

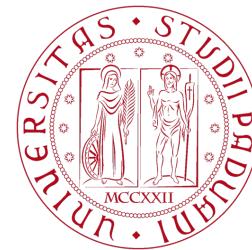
Simulation of Healthcare Processes: Challenges, Solutions and Benefits

Candidate: Marco Francesco Sommaruga

Supervisor: Massimiliano De Leoni

July 19, 2022

Master Degree in Data Science



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Process mining in healthcare

Healthcare managers have to face several challenges:



Tightening of government budgets



Scarce resource availability



Offer efficient services to patients



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PROCESS SIMULATION



Introduction

Business Process Simulation

Business Process Simulation is a process mining technique that allows the creation of a process in a virtual environment on the basis of a given event log.

Emergency department case study



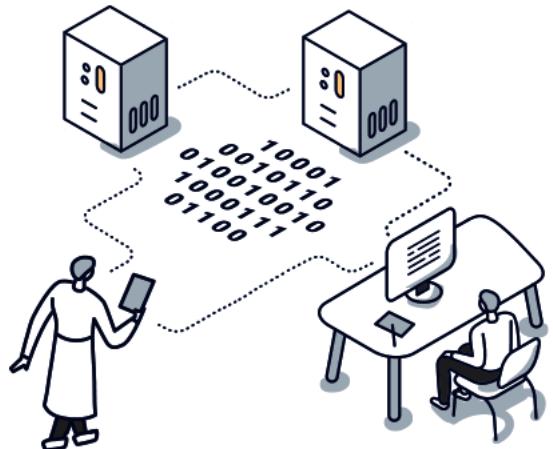
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Emergency department case study



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case	C02_IDUNIVOCASSISTITO	ETA_ACCESSO	C05_ACCESSO	C05B_PATOLOGIA_TRIAGE	C06_DIAGNOSI_PRINCIPALE	C07_ESITO_DIMISSIONE	C100_EVENTO	C101_TIMESTAMP1	C103_ATTRIBUTE
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4	09060203-PS-2017000001	3011.0	49.0	01/01/2017	C8-MANIFESTAZIONI CUTANEE	V679-VISITA DI CONTROLLO	DIMISSIONE A DOMICILIO	USCITA	01/01/2017 01.28.51
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Emergency department case study



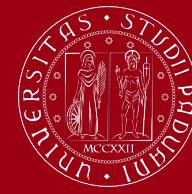
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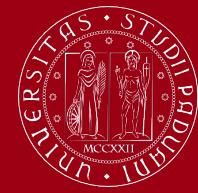
! Missing start timestamps

Estimation of start timestamps of activities



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Estimation of start timestamps of activities



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Given:

- The original event log \mathcal{L}
- $\alpha_1, \alpha_2, \dots, \alpha_n$ with $\alpha_i \in [0,1] \forall i = 1, \dots, n$

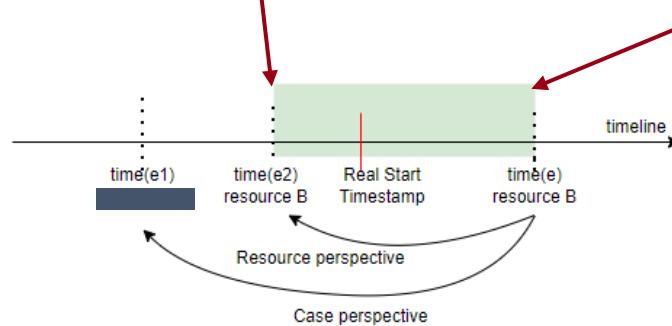
$$time(e') = \alpha(a) * mintime(e) + (1 - \alpha(a)) * time(e)$$

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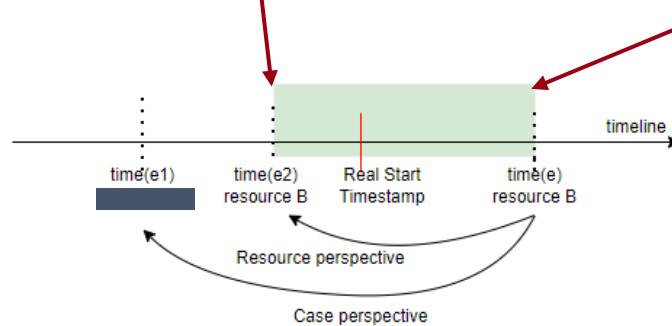


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$$time(e') = \alpha(a) * mintime(e) + (1 - \alpha(a)) * time(e)$$



Problem

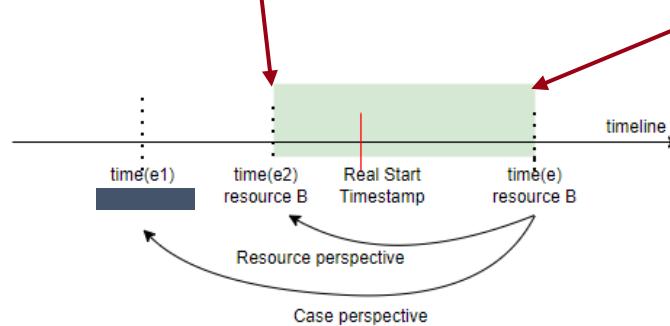
Find the vector $[\alpha_1, \alpha_2, \dots, \alpha_n]$ that best characterizes the start timestamps.

