



Operating room planning and scheduling

Real Portuguese cases

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Agenda

- OpLog brief introduction
- Scheduling frame and challenges
- Operating room (OR) planning and scheduling: motivation
- Case 1: Integrated tactical and operational decisions
- Case 2: Operational decisions
- Conclusions, challenges and future work

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- **OpLog brief introduction**
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Short background

BAC,
Brussels



Operations
Research



Maths
Applied to
Economics
and
Business



Statistics
and
Operations
Research

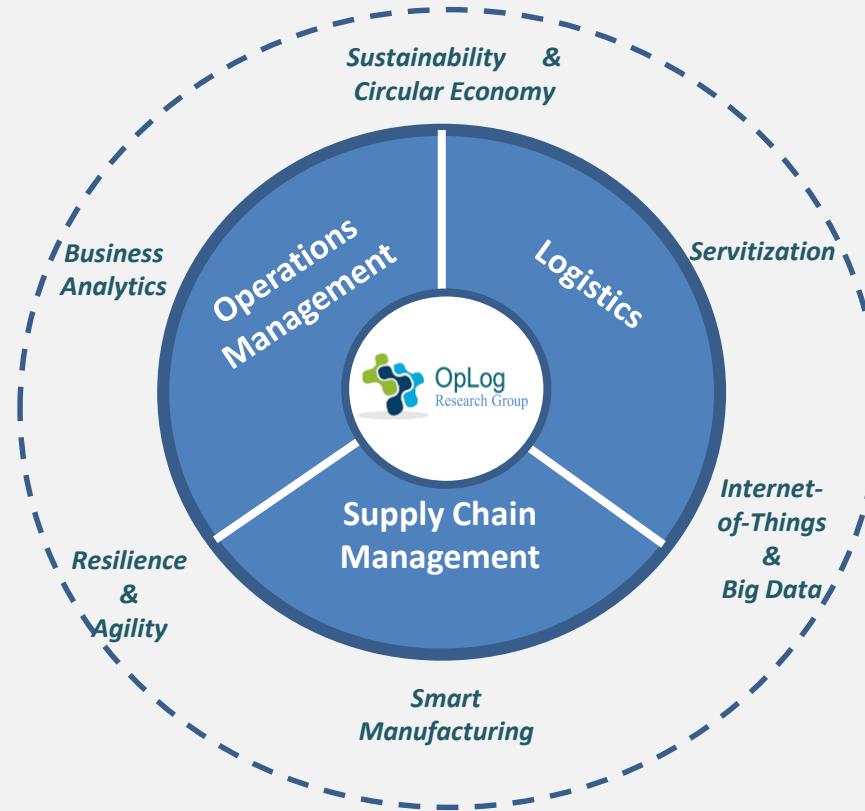
Topic: Operating Room
Planning & Scheduling

Assistant
Professor
at IST



TITLE

OpLog main research pillars



Provide support to organizations by developing OR-based methods to inform decision-making.

TITLE

OpLog develops innovative, theoretically sound and demand-driven research ...



... in a closed **collaboration** with national and international:

- Industrial and Service Organizations
- Academic Partners

Targeting

- economic
- environmental and
- social

drivers

OpLog team

Coordinator

Ana Póvoa

Senior Researchers

Susana Relvas

Ana Carvalho

Tânia Pinto Varela

Tânia Ramos

Inês Marques



External Research Affiliates

Teresa Grilo

Leão Fernandes

Jorge Vicente

Post Docs

Bruna Mota

Miguel Vieira

+1

15 PhD Candidates

40+ Ongoing MSc Students

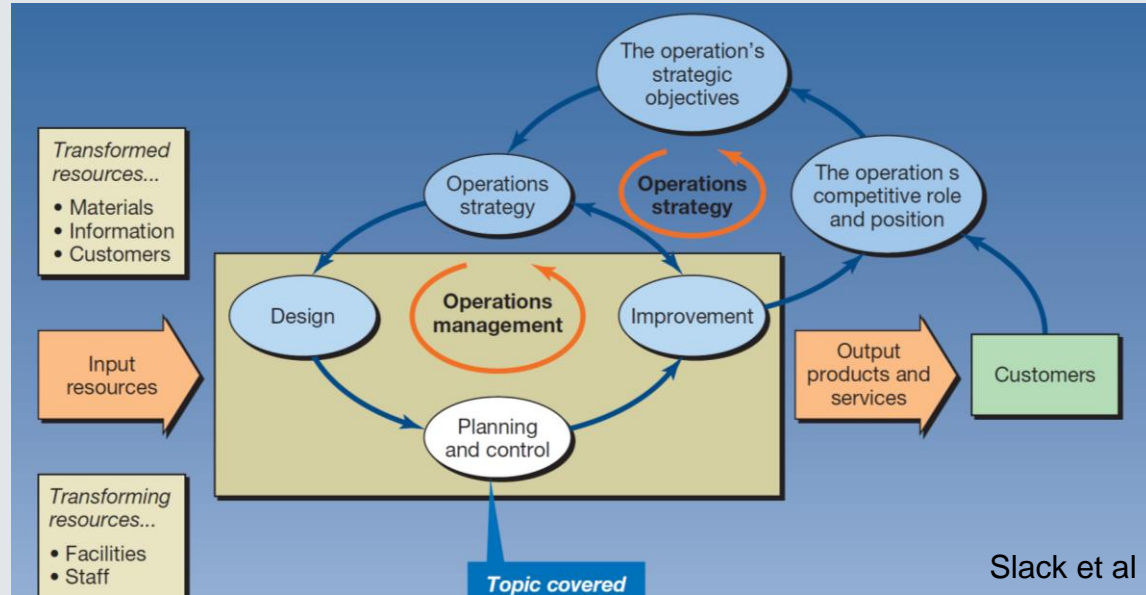


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Scheduling

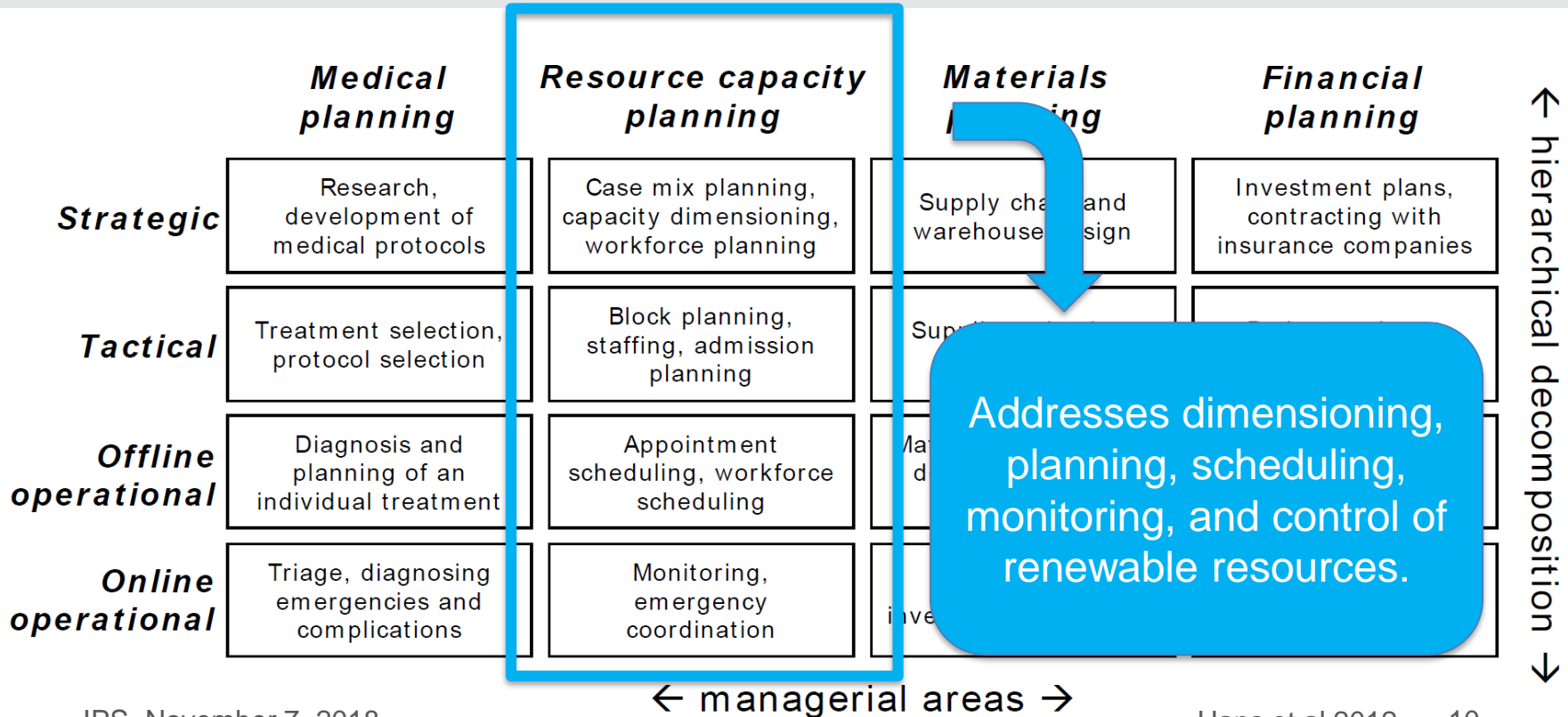
- ✓ Planning activities of the transformation process
- ✓ Develop capabilities to improve process performance
- ✓ Central to the ability of an effective delivery of services and products
- ✓ Bring supply and demand together



Slack et al



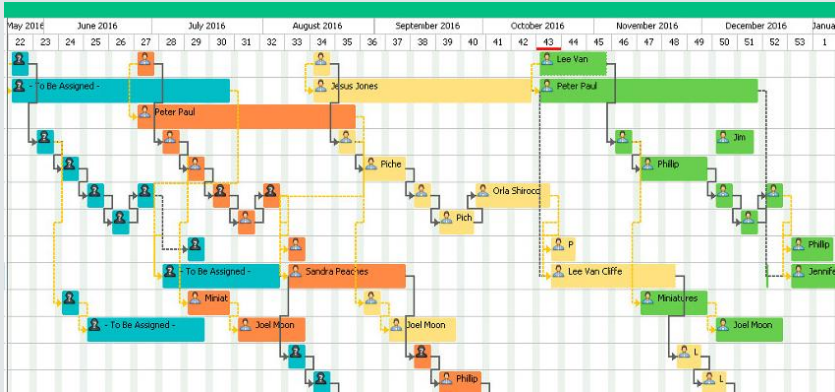
Hospital planning and control



Scheduling



Detailed timetable of **WHAT**, **WHEN**, and **WHERE** work should be done



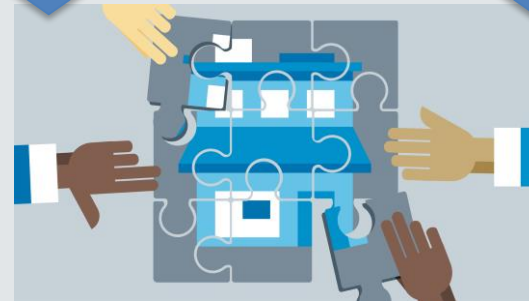
Scheduling: challenges

Scheduling is one of the most complex tasks in operations management

- ✓ Nb of possible schedules increase rapidly with the nb of activities and processes
- ✓ Approximate models: simplification and assumptions
- ✓ Approximate solutions: heuristic approaches

Different type of machines

Staff with different skills



Different type of resources

Scheduling: challenges

Scheduling is one of the most complex tasks in operations management

- ✓ To provide time knowledge and effective and better decisions to complex real-world problems...

