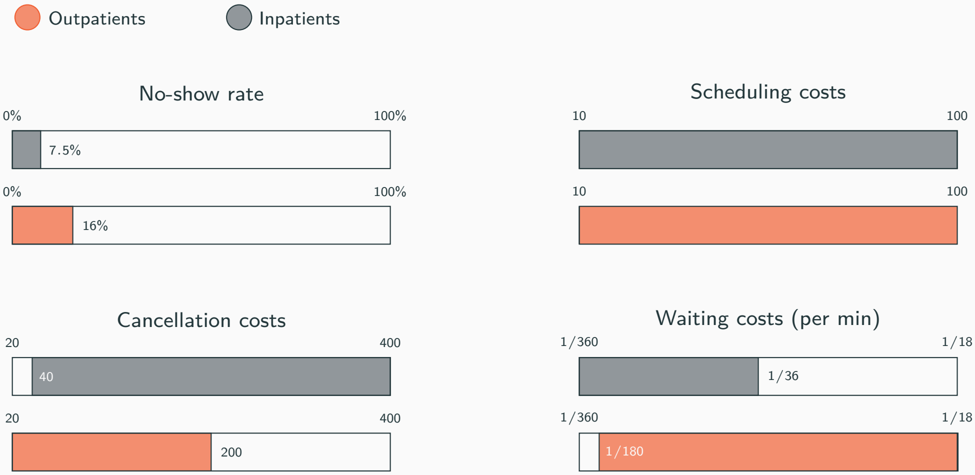
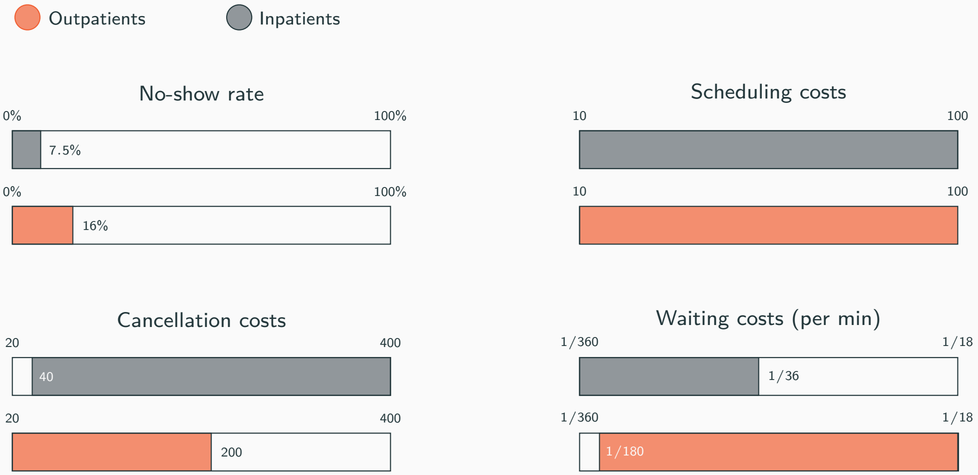