Uncertainty and variability

Stakeholders with different agendas

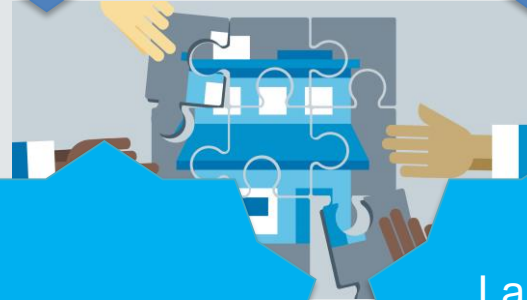
Rescheduling

Large data sets of information

Different type of machines

Staff with different skills

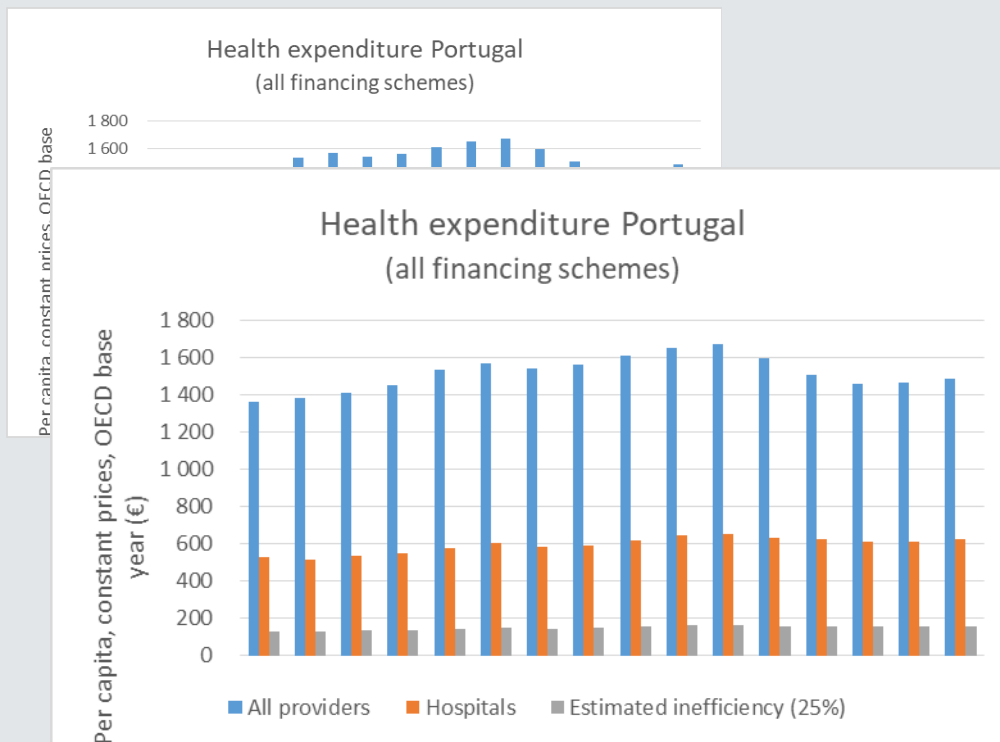
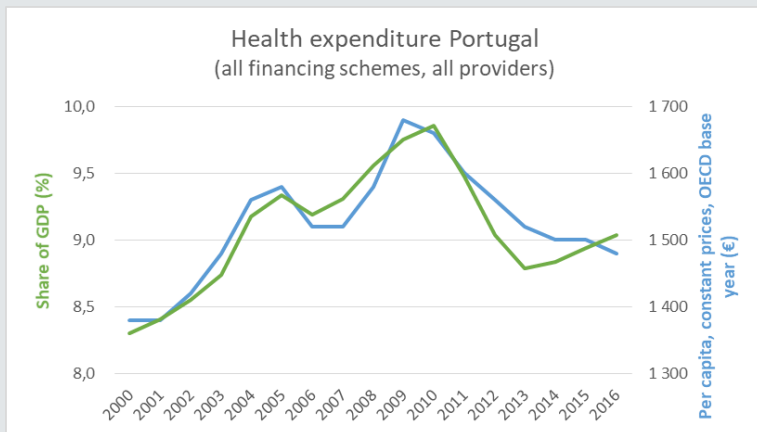
Different type of resources



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Health expenditure Portugal



25% potential inefficiencies in hospitals

Why to optimize ORs?

- Significant source of hospital's income
 - about 28% of the hospitals' overall funding is by surgical activities
- Majority of hospital admission undergo surgery
 - about 46% of the hospital admissions
 - 70-80% of the elective admissions
- Cost intensive (capital and labor)
 - highly specialized equipment and staff
- Capacity depends on multiple specialized staff



Why to optimize ORs?

- Determine *the pace* of the hospital
 - the hospital's heart
 - up and downstream implications and dependencies
- Have a lot of variability
 - Diversity surgical procedures, complications, emergency arrivals, surgery durations
 - Every patient is different
- Large waiting lists for surgery: a social concern



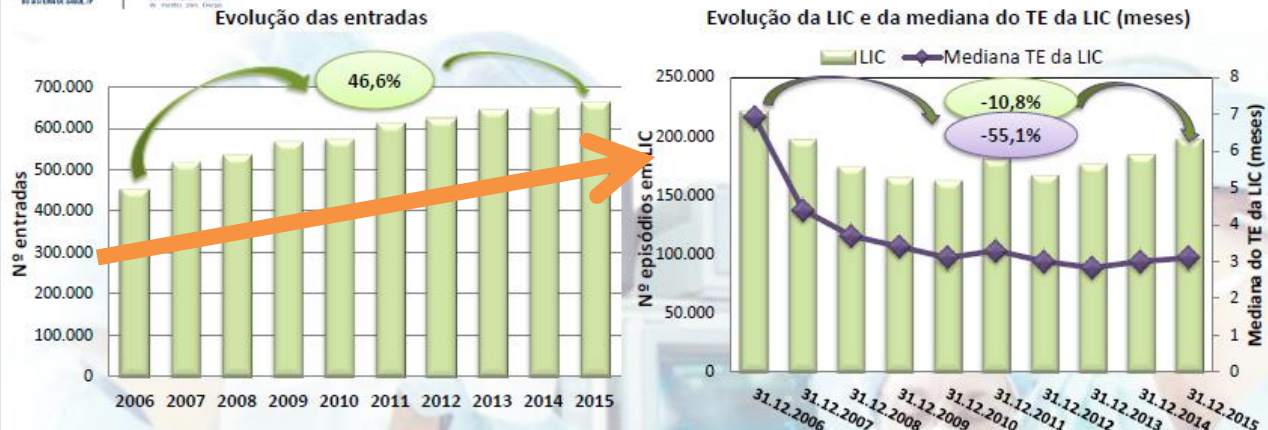
8,057 different procedure-surgeon combinations;
98.3% with less than 30 samples
data with 50,569 surgeries (2013–2016)



Access to surgical care

SIGIC goals:

- < 9.6% patients operated exceeding the MGRT
- average waiting time < 120 days



SIGIC = System for Management of Patients Waiting for Surgery
 MGRT = Maximum guaranteed response time

Indicadores	2006	...	2010	2011	2012	2013	2014	2015	Δ 2006/ 2015	Δ 2014/ 2015
Entradas em LIC	451.942		573.527	611.535	624.226	644.178	649.386	662.642	46,6%	2,0%
Nº de utentes inscritos (LIC)	221.208		162.211	180.356	166.798	176.129	184.077	197.401	-10,8%	7,2%
Mediana TE da LIC em meses	6,9		3,1	3,3	3	2,8	3	3,1	-55,1%	3,3%
Percentil 90 TE da LIC em meses	24,9		9,2	10,3	10,4	9,3	9,1	9,3	-62,7%	1,8%
% Inscritos que ultrapassam o TMRG	43,50%		13,00%	15,80%	15,10%	12,80%	12,00%	12,2%	-71,9%	2,2%

Legenda:

LIC – Lista de inscritos para cirurgia
 Nº – Número
 TE – Tempo de espera
 TMRG – Tempo máximo de resposta garantido

Source:
Relatório síntese da atividade cirúrgica programada – Ano 2015,
 ACSS, 2016

Fonte: SNS/IC
 Indicadores do ano de 2006 extraídos a 27.03.2007; Indicadores do ano de 2007 extraídos a 23.01.2008;
 Indicadores do ano de 2008 extraídos a 27.02.2009; Indicadores do ano de 2009 extraídos a 06.04.2010;
 Indicadores do ano de 2010 extraídos a 14.11.2011; Indicadores do ano de 2011 extraídos a 21.02.2012 (com 18 es efetuadas a 28.03.2012);
 Indicadores do ano de 2012 extraídos a 01.09.2013; Indicadores do ano de 2013 extraídos a 15.03.2014;
 Indicadores do ano de 2014 extraídos a 03.05.2015; Indicadores do ano de 2015 extraídos 03.06.2016:



Accessed Oct 8



SNS SERVIÇO NACIONAL DE SAÚDE



TEMPOS MÉDIOS DE ESPERA

INSTITUIÇÕES

CIRURGIA

CONSULTA

INFORMAÇÃO

Cirurgia

Tempos Médios de Resposta para Cirurgia – Sistema Integrado de Gestão de Inscritos para Cirurgia (SIGIC).

Número de utentes a aguardar por cirurgia programada a 31/07/2017 e o tempo médio de resposta dos utentes operados (em dias), por especialidade, prioridade e patologia (situação neoplásica maligna ou benigna).











Dados de maio, junho e julho de 2017.

Tempo Máximo de Resposta Garantido (TMRG) : Muito Prioritário – Doença Oncológica e não Oncológica – 15 dias | Prioritário – Doença Oncológica – 45 dias | Prioritário – Doença não Oncológica – 60 dias | Normal – Doença Oncológica – 120 dias | Normal – Doença Não Oncológica – 270 dias.







Procurar Especialidade

Cirurgia Geral

Muito Prioritário – Doença Oncológica e não Oncológica		17 pessoas		8 dias
Prioritário – Doença Oncológica		49 pessoas		43 dias
Prioritário – Doença Não Oncológica		172 pessoas		25 dias
Normal – Doença Oncológica		2 pessoas		5 dias
Normal – Doença Não Oncológica		2619 pessoas		214 dias



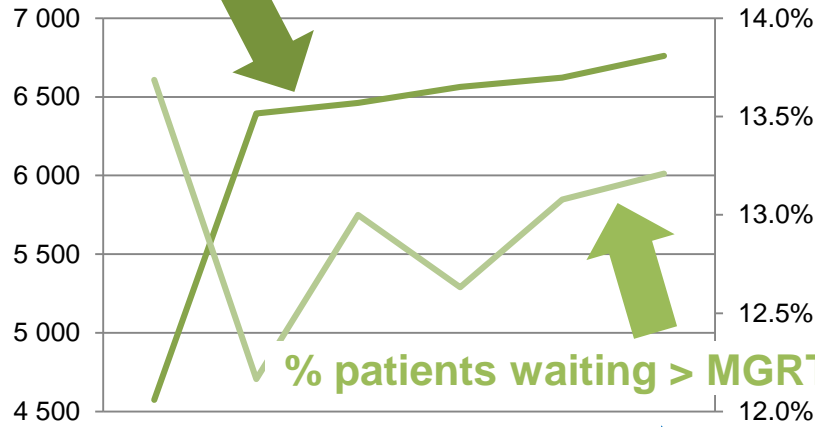
Cirurgia Maxilo Facial

Muito Prioritário – Doença Oncológica e não Oncológica		0 pessoas		6 dias
Prioritário – Doença Oncológica		0 pessoas		12 dias

Access in a NHS hospital

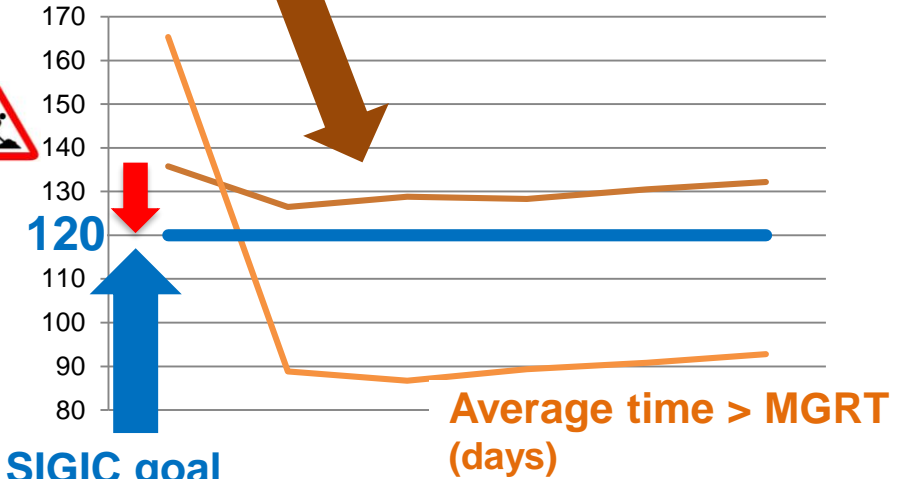


Patients waiting for surgery



SIGIC goal 9.6%

Average waiting time (days)



SIGIC goal



Improve **EFFICIENCY** and **TIMELY ACCESS** to increasing surgical demand!

OR planning & scheduling



Strategic level

Case mix planning

Allocation of total OR capacity to surgical specialties; year

Tactical level

Master surgery scheduling

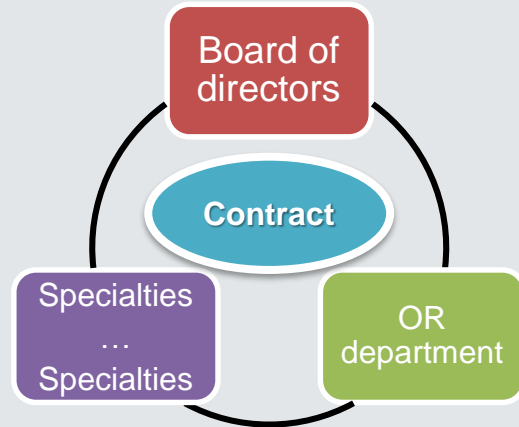
Weekly allocation of OR time to specialties; month

Operational level

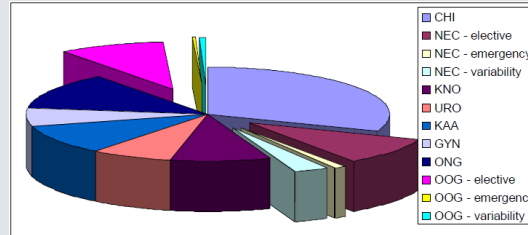
Elective case scheduling


Scheduling of surgeries; monitoring and control; week or day

Strategic OR planning



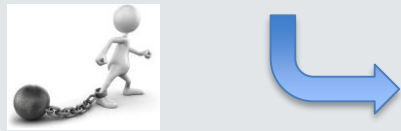
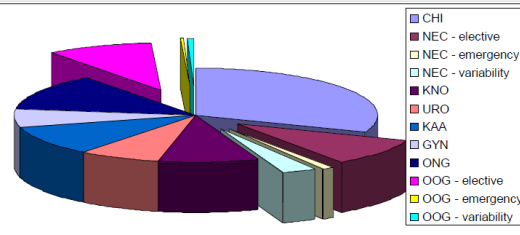
- Budget
- Surgical (forecasted) demand
- Staff available in the hospital



- 
- ✓ Maximize income
 - ✓ Maximize surgeons' satisfaction
 - ✓ SIGIC goals
 - ✓ Be able to capture and answer to demand

- Capacity dimensioning
 - Operating rooms, equipment and staff
- Capacity distribution among specialties

Tactical OR planning

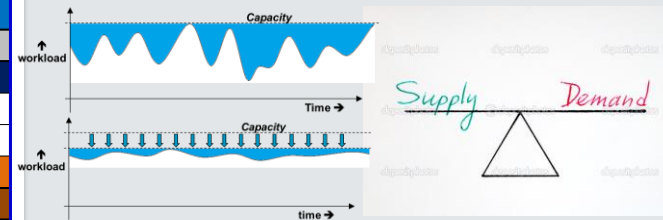


- OR time distribution among specialties
- Staff available in the hospital



OR	Monday	Tuesday	Wednesday	Thursday	Friday
MORNING SHIFTS (8h15-15h)					
1	PDT	ORL	PDT	ORL	
2	ORL	ORL	ORL	ORL	
3	ORTb	ORTa	ORTb	PLT	
4	ORTb	ORTa	ORTb	ORTa	ORTa
5	URO	URO	URO	URO	SRGb
6	OPT	OPT	OPT	OPT	OPT
7	<i>RESERVED TO URGENT CASES</i>				
8	GYN	GYN	GYN	GYN	GYN
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	SRGc	SRGc	SRGc	SRGc	SRGc
11	MXL	PLT	URO	URO	GYN
AFTERNOON SHIFTS (15h-21h)					
1					
2	ORL		ORL		ORL
3		SRGb			
4	ORTb	ORTa	ORTb	ORTa	ORTb
5	URO	URO	SRGb	SRGc	URO
6	OPT	OPT	OPT	OPT	OPT
7	<i>RESERVED TO URGENT CASES</i>				
8	SRGc	SRGc	PDT	GYN	
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	PLT	PLT	SRGc	PLT	SRGc
11	PLT	PLT	MXL	PLT	

- Match supply and demand
- Level the workload of downstream departments (ICU, wards)

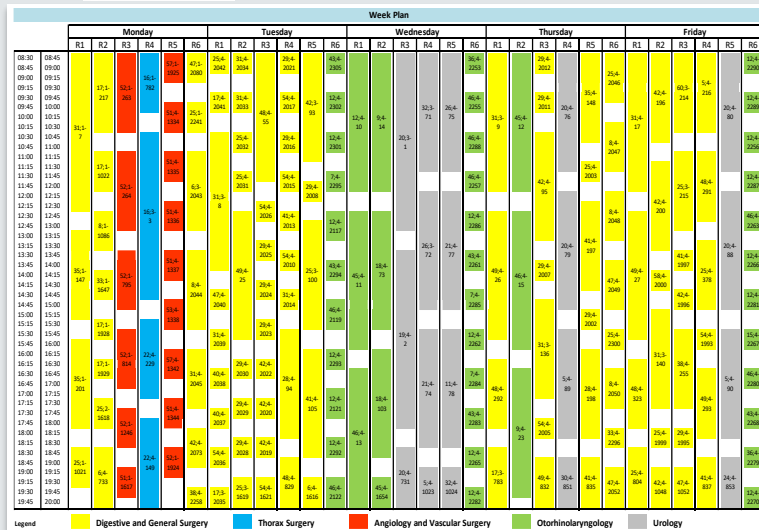


Operational OR scheduling

OR	Monday	Tuesday	Wednesday	Thursday	Friday
MORNING SHIFTS (8h15-15h)					
1	PDT	ORL	PDT	ORL	
2	ORL	ORL	ORL	ORL	
3	ORTb	ORTa	ORTb	PLT	
4	ORTb	ORTa	ORTb	ORTa	ORTa
5	URO	URO	URO	URO	SRGb
6	OPT	OPT	OPT	OPT	OPT
7	<i>RESERVED TO URGENT CASES</i>				
8	GYN	GYN	GYN	GYN	GYN
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	SRGc	SRGc	SRGc	SRGc	SRGc
11	MXL	PLT	URO	URO	GYN
AFTERNOON SHIFTS (15h-21h)					
1			ORL		ORL
2	ORL				ORL
3		SRGb			
4	ORTb	ORTa	ORTb	ORTa	ORTb
5	URO	URO	SRGb	SRGc	URO
6	OPT	OPT	OPT	OPT	OPT
7	<i>RESERVED TO URGENT CASES</i>				
8	SRGc	SRGc	PDT	GYN	
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	PLT	PLT	SRGc	PLT	SRGc
11	PLT	PLT	MXL	PLT	



- Select the patients to be scheduled
- Schedule patients into available timeslots



- MSS
- Resources capacity: OR time, equipment, surgeons and other staff, beds in ICU



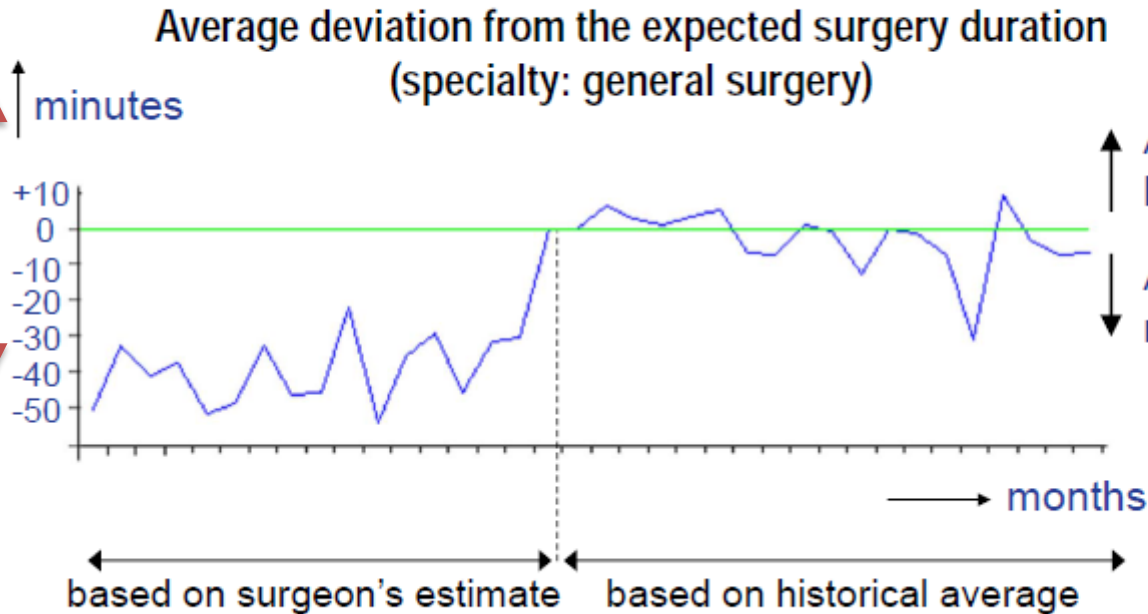
- ✓ Improve OR efficiency and effectiveness
- ✓ Meet SIGIC targets
- ✓ Improve staff satisfaction
- ✓ Minimize expected overtime
- ✓ Maximize throughput
- ✓ Guidelines (priority and seniority)

Challenge: Surgeries duration



Idle time
Waste of resources

Cancellations
Overtime
Dissatisfaction



overestimation

Actual duration was less than expected

Actual duration was more than expected

underestimation



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Case 1: Integrated tactical+operational decisions



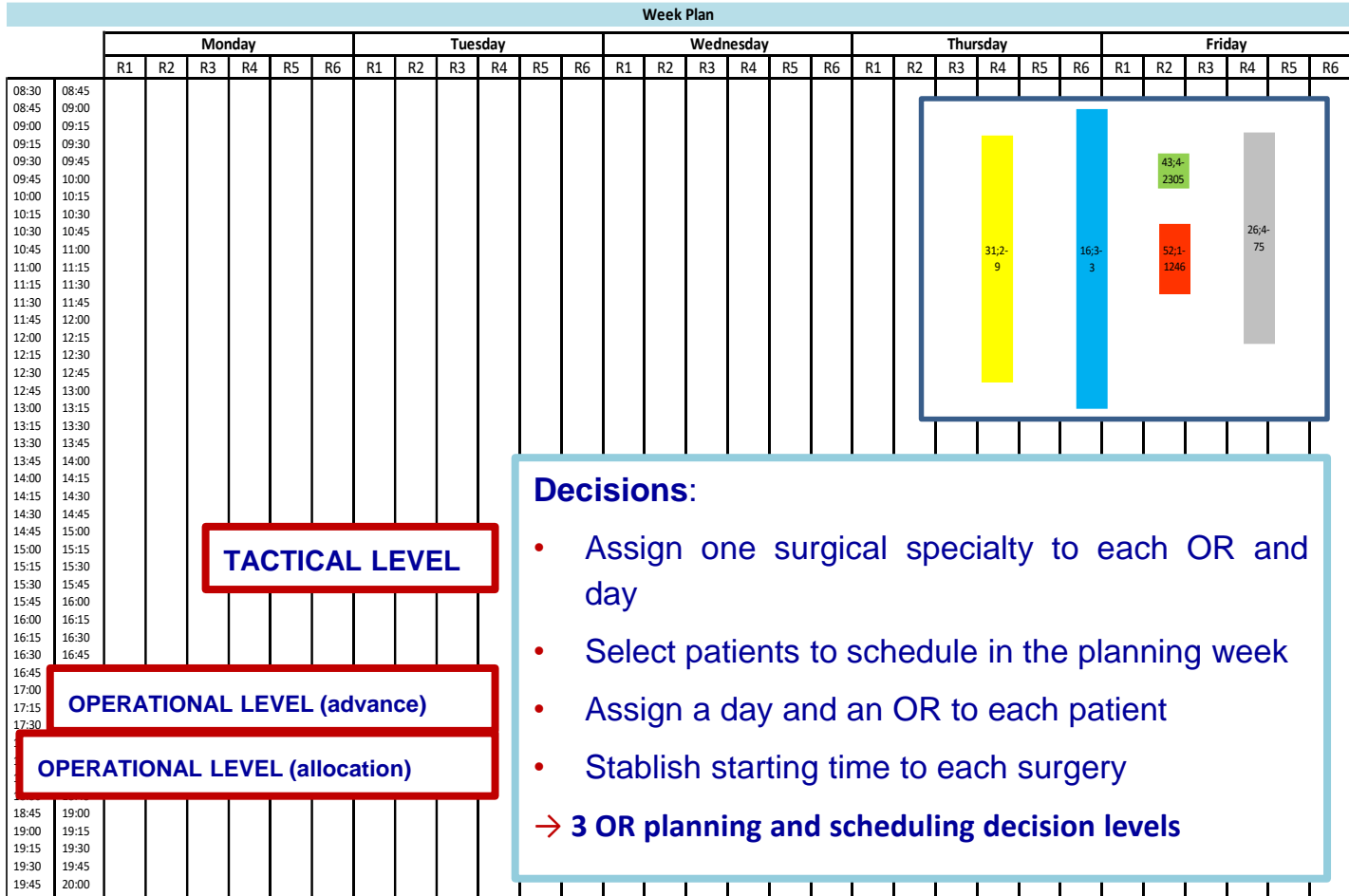
- Assign a surgical specialty to each OR and day
- Select patients to schedule in the planning week
- Assign a day, an OR and a starting time to each patient