Instance Generation



Idle time cost $= 1/6$ per minute

Overtime cost $= 1/9$ per minute

SAA vs SCI

Instances				SSA_N (600s)			SSA_N (60s)				SCI		
Spec.	$\lvert W\rvert$	SMIP	α	o.f. value	r. time (sec)	robust. ratio	o.f. value	r. time (sec)	robust. ratio	short SAA_N o.f. value	o.f. value	r. time (sec)	robust. ratio
ORTH	70	$\mathcal{A}_{ORTH}$	0.1	0.0	33.0	0.903	0.000	22.4	0.905	0.000	0.000	0.3	0.984
			0.3	0.000	33.1	0.909	0.000	22.5	0.929	0.000	0.000	0.3	0.980
		$\mathcal{B}_{ORTH}$	0.1	5.408	43.7	0.917	5.408	35.5	0.913	5.408	5.408	2.1	0.914
			0.3	5.408	40.7	0.904	5.408	TL	0.913	5.408	5.408	1.8	0.895
	100	$\mathcal{A}_{ORTH}$	0.1	-	46.5	-	-	31.3	-	0.000	0.000	1.6	0.956
			0.3	0.000	45.3	0.852	0.000	31.0	0.891	0.000	0.000	1.3	0.957
		$\mathcal{B}_{ORTH}$	0.1	-	196.00	-	-	TL	-	RFF	29.035	39.2	0.998
			0.3	9.389	158.5	0.822	9.389	TL	0.833	9.389	9.389	3.4	0.878
	150	$\mathcal{A}_{ORTH}$	0.1	-	76.8	-	-	51.9	-	RFF	310.000	41.8	0.984
			0.3	163.000	75.2	0.839	163.000	50.6	0.831	163.000	163.000	1.1	0.855
		$\mathcal{B}_{ORTH}$	0.1	-	282.2	-	-	TL	-	RFF	314.004	58.1	0.987
			0.3	166.021	245.1	0.85	166.021	TL	0.861	166.021	166.021	5.3	0.853
	200	$\mathcal{A}_{ORTH}$	0.1	-	107.1	-	-	TL	-	RFF	795.000	46.4	0.988
			0.3	579.000	92.3	0.837	579.000	TL	0.869	579.000	579.000	0.9	0.853
		$\mathcal{B}_{ORTH}$	0.1	-	205.2	-	-	TL	-	RFF	801.736	56.7	0.981
			0.3	585.463	127.4	0.807	585.463	TL	0.822	585.463	585.463	3.9	0.873
	300	$\mathcal{A}_{ORTH}$	0.1	-	157.9	-	-	TL	-	RFF	1316.000	39.0	0.983
			0.3	1151.000	146.3	0.816	1151.000	TL	0.793	1151.000	1151.000	2.1	0.829
		$\mathcal{B}_{ORTH}$	0.1	-	324.7	-	-	TL	-	RFF	1321.326	57.8	0.988
			0.3	1155.714	280.6	0.830	1155.714	TL	0.822	1155.714	1155.714	5.6	0.861
	500	$\mathcal{A}_{ORTH}$	0.1	-	395.3	-	-	TL	-	RFF	2743.000	TL	0.974
			0.3	2541.000	TL	0.812	2541.000	TL	0.827	2541.000	2541.000	2.6	0.851
		$\mathcal{B}_{ORTH}$	0.1	-	TL	-	-	TL	-	RFF	2748.111	TL	0.959
			0.3	2543.992	TL	0.832	2544.031	TL	0.811	2544.452	2544.167	TL	0.827

For instances with higher level of robustness the SAA approach is not able to find a feasible solution when the number of patients increases. SCI's solutions are very close to that of SAA, but it provides always a feasible solution due to RFF.