- **Structural:** non-overlapping of patients and of surgeons; cleaning time; up to one specialty to each room and day
- **Priority constraints:** level 1 for Monday; level 2 for the planning week; levels 3+4 not necessarily scheduled
- **Capacity constraints:** OR regular time and surgeon operating time
- **OR characteristics:** dedicated room to outpatients



- Maximize OR occupation (z_1)
- Maximize throughput (z_2)



Legend

Digestive and General Surgery

Thorax Surgery

Angiology and Vascular Surgery

Otorhinolaryngology

Urology

Week Plan

		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Decisions:

- Assign one surgical specialty to each OR and day
- Select patients to schedule in the planning week
- Assign a day and an OR to each patient
- Establish starting time to each surgery

→ 3 OR planning and scheduling decision levels

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Otorhinolaryngology

Urology

Week Plan

		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Constraints:

- Structural constraints
non-overlapping of patients

Legend

Digestive and General Surgery

Thorax Surgery

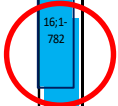
Angiology and Vascular Surgery

Otorhinolaryngology

Urology

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		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Constraints:

- Structural constraints
- non-overlapping of patients

Legend

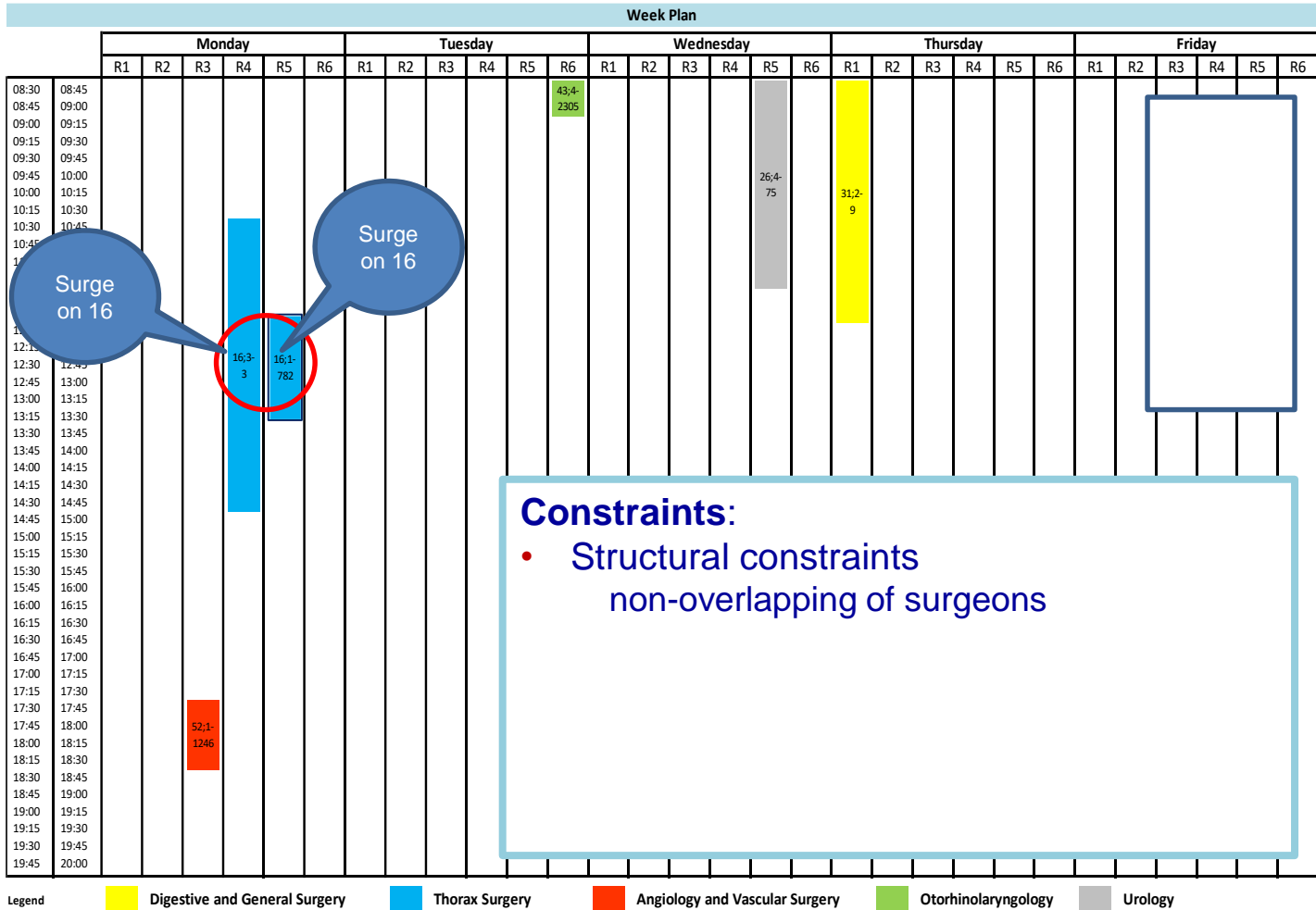
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Constraints:

- Structural constraints cleaning time

Legend

Digestive and General Surgery

Thorax Surgery

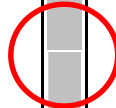
Angiology and Vascular Surgery

Otorhinolaryngology

Urology

Week Plan

		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Constraints:

- Structural constraints cleaning time

Legend

Digestive and General Surgery

Thorax Surgery

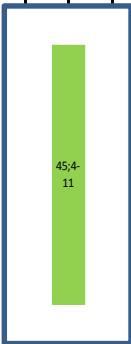
Angiology and Vascular Surgery

Otorhinolaryngology

Urology

Week Plan

		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Constraints:

- Structural constraints up to one specialty to each room and day

Legend

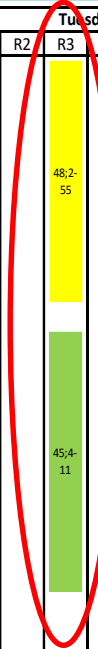
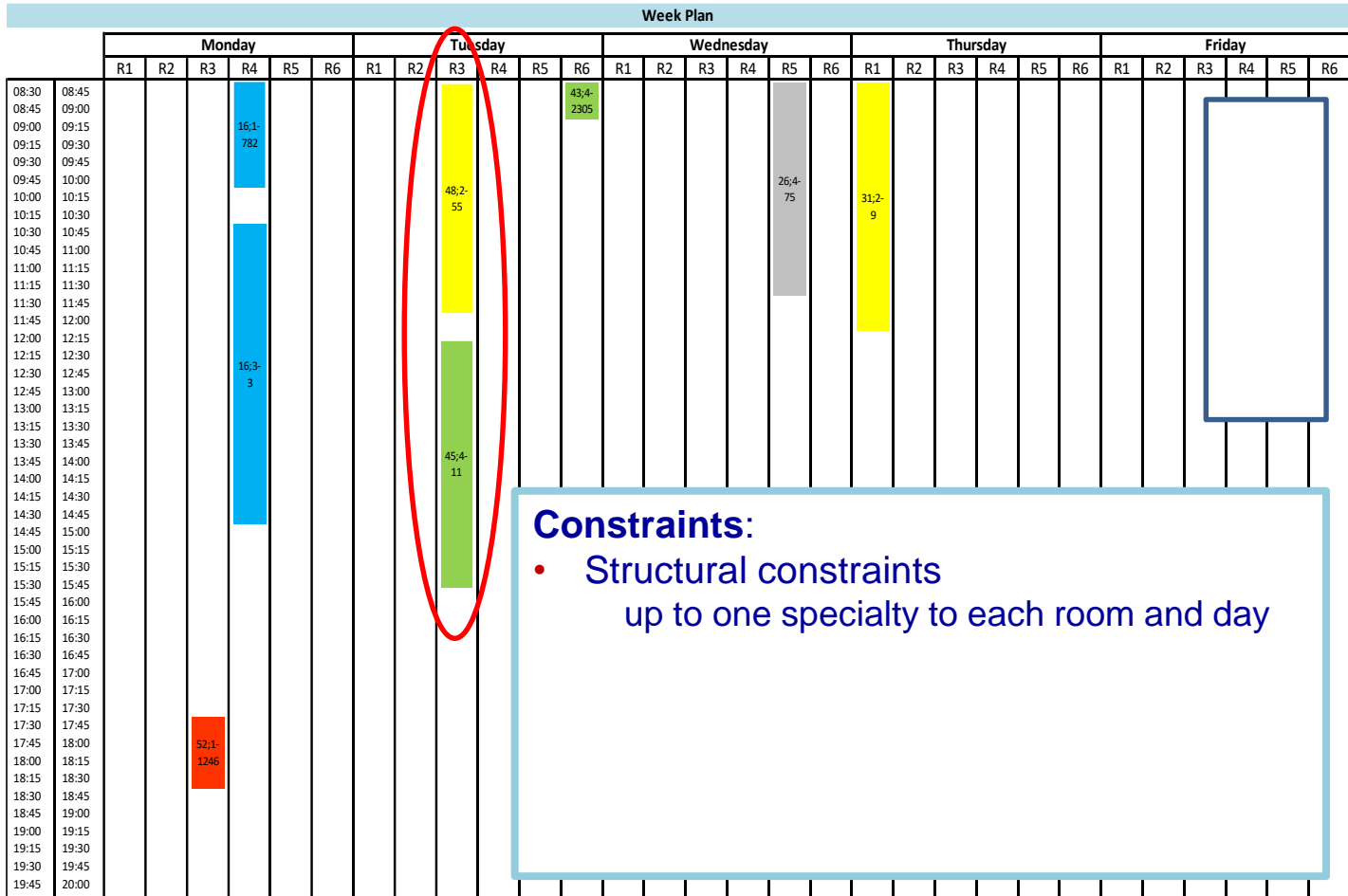
Digestive and General Surgery

Thorax Surgery

Angiology and Vascular Surgery

Otorhinolaryngology

Urology



Constraints:

- Structural constraints up to one specialty to each room and day

Legend

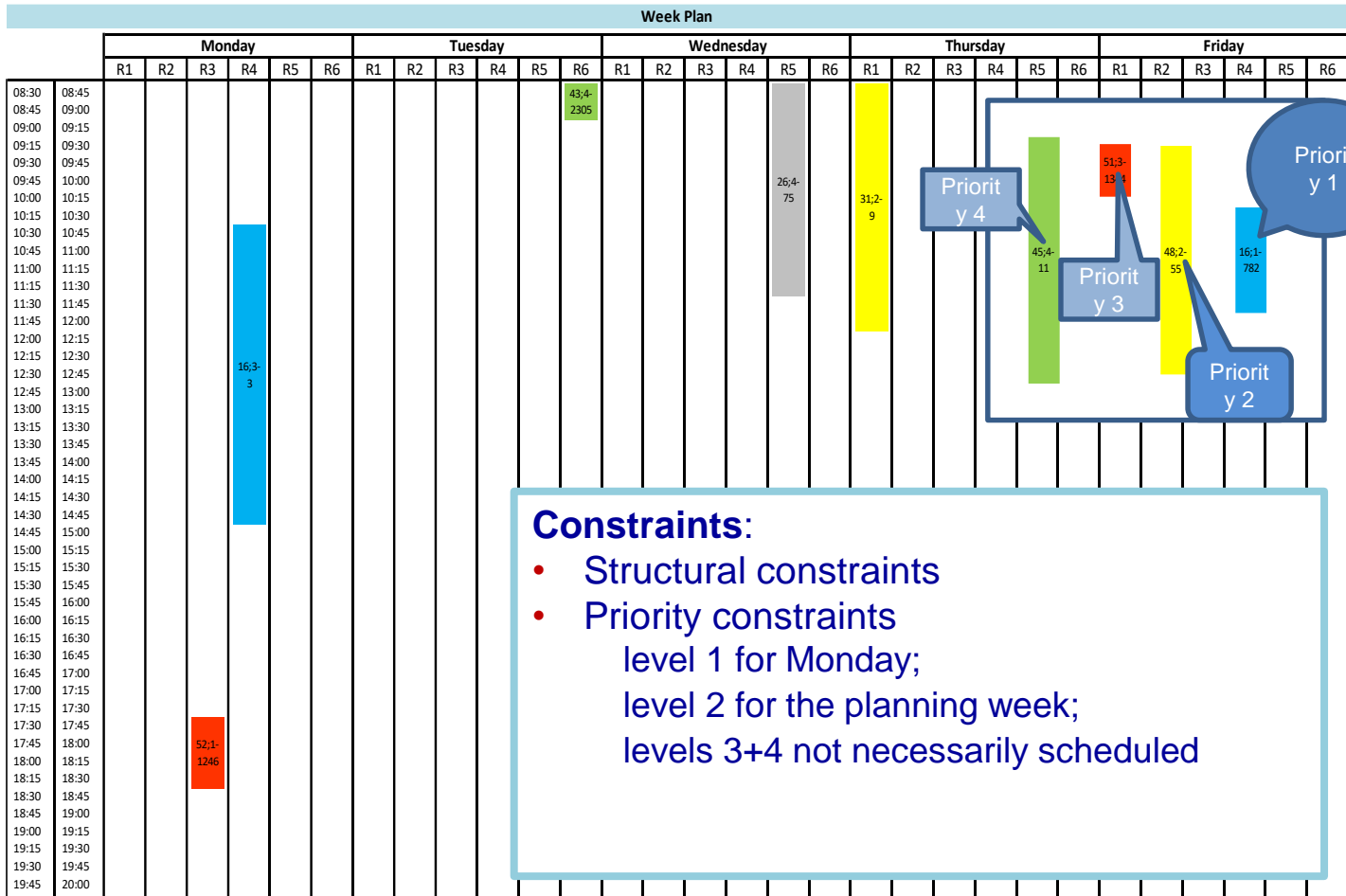
Digestive and General Surgery

Thorax Surgery

Angiology and Vascular Surgery

Otorhinolaryngology

Urology



Constraints:

- Structural constraints
- Priority constraints
 level 1 for Monday;
 level 2 for the planning week;
 levels 3+4 not necessarily scheduled

Legend

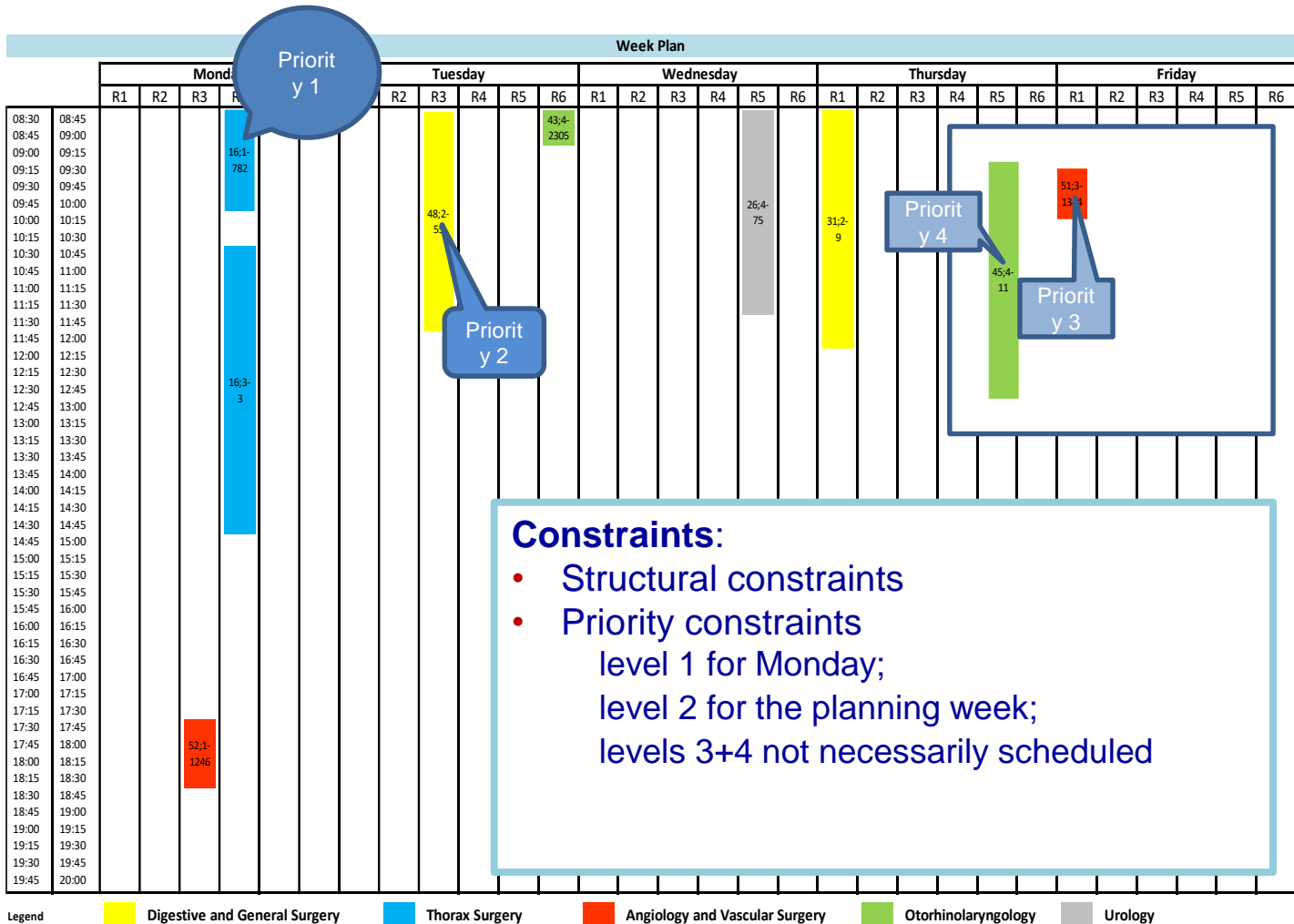
Digestive and General Surgery

Thorax Surgery

Angiology and Vascular Surgery

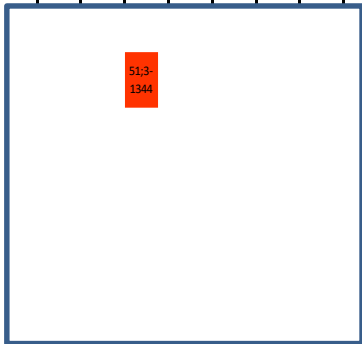
Otorhinolaryngology

Urology



Week Plan

		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Constraints:

- Structural constraints
- Priority constraints
- Capacity constraints
OR regular time (and surgeon operating time)

Legend

- Digestive and General Surgery
- Thorax Surgery
- Angiology and Vascular Surgery
- Otorhinolaryngology
- Urology

CONVENTIONAL SURGERIES

Week Plan

AMBULATORY SURGERIES

		Monday						Tuesday						Wednesday						Thursday						Friday					
		R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
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Constraints:

- Structural constraints
- Priority constraints
- Capacity constraints
- OR characteristics

dedicated room to outpatients

Legend

Digestive and General Surgery

Thorax Surgery

Angiology and Vascular Surgery

Otorhinolaryngology

Urology

Case 1: Integrated tactical+operational decisions



- Monocriterion versions
 - ILP model

$$x_{crt d} = \begin{cases} 1 & \text{if surgery } c \text{ starts in room } r \text{ at the beginning of period } t \text{ on day } d \\ 0 & \text{otherwise} \end{cases} \quad (c \in C, r \in R, t \in T_c, d \in D)$$

$$y_{jrd} = \begin{cases} 1 & \text{if a surgery of specialty } j \text{ starts in room } r \text{ on day } d \\ 0 & \text{otherwise} \end{cases} \quad (j \in J, r \in R, d \in D)$$

Max OR occupancy

$$\max \sum_{c \in C} \sum_{r \in R} \sum_{t \in T_c} \sum_{d \in D} p_c x_{crt d}$$

Max throughput

$$\max \sum_{c \in C} \sum_{r \in R} \sum_{t \in T_c} \sum_{d \in D} x_{crt d}$$

Priority constraints

$$\sum_{r \in R} \sum_{t \in T_c} x_{crt 1} = 1, \quad \forall c \in C_1^{PR}$$

$$\sum_{r \in R} \sum_{t \in T_c} \sum_{d \in D} x_{crt d} = 1, \quad \forall c \in C_2^{PR}$$

$$\sum_{r \in R} \sum_{t \in T_c} \sum_{d \in D} x_{crt d} \leq 1, \quad \forall c \in C \setminus (C_1^{PR} \cup C_2^{PR})$$

Structural constraints

$$\sum_{\substack{c \in C: t' = t - p_c + 1 \\ h_c = h}} \sum_{t' \in T_c} \sum_{r \in R} x_{crt' d} \leq 1, \quad \forall h \in H, d \in D, t \in T$$

$$\sum_{c \in C} \sum_{\substack{t' = t - p_c - \gamma \\ t' \in T_c}} x_{crt' 1} \leq 1, \quad \forall r \in R, t \in T, d \in D$$

Capacity constraints

$$\sum_{\substack{c \in C: r \in R \\ h_c = h}} \sum_{t \in T_c} p_c x_{crt d} \leq T_{hd}^{MAXd}, \quad \forall h \in H, \forall d \in D$$

$$\sum_{\substack{c \in C^h: d \in D \\ h_c = h}} \sum_{r \in R} \sum_{t \in T_c} p_c x_{crt d} \leq T_h^{MAXw}, \quad \forall h \in H$$

OR characteristics

$$\sum_{j \in E} y_{jrd} \leq 1, \quad \forall r \in R, d \in D$$

$$\sum_{c \in C_j^{SP}} \sum_{t \in T_c} x_{crt d} \leq y_{jrd} |T|, \quad \forall j \in J, r \in R, d \in D$$

$$x_{crt d} \in \{0, 1\}, \quad \forall c \in C, r \in R, t \in T_c, d \in D$$

$$y_{jrd} \in \{0, 1\}, \quad \forall j \in J, r \in R, d \in D$$

Case 1: Integrated tactical+operational decisions



- Monocriterion versions
 - ILP model: too much computational time and not so good quality solutions
 - Local search (LS) heuristics → genetic algorithm (GA)

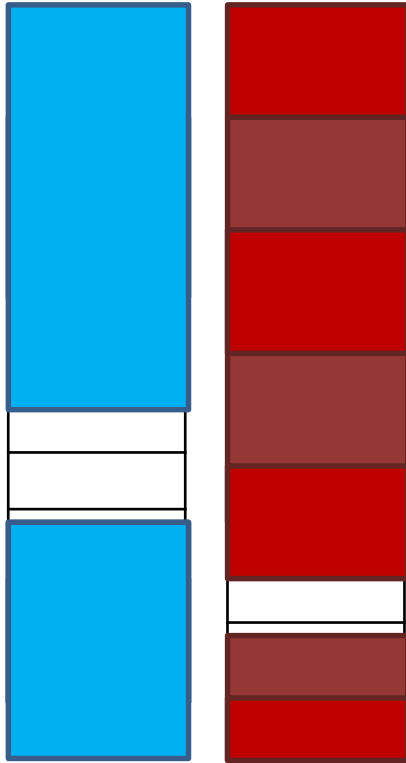
Constructive heuristic:

In **descending/ascending** order of duration and descending order of antiquity, taking into account problem constraints:

1. Schedules all deferred urgency surgeries on Monday;
2. Schedules all high priority surgeries on the first day and room possible;
3. Tries to schedule the remaining surgeries on the first day and room possible.

Maximize surgical suite occupation

Maximize waiting list reduction



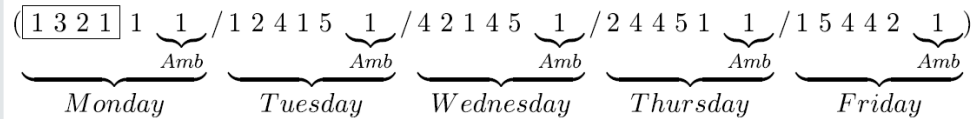
Improving heuristic:

1. Pushes all surgeries as early in the day as possible, retaining the same order;
2. Tries to assign unscheduled surgeries to the end of the day in each room;
3. Tries to exchange **two or three** consecutive scheduled surgeries, with Priority or Normal level of priority, for **one** unscheduled surgery whose duration is no greater than the duration of the consecutive ones (**or vice versa**);
4. Tries to exchange the last surgery scheduled at the end of the day for **one (or two)** unscheduled surgery that fills the remainder of the regular time in the day.