SAA vs BRKGA

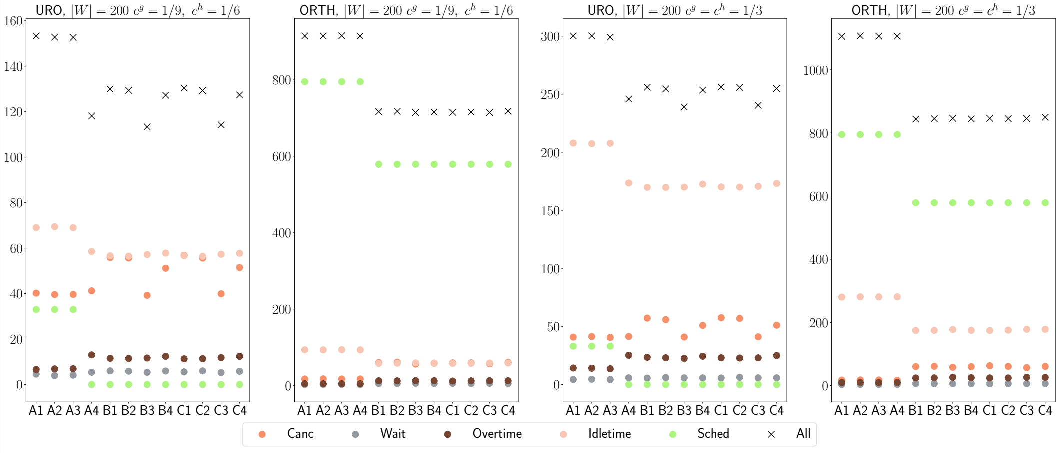
Spec.	# Pat.	a.f.	SAA(10 min)			SAA$_N$(10 min)			BRGKA	
			o.f.	time	#feas./tot	o.f.	time	#feas./tot	o.f. (10min)	o.f. (1min)
ORTH	2-5	yes	115.30	8.27	24/24	99.83	0.49	24/24	**97.41**	**97.41**
		no	-	-	0/20	**155.17**	4.76	20/20	159.26	161.78
	6+	no	-	-	0/4	172.06	10	4/4	**145.23**	147.83
URO	2-5	yes	35.97	7.51	4/4	34.26	1.05	4/4	**33.28**	**33.28**
		no	-	-	0/9	**40.28**	6.71	9/9	67.41	70.49
	6+	no	-	-	0/35	170.19	10	34/35	**143.33**	150.13
GYN	2-5	yes	92.70	3.10	3/3	91.21	0.21	3/3	**64.43**	**64.43**
		no	-	-	0/15	102.26	8.97	15/15	**89.18**	**89.18**
	6+	no	-	-	0/46	167.37	10	42/46	**149.15**	152.22
MED	2-5	no	-	-	0/2	78.25	10	2/2	**76.71**	**76.71**
	6+	no	-	-	0/6	222.78	10	5/6	**176.60**	176.75
CARDIO	2-5	yes	46.63	9.89	4/4	36.22	1.76	4/4	**31.39**	**31.39**
		no	-	-	0/20	**157.08**	6.53	20/20	191.53	199.38
	6+	no	-	-	0/16	254.73	10	16/16	**223.97**	234.57
GASTRO	2-5	yes	139.60	6.84	13/13	**108.74**	1.87	13/13	109.40	111.01
		no	-	-	0/22	112.41	6.62	22/22	**106.70**	117.37
	6+	no	-	-	0/13	223.15	10	13/13	**182.55**	**182.55**

BRGKA always finds a better solution as soon as the **dimension of the problem** becomes challenging (6+ patients).

Scenario Analysis: Parameter Variation

Robustness level: A = high ($\alpha = 0.1$), B = medium ($\alpha = 0.2$), C = low ($\alpha = 0.3$).
Cost balancing: 1 = none, 2 = cancellations, 3 = both ($\beta = \nu = 0.5$), 4 = waiting times.

Scenario 1 | Scenario 2



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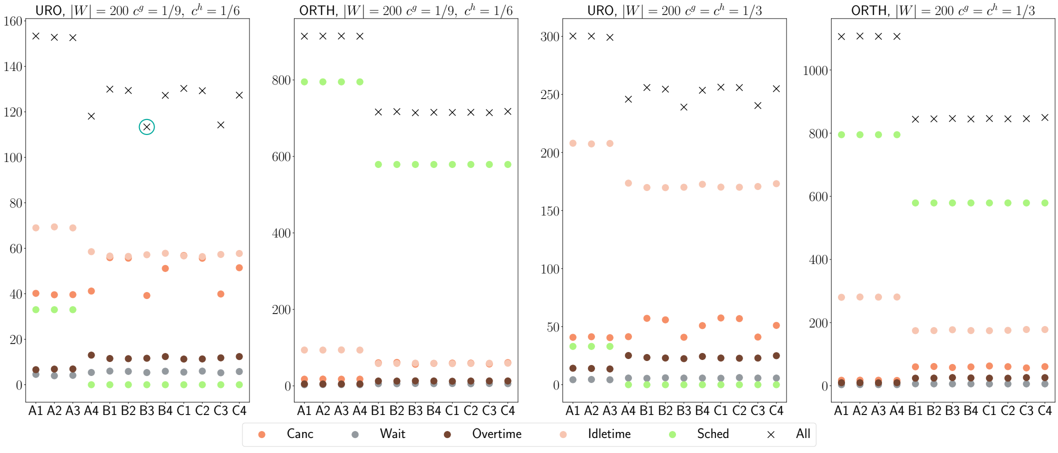