■ **Solution representation: Days × Rooms chromosome**

TACTICAL LEVEL

- Decisions: surgical specialty assigned to each day and OR



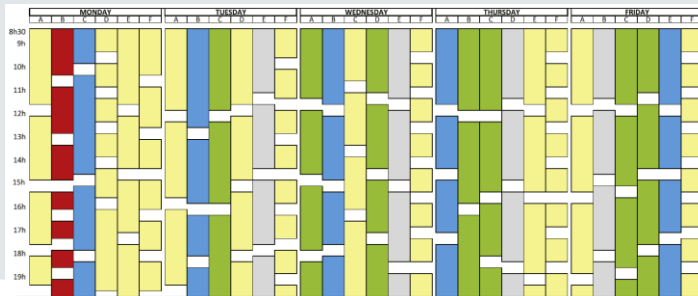
1 = digestive and general surgery; 2 = thorax surgery; 3 = angiology and vascular surgery;
4 = otorhinolaryngology; 5 = urology

■ **Chromosome decoder:**

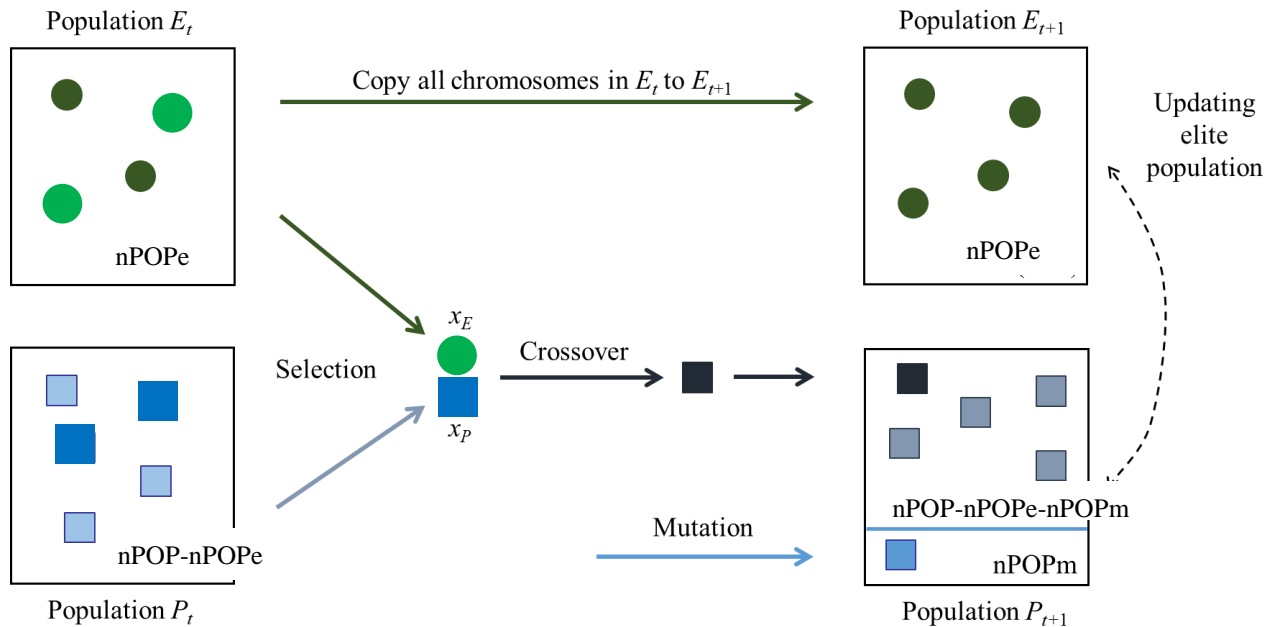
OPERATIONAL LEVEL

(adaptation of the previous) constructive and improvement heuristics

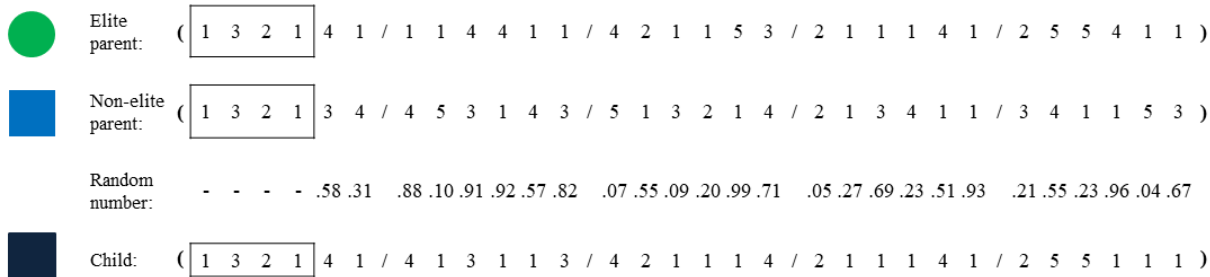
- Decisions: patients to be scheduled; assign a day, an OR and a starting time to each patient



IPS, November 7, 2018




Parameterized uniform crossover



Case 1: Integrated tactical+operational decisions



- Monocriterion versions
 - ILP model: too much computational time and not so good quality solutions
 - Local search (LS) heuristics → genetic algorithm (GA)

Objective 	ILP		LS		GA	
	Gap (%)	Time (s)	Gap (%)	Time (s)	Gap (%)	Time (s)
Max OR occupation (z_1)	2.4	> 90,000	3.6	≈ 0	1.9	86
Max throughput (z_2)	2.5	> 100,000	5.1	≈ 0	3.4	47

Case 1: Integrated tactical+operational decisions

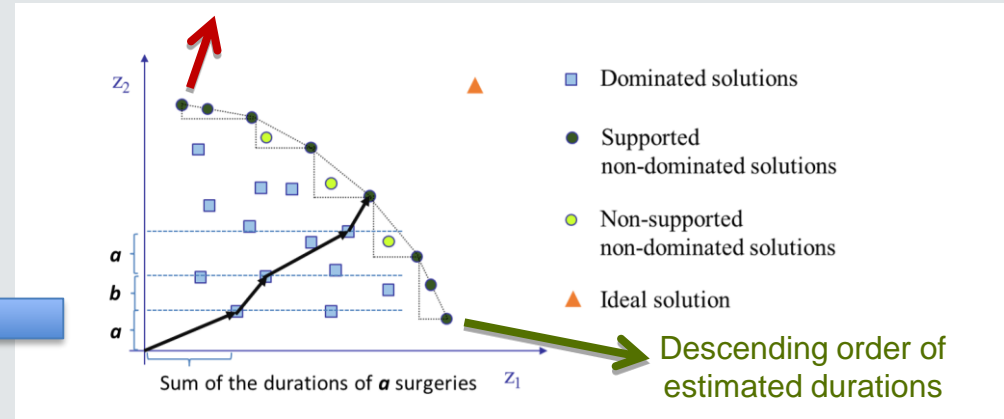


- Bicriteria version: Bicriteria heuristic (based on LS)
 - Minimize a weighted Chebyshev distance to a reference point

$$\min \max \left\{ \lambda \frac{z_1^* - z_1}{\bar{p}}, (1 - \lambda)(z_2^* - z_2) \right\}$$

Results are good (< 1s to obtain 1 solution) but solutions are strictly dependent on the value of the weights reflecting DM preferences!

- Weights $(\lambda, 1-\lambda)$ define the order (a, b) to schedule lower level priority surgeries



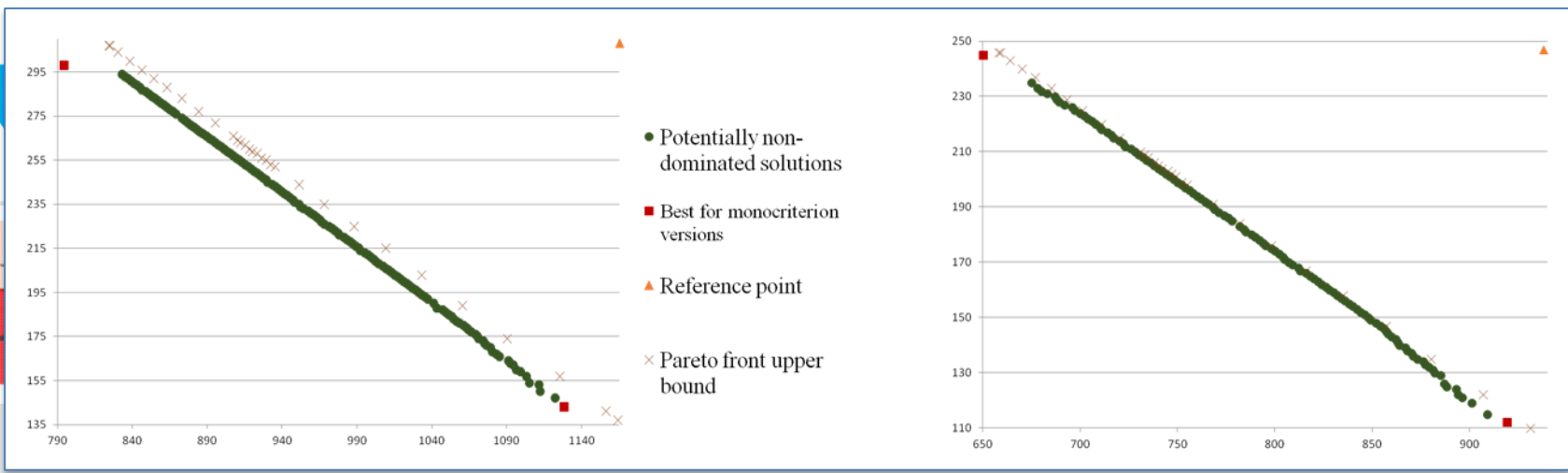
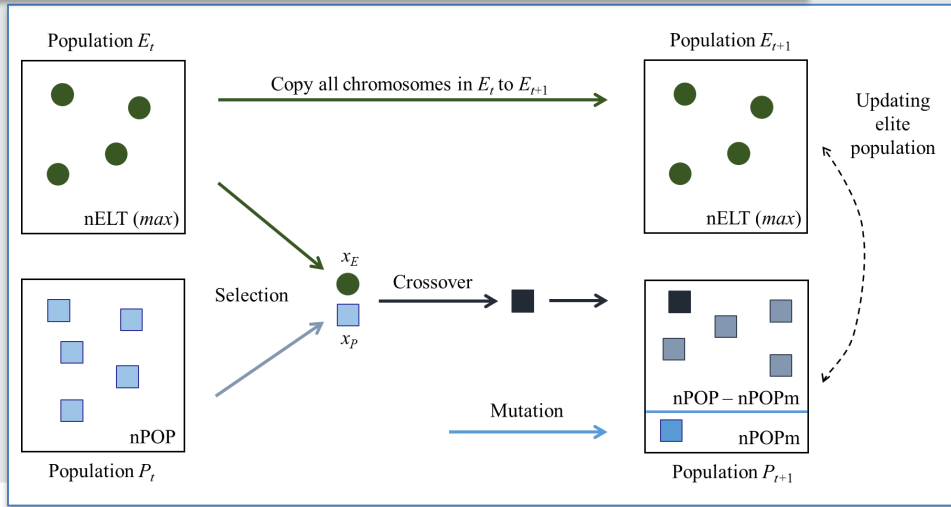


Table 9
Comparison of bicriteria heuristic [4] and evolutionary algorithm regarding closeness and diversity (M_1 , M'_2 and M'_3).

Instance	Bicriteria heuristic				Evolutionary algorithm			
	PND	M_1	M'_2	M'_3	PND	M_1	M'_2	M'_3
I1_2042	16	17.9	0.783	0.911	133.2	5.64	0.995	0.911
I2_1982	16	18.9	0.783	0.893	128.3	9.20	0.996	0.904
I3_1944	16	15.8	0.850	0.923	134.6	5.49	0.994	0.923
I4_1899	16	17.9	0.783	0.911	123.5	5.20	0.998	0.911
I5_1866	14	15.8	0.857	0.933	131.6	5.24	0.998	0.933
I6_1887	16	16.9	0.833	0.931	123.0	5.36	0.996	0.930
I7_1897	15	14.6	0.810	0.919	125.3	4.56	0.994	0.918
Average	15.6	16.8	0.814	0.917	128.5	5.81	0.996	0.919

< 15s (for 23 solutions)
0,01s/PND

< 1 min
0,32s/PND



Agenda

- OpLog brief introduction
- Scheduling frame and challenges
- Operating room (OR) planning and scheduling: motivation
- Case 1: Integrated tactical and operational decisions
- **Case 2: Operational decisions**
- Conclusions, challenges and future work

Case 2: Operational decisions



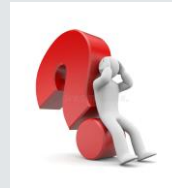
- ~~Assign a surgical specialty to each OR and day~~
- Select patients to schedule in the planning week
- Assign a day, an OR and ~~a starting time~~ to each patient



- Structural and priority constraints
- Capacity constraints (OR time and surgeon operating time)
- MSS



**ADMINISTRATION
GOALS**



**HOSPITAL
PRACTICE**

MIXED STRATEGY

OR	Monday	Tuesday	Wednesday	Thursday	Friday
MORNING SHIFTS (8h15-15h)					
1	PDT	ORL	PDT	ORL	
2	ORL	ORL	ORL	ORL	
3	ORTb	ORTa	ORTb	PLT	
4	ORTb	ORTa	ORTb	ORTa	ORTa
5	URO	URO	URO	URO	SRGb
6	OPT	OPT	OPT	OPT	OPT
7	<i>RESERVED TO URGENT CASES</i>				
8	GYN	GYN	GYN	GYN	GYN
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	SRGc	SRGc	SRGc	SRGc	SRGc
11	MXL	PLT	URO	URO	GYN
AFTERNOON SHIFTS (15h-21h)					
1					
2	ORL		ORL		ORL
3		SRGb			
4	ORTb	ORTa	ORTb	ORTa	ORTb
5	URO	URO	SRGb	SRGc	URO
6	OPT	OPT	OPT	OPT	OPT
7	<i>RESERVED TO URGENT CASES</i>				
8	SRGc	SRGc	PDT	GYN	
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	PLT	PLT	SRGc	PLT	SRGc
11	PLT	PLT	MXL	PLT	

- ✓ Priority constraints: Deferred urgency surgeries with DD in the planning horizon must be scheduled; Remaining surgeries are either scheduled or not
- ✓ MSS constraints: Surgeries are scheduled to a feasible time block
- ✓ Capacity constraints: Time block capacity constraints; Daily and weekly time limits for each surgeon
- ✓ Structural constraints: Non-overlapping of surgeons

OR	Monday	Tuesday	Wednesday	Thursday	Friday
MORNING SHIFTS (8h15-15h)					
1	PDT	ORL	PDT	ORL	
2	ORL	ORL	ORL	ORL	
3	ORTb	ORTa	ORTb	PLT	
4	ORTb	ORTa	ORTb	ORTa	ORTa
5	URO	URO	URO	URO	SRGb
6	OPT	OPT	OPT	OPT	OPT
7	RESERVED TO URGENT CASES				
8	GYN	GYN	GYN	GYN	GYN
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	SRGc	SRGc	SRGc	SRGc	SRGc
11	MXL	PLT	URO	URO	GYN
AFTERNOON SHIFTS (15h-21h)					
1					
2	ORL		ORL		ORL
3		SRGb			
4	ORTb	ORTa	ORTb	ORTa	ORTb
5	URO	URO	SRGc	SRGc	URO
6	OPT	OPT	OPT	OPT	OPT
7	RESERVED TO URGENT CASES				
8	SRGc	SRGc	PDT	GYN	
9	SRGb	SRGb	SRGb	SRGb	SRGb
10	PLT	PLT	SRGc	PLT	SRGc
11	PLT	PLT	MXL	PLT	

Priority constraints

MSS constraints

Capacity constraints

Structural constraints

$$\begin{cases}
 \sum_{d' \in D_c} \sum_{b \in B_d} x_{cd'b} = 1, \forall c \in C^p, d \in D \\
 \sum_{d \in D_c} \sum_{b \in B_d} x_{cdb} + z_c = 1, \forall c \in C^{NP} \\
 \sum_{c \in C_{sd}} x_{cdb} \leq a_{db}^s M, \forall d \in D, b \in B_d, s \in S \\
 \sum_{c \in C_{sd}} (t_c^{TOT} + t_c^{CLN}) x_{cdb} \leq k_{db}^B, \forall d \in D, b \in B_d, \text{ for } s: a_{db}^s = 1 \\
 \sum_{c \in C_{hd}^{HD}} \sum_{b \in B_d} t_c^{SRG} x_{cdb} \leq k_{hd}^{HD}, \forall h \in H, d \in D \\
 \sum_{c \in C_h^H} \sum_{d \in D_c} \sum_{b \in B_d} t_c^{SRG} x_{cdb} \leq k_h^{HPH}, \forall h \in H \\
 \sum_{c \in C_{hd}^{HD}} \sum_{b \in B_d^j} t_c^{SRG} x_{cdb} \leq \max_{b \in B_d^j} k_{hd}^{HD}, \forall h \in H, d \in D, j = M, A \\
 x_{cdb} \in \{0,1\}, \forall c \in C, d \in D_c, b \in B_d \quad z_c \geq 0, \forall c \in C^{NP}
 \end{cases}$$

$$x_{cdb} = \begin{cases} 1 & \text{if surgery } c \text{ is scheduled to block } b \text{ on day } d \\ 0 & \text{otherwise} \end{cases} \quad (c \in C, d \in D_c, b \in B_d)$$

$$z_c = \begin{cases} 1 & \text{if surgery } c \text{ is not scheduled} \\ 0 & \text{otherwise} \end{cases} \quad (c \in C^{NP})$$

Case 2: Operational decisions

ADMINISTRATION GOALS:

- ✓ Improve **timely access** for operated and waiting patients
- ✓ Improve **equity in the access** (FIFO strategy for patients with the same priority level)

HOSPITAL PRACTICE:

- ✓ Patients waiting for fewer days are firstly scheduled (LIFO strategy) – MORNING SHIFTS
- ✓ Incentive program: surgeons are free to schedule patients and are paid per surgery performed – AFTERNOON SHIFTS

MIXED STRATEGY:

- ✓ Administration goals – MORNING SHIFTS
- ✓ Incentive program – AFTERNOON SHIFTS

week	version	avgBlockOCP		Scheduled Surgeries						Unscheduled Surgeries					CommonSurg		
		withoutCT	withCT	nb	pctWL	avgDaysWL	avgDaysTDD	nbOoD	avgDaysWL	avgDaysTDD	nbOoD	nb	pctSch				
				days	norm	days	norm		days	norm	days	norm					
W1.4.1.1.13	A			8.7	344.1	1.329	-131.9	-0.507	362	122.4	0.464	142.1	0.536	328	15	5.2	
	H				60.1	0.349	177.7	0.651	18	146.8	0.681	115.2	0.319	679	-	-	
W2.6.1.1.14	A			17.4	1.218	-107.4	-0.412	340	118.9	0.453	145.4	0.547	286	22	6.6		
	H				58.1	0.487	178.1	0.513	19	141.4	0.620	119.8	0.380	615	-	-	
W3.5.1.1.15	A			240.0	0.923	-57.1	-0.217	274	127.8	0.506	134.5	0.494	571	5	3.4		
	H			2.5	89.3	0.550	124.5	0.450	19	134.2	0.672	124.6	0.328	831	-	-	
W4.2.3.1.15	A	73.1		382	6.0	266.9	1.040	-75.3	-0.293	356	124.0	0.477	139.3	0.523	556	9	4.3
	H	59.3	74.1	211	3.3	65.8	0.432	148.5	0.568	13	134.4	0.646	126.2	0.354	905	-	-

Stakeholders with different agendas

DISSIMILARITY level

Relative distance between two solutions concerning the set of patients selected to be scheduled in the planning week

Versions	Planning week				Average
	W1.4.1.1.13	W2.6.1.1.14	W3.5.1.1.15	W4.2.3.1.15	
Administration - Surgeon	0.9513	0.9518	0.9616	0.9451	0.9525
Administration - Mixed	0.7436	0.7483	0.5281	0.6437	0.6659
Surgeon - Mixed	0.7302	0.7284	0.9632	0.8356	0.8144
Administration - Hospital	0.9561	0.9381	0.9776	0.9696	0.9604
Surgeon - Hospital	0.8448	0.8507	0.9512	0.9216	0.8921
Mixed - Hospital	0.8782	0.8704	0.9822	0.9502	0.9203

Case 2: Operational decisions

- ❖ **Overbooked surgical schedules**
=> cancellation of surgeries; unsatisfied patients; stress for the hospital staff
- ❖ Deterministic solutions can be **disruptive** to a smooth running of the surgical suite

		Surgical schedule with real duration of surgeries												
		avgBlockOCPT				ExtraTimeBlocks								
		withoutCT		withCT		nb	pctBlocks	minET	maxET	avgET	medET			
V	H	-	-	-	286	100	55.3	69.8	14	16.3	3	146	52.6	47
	A	270	77.0	99.4	148	27.8	80.6	101.3	29	34.5	1	262	62.9	35
	S	-	-	-	-	-	67.8	100.4	34	40.5	2	277	45.7	32
	M	-	-	-	-	-	71.5	98.8	36	42.9	1	259	52.4	49
	H	-	-	-	-	-	65.1	82.3	23	26.7	3	214	50.1	41
W3.5.1.15	A	301	71.3	99.3	75	24.9	81.4	109.1	25	48.1	1	313	87.9	32
	S	429	60.9	99.5	173	40.3	65.1	103.2	28	53.8	2	289	50.1	25
	M	305	71.1	99.1	77	25.2	80.6	108.4	23	44.2	2	315	90.1	44
	H	-	-	-	145	100	62.8	76.1	9	17.3	19	104	47.8	40
W4.2.3.15	A	382	73.1	99.2	115	30.1	88.5	114.5	32	47.8	1	438	97.3	53
	S	529	62.2	98.9	262	49.5	73.4	109.9	40	59.7	3	409	88.2	30
	M	432	68.0	98.6	154	35.6	80.9	111.4	38	56.7	-	-	-	-
	H	-	-	-	211	100	59.3	74.1	9	13.4	-	-	-	-

ROBUST OPTIMIZATION APPROACH



Simulation in a real case scenario

Case 2: Operational decisions

(cardinality constrained) UNCERTAINTY SETS:

- For each constraint subject to uncertainty, the solution is protected for a bounded number of parameters that are allowed to vary from their nominal values
 - Γ is the **budget of uncertainty** for each constraint
- Allows to control the **level of conservatism** in the solution



**ROBUST OPTIMIZATION
APPROACH**

- Does not require knowledge about probabilistic distribution of the uncertain parameters
- Keeps computational tractability of the deterministic models
 - Primer motivation for application areas with large real-life instances (>4,000 patients)

WHY?

$$\sum_{d \in D_c} \sum_{b \in B_d} x_{cd'b} = 1, \forall c \in C_d^p, d \in D$$

$$\sum_{d \in D_c} \sum_{b \in B_d} x_{cdb} + z_c = 1, \forall c \in C^{NP}$$

$$\sum_{c \in C_{sd}} x_{cdb} \leq a_{db}^s M, \forall d \in D, b \in B_d, s \in S$$

$$\sum_{c \in C_{sd}} (t_c^{TOT} + t_c^{CLN}) x_{cdb} \leq k_{db}^B, \forall d \in D, b \in B_d, \text{ for } s: a_{db}^s = 1$$

$$\sum_{c \in C_{hd}^{HD}} \sum_{b \in B_d} t_c^{SRG} x_{cdb} \leq k_{hd}^{HD}, \forall h \in H, d \in D$$

$$\sum_{c \in C_{hd}^H} \sum_{d \in D_c} \sum_{b \in B_d} t_c^{SRG} x_{cdb} \leq k_h^{H_{PH}}, \forall h \in H$$

$$\sum_{c \in C_{hd}^{HD}} \sum_{b \in B_d^j} t_c^{SRG} x_{cdb} \leq \max_{b \in B_d^j} k_{hd}^{HD}, \forall h \in H, d \in D, j = M, A$$

$$x_{cdb} \in \{0,1\}, \forall c \in C, d \in D_c, b \in B_d \quad z_c \geq 0, \forall c \in C^{NP}$$