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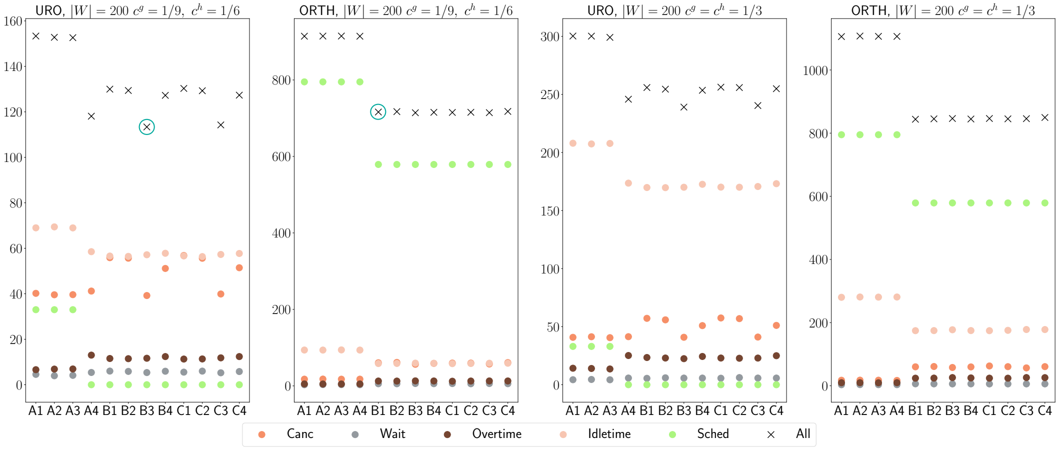

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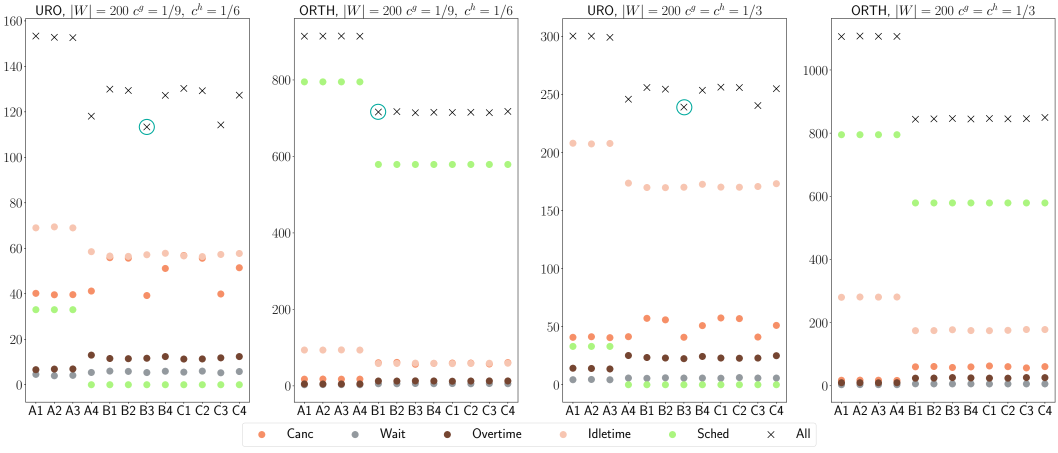