Model from the **same class** as the deterministic approach with **more $\alpha(|H| \cdot |C| \cdot |D|)$ real variables and constraints** (result from the linearization of the non-linear robust counterpart)

$$\sum_{c \in C_{sd}} (t_c^{TOT} + t_c^{CLN}) x_{cdb} + \Gamma_{db}^{TBC} v_{db}^{TBC} + \sum_{c \in C_{sd}} w_{cdb}^{TBC} \leq k_{db}^B, \forall d \in D, b \in B_d, \text{ for } s: a_{db}^s = 1$$

$$v_{db}^{TBC} + w_{cdb}^{TBC} \geq \delta_c^{TOT} x_{cdb}, \forall c \in C_{sd}, d \in D, b \in B_d, \text{ for } s: a_{db}^s = 1$$

$$w_{cdb}^{TBC} \geq 0, \forall c \in C_{sd}, d \in D, b \in B_d, \text{ for } s: a_{db}^s = 1$$

$$v_{db}^{TBC} \geq 0, \forall d \in D, b \in B_d$$

$$\sum_{c \in C_{hd}^{HD}} \sum_{b \in B_d} t_c^{SRG} x_{cdb} + \Gamma_{hd}^{DTL} v_{hd}^{DTL} + \sum_{c \in C_{hd}^{HD}} w_{chd}^{DTL} \leq k_{hd}^{HD}, \forall h \in H, d \in D$$

$$v_{hd}^{DTL} + w_{chd}^{DTL} \geq \sum_{b \in B_d} \delta_c^{SRG} x_{cdb}, \forall c \in C_{hd}^{HD}, h \in H, d \in D$$

$$w_{chd}^{DTL} \geq 0, \forall c \in C_{hd}^{HD}, h \in H, d \in D$$

$$v_{hd}^{DTL} \geq 0, \forall h \in H, d \in D$$

$$\sum_{c \in C_h^H} \sum_{d \in D_c} \sum_{b \in B_d} t_c^{SRG} x_{cdb} + \Gamma_h^{WTL} v_h^{WTL} + \sum_{c \in C_h^H} w_{ch}^{WTL} \leq k_h^{H_{PH}}, \forall h \in H$$

$$v_h^{WTL} + w_{ch}^{WTL} \geq \sum_{d \in D_c} \sum_{b \in B_d} \delta_c^{SRG} x_{cdb}, \forall c \in C_h^H, h \in H$$

$$w_{ch}^{WTL} \geq 0, \forall c \in C_h^H, h \in H$$

$$v_h^{WTL} \geq 0, \forall h \in H$$

$$\sum_{c \in C_{hd}^{HD}} \sum_{b \in B_d^j} t_c^{SRG} x_{cdb} + \Gamma_{hd}^{SNO} v_{hd}^{SNO} + \sum_{c \in C_{hd}^{HD}} w_{chd}^{SNO} \leq \max_{b \in B_d^j} k_{hd}^{HD}, \forall h \in H, d \in D, j = M, A$$

$$v_{hd}^{SNO} + w_{chd}^{SNO} \geq \sum_{b \in B_d^j} \delta_c^{SRG} x_{cdb}, \forall c \in C_{hd}^{HD}, h \in H, d \in D, j = M, A$$

$$w_{chd}^{SNO} \geq 0, \forall c \in C_{hd}^{HD}, h \in H, d \in D$$

$$v_{hd}^{SNO} \geq 0, \forall h \in H, d \in D$$

DETERMINISTIC models

instance	approach	shift	ADMINISTRATION'S VERSION						SURGEONS' VERSION						MIXED VERSION						
			Avars	Acst	TL				Avars	Acst	TL				Avars	Acst	TL				
					Agap	nbOS	Atime	Ttime			Agap	nbOS	Atime	Ttime			Agap	nbOS	Atime	Ttime	
W1_4.1.1	D	M	5,898	542	0.33	1/10	545	6,000	3,245	531	0.04	2/10	246	2,708	3,245	531	0.23	4/10	193	2,123	
		A							2,442	472	0.73	4/10	191	2,100	2,521	485	0.36	7/10	127	1,398	
	R	M	14,380	8,410	3.83	1/10	545	6,000	8,352	5,566	0.42	2/10	253	2,781	8,347	5,566	1.63	2/10	245	2,700	
		A							6,491	4,453	3.63	5/10	180	1,977	6,676	4,580	3.51	4/10	192	2,115	
	W2_6.1.1	D	M	6,403	574	0.28	2/9	491	5,400	3,567	563	0.04	3/9	218	2,400	3,567	563	0.31	3/9	219	2,414
			A							2,591	495	0.57	5/9	138	1,517	2,688	511	0.36	5/9	138	1,513
R		M	15,817	9,112	4.38	2/9	491	5,401	9,209	6,121	0.51	1/9	273	3,000	9,209	6,121	1.82	2/9	218	2,400	
		A							6,908	4,736	4.74	3/9	218	2,401	7,147	4,898	4.25	3/9	218	2,401	
W3_5.1.1	D	M	6,755	717	0.24	4/9	382	4,206	6,645	716	0.04	2/9	245	2,700	6,645	716	0.25	4/9	191	2,105	
		A							306	105	0	3/3	0	0	314	108	0	3/3	0	0	
	R	M	16,832	10,038	2.00	2/9	491	5,402	15,955	9,947	0.38	2/9	247	2,718	15,955	9,947	2.00	2/9	246	2,702	
		A							934	934	0	3/3	0	0	953	953	0	3/3	0	0	
W4_2.3.1	D	M	12,695	895	0.29	2/8	491	5,400	8,733	886	0.03	1/8	273	3,000	8,733	886	0.09	3/8	218	2,401	
		A							4,934	673	0.37	5/6	82	900	5,011	514	0.20	5/6	82	900	
	R	M	29,909	17,673	2.62	2/8	492	5,408	21,268	13,342	0.30	2/8	257	2,823	21,268	13,342	1.11	3/8	223	2,452	
		A							12,189	7,861	1.85	5/6	82	907	12,360	7,975	1.44	5/6	82	907	

ROBUST models

Time limit: 10 minutes per service (5 minutes per service and shift)

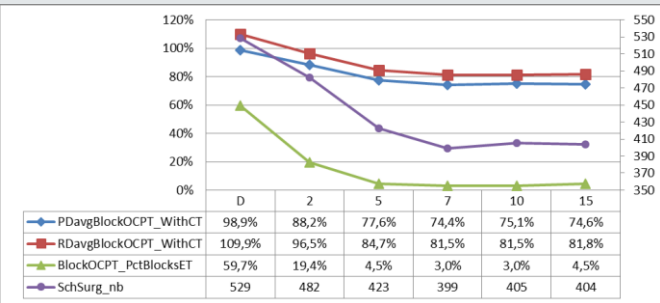
$\Gamma = 2$ for all the constraints subject to uncertainty

Case 2: Operational decisions

Price of robustness

$\Gamma = 2$

$\Gamma = 5$



Γ = budget of uncertainty

week	version	Surgical schedule			Surgical schedule with real duration of surgeries									
		Surg	avgBlockOCPT		SurgRealDur		avgBlockOCPT		ExtraTimeBlocks					
		nb	withoutCT	withCT	nb	pctSch	withoutCT	withCT	nb	pctBlocks	minET	maxET	avgET	medET
W1.4.1.13	A	345	60.0	78.8	116	33.6	62.5	81.2	7	8.3	4	234	77.5	27
	S	566	56.7	86.2	384	67.8	57.5	87.1	12	14.3	2			
	M	472	57.9	82.8	253	53.6	59.9	84.6	9	10.7	2			
	H	-	-	-	286	100	55.3	69.8	14	16.3	3			
W2.6.1.14	A	335	61.1	78.5	126	37.6	63.5	80.9	9	10.7	1			
	S	558	57.3	86.5	371	66.5	59.8	88.9	13	15.5	3			
	M	462	58.2	82.6	251	54.3	60.1	84.4	10	11.9	2			
	H	-	-	-	333	100	65.1	82.3	23	26.7	3			
W3.5.1.15	A	261	59.8	83.3	62	23.8	70.4	93.8	7	13.5	18			
	S	389	54.8	88.9	171	44.0	61.8	96.0	9	17.3	2			
	M	274	59.7	85.0	64	23.4	71.6	96.8	8	15.4	38			
	H	-	-	-	145	100	62.8	76.1	9	17.3	19			
W4.2.3.15	A	341	58.7	82.5	108	31.7	71.6	95.5	12	17.9	7			
	S	482	55.0	88.2	246	51.0	63.5	96.5	13	19.4	3			
	M	390	57.1	84.4	140	35.9	68.9	96.2	11	16.4	29			
	H	-	-	-	211	100	59.3	74.1	9	13.4	1			
W1.4.1.13	A	316	54.8	72.3	105	33.2	57.5	74.9	1	1.2	89			
	S	495	50.1	76.4	332	67.1	52.5	78.7	4	4.8	82			
	M	424	52.3	75.0	215	50.7	54.1	76.8	3	3.6	1			
	H	-	-	-	286	100	55.3	69.8	14	16.3	3			
W2.6.1.14	A	302	55.8	71.6	110	36.4	57.7	73.4	4	4.8	10			
	S	489	49.4	75.0	311	63.6	51.4	77.0	5	6.0	9			
	M	412	52.2	73.9	221	53.6	54.1	75.7	3	3.6	17			
	H	-	-	-	333	100	65.1	82.3	23	26.7	3			
W3.5.1.15	A	230	53.2	73.7	53	23.0	59.8	80.5	5	9.6	18			
	S	348	48.3	79.4	157	45.1	52.6	83.7	2	3.8	9			
	M	237	52.3	74.4	52	21.9	58.6	80.7	4	7.7	30			
	H	-	-	-	145	100	62.8	76.1	9					
W4.2.3.15	A	303	51.9	73.7	89	29.4	64.5	86.3	5					
	S	423	48.2	77.6	226	53.4	55.3	84.7	3					
	M	342	51.2	75.2	125	36.5	60.0	83.9	6					
	H	-	-	-	211	100	59.3	74.1	9					

DETERMINISTIC solutions

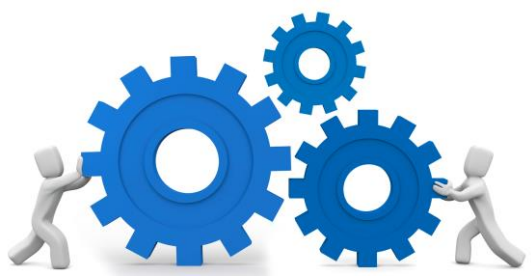
	withCT	nb	pctBlocks
	101.3	29	34.5
	100.9	41	48.8
	100.3	29	34.5
	69.8	14	16.3
	101.3	29	34.5
	100.4	34	40.5
	98.8	36	42.9
	82.3	23	26.7
	109.1	25	48.1
	103.2	28	53.8
	108.4	23	44.2
	76.1	9	17.3
	114.5	32	47.8
	109.9	40	59.7
	111.4	38	56.7
	74.1	9	13.4

Simulation in a real case scenario

Agenda

- OpLog brief introduction
- Scheduling frame and challenges
- Operating room (OR) planning and scheduling: motivation
- Case 1: Integrated tactical and operational decisions
- Case 2: Operational decisions
- **Conclusions, challenges and future work**

Limitations and future work



✓ Methods from stakeholders theory

- Methods and approaches from OR&MS
- Stakeholders' perspectives
- Uncertainty
- Up and downstream resources



Main challenges

- Dimension of real problems
- Massive amount of data
- Complexity of scheduling problems
- Uncertainty
- Integration of different departments
- Stakeholders participation and engagement
- Implementation barrier



Selected publications

- Mateus C, Marques I, Captivo ME (2017). Local search heuristics for a surgical case assignment problem. *Operations Research for Health Care* 17: 71-81.
- Marques I, Captivo ME (2017). Different stakeholders' perspectives for a surgical case assignment problem: deterministic and robust approaches. *European Journal of Operational Research* 261(1): 260-278.
- Marques I, Captivo ME (2015). Bicriteria elective surgery scheduling using an evolutionary algorithm. *Operations Research for Health Care* 7: 14-26.
- Marques I, Captivo ME, Pato MV (2015). A bicriteria heuristic for an elective surgery scheduling problem. *Health Care Management Science* 18(3): 251-266.
- Marques I, Captivo ME, Pato MV (2014). Scheduling elective surgeries in a Portuguese hospital using a genetic heuristic. *Operations Research for Health Care* 3(2): 59-72.
- Marques I, Captivo ME, Pato MV (2012). An integer programming approach to elective surgery scheduling. *OR Spectrum* 34(2): 407-427.



Operating room planning and scheduling

Real Portuguese cases

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