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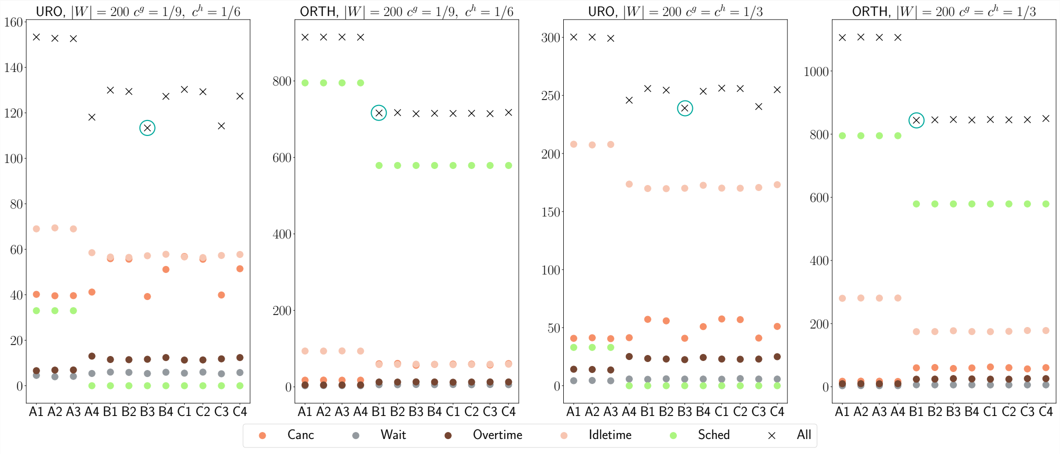
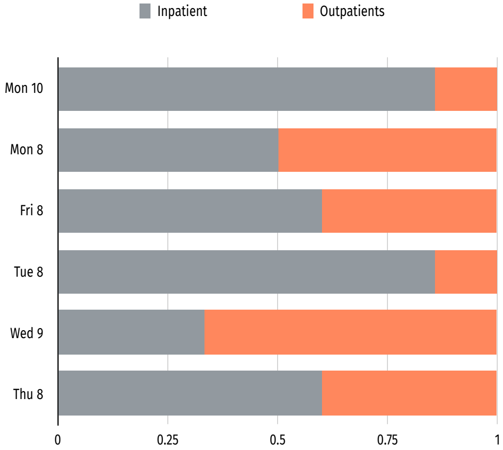
Scenario 2

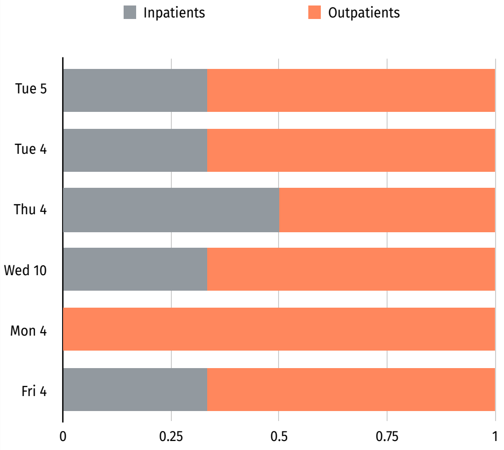


Scenario Analysis: Inpatients vs Outpatients

URO

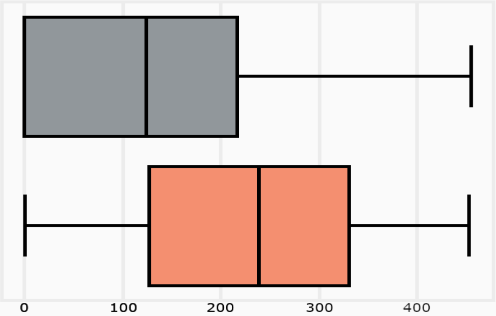


ORTH

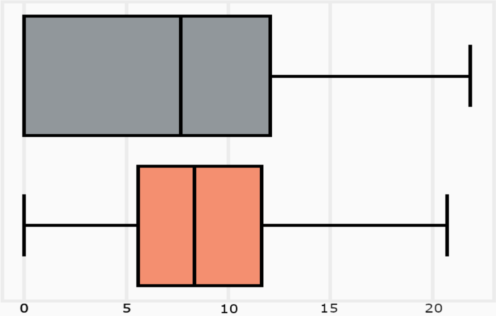


Scenario Analysis: Inpatients vs Outpatients

Scheduled Start Times (min)

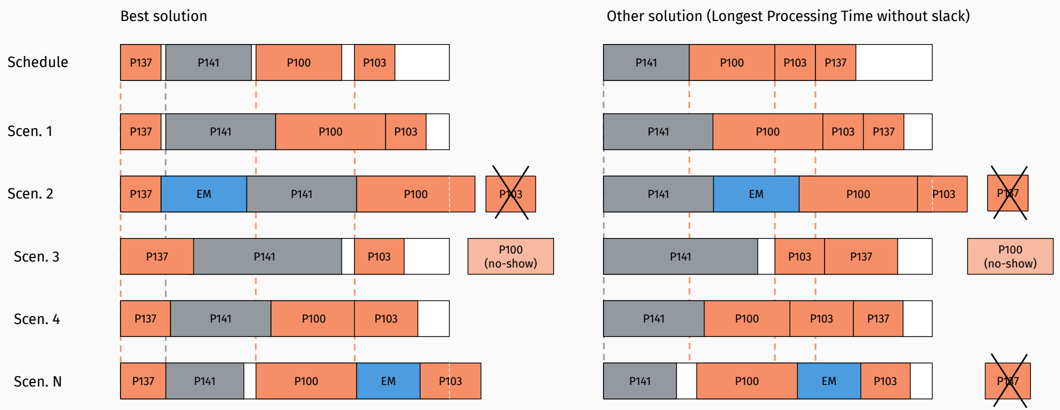


Expected Direct Waiting Time (min)

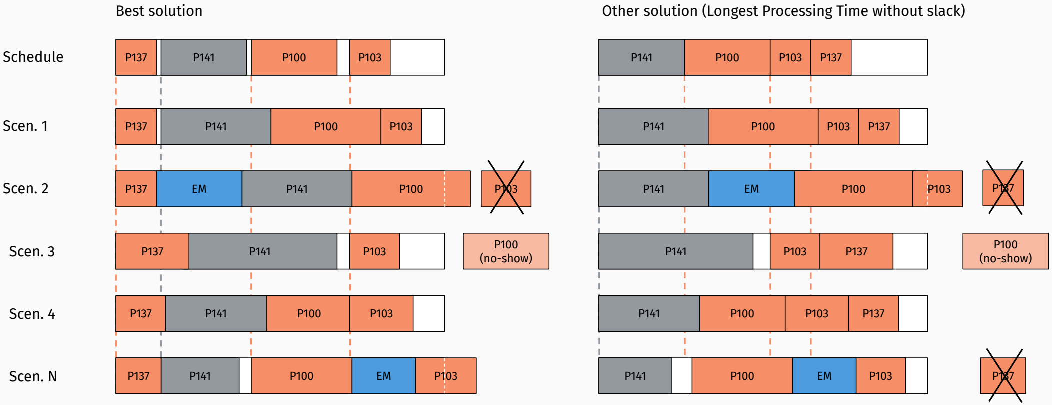


Outpatients Inpatients

Scheduling Examples



Scheduling Examples



Testi et al. A three-phase approach for operating theatre schedules. Health Care Manage Sci 10, 163–172 (2007).

User Interface

Video presentation - UI

Conclusions

Final Remarks & Future Perspectives

Comprehensive approach to deal with different types of patients under uncertainty;

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Comprehensive approach to deal with different types of patients under uncertainty;

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Integrating SCI and BRKGA;

Alternative real-time policies: stochastic optimization + online optimization;

impact of “robust decisions” over time.

That's all Folks!

Any Questions?

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