Estimation of start timestamps of activities

Given:

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- $\alpha_1, \alpha_2, \dots, \alpha_n$ with $\alpha_i \in [0,1] \forall i = 1, \dots, n$

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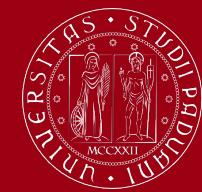


Optimization problem:

$$\Delta(\mathcal{L}^{sim}, \mathcal{L}^\alpha) = \varepsilon_{(\mathcal{L}^{sim}, \mathcal{L}^\alpha)} * \gamma + \sum_i \varphi_i(\mathcal{L}^{sim}, \mathcal{L}^\alpha) * \theta_i$$

where:

- \mathcal{L}^{sim} : simulated event log
- \mathcal{L}^α : original event log \mathcal{L} enriched with start timestamps found with the given set of α



Optimization approaches

Local-based search
algorithm



Optimization approaches

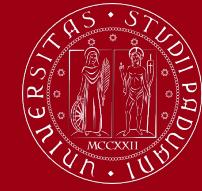
Local-based search
algorithm



Genetic algorithms

MOGAII

NSGAII



Validation of the technique

Two case studies with both start and completion timestamps:



Students' credential recognition process



Purchase process

Assess the technique by removing the original start timestamp and by re-discovering them.



Validation of the technique

Comparison of the results through boxplots obtained as:

$$\frac{|t_s - \tilde{t}_s|}{t_c - t_s}$$

where:

- t_s and t_c are the actual start and completion timestamps
- \tilde{t}_s is the estimated start timestamp

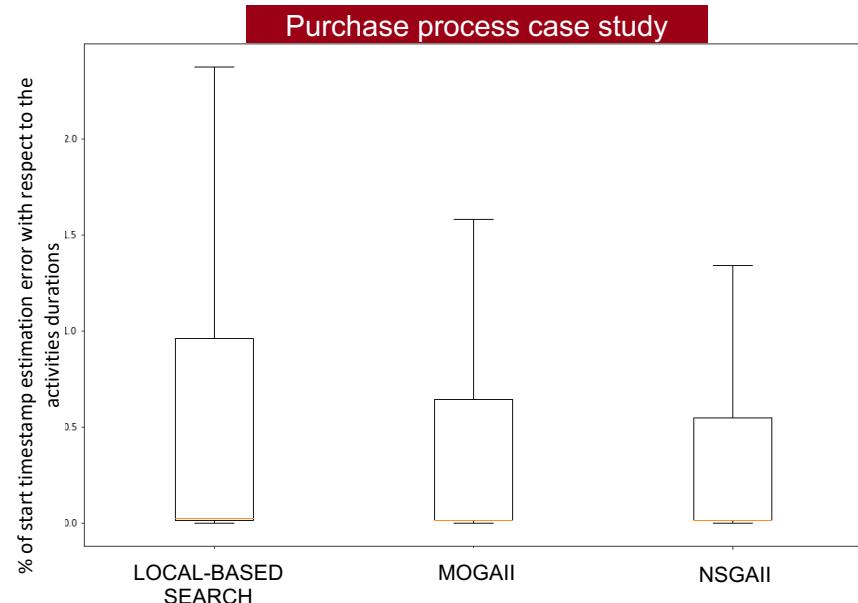
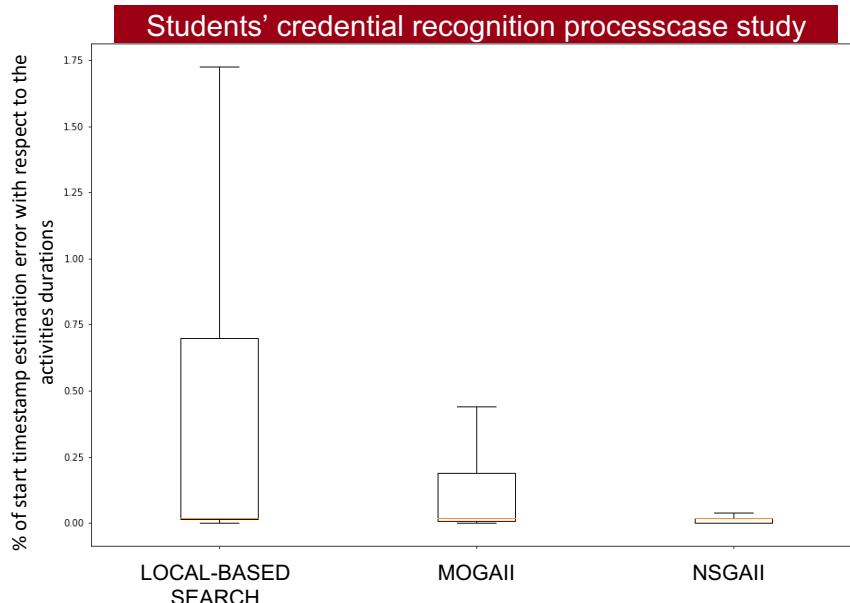
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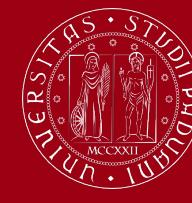
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Emergency department case study

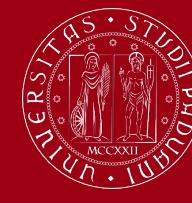


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! Missing start timestamps

✓ Leveraged MOGAI to estimate start timestamps

Emergency department case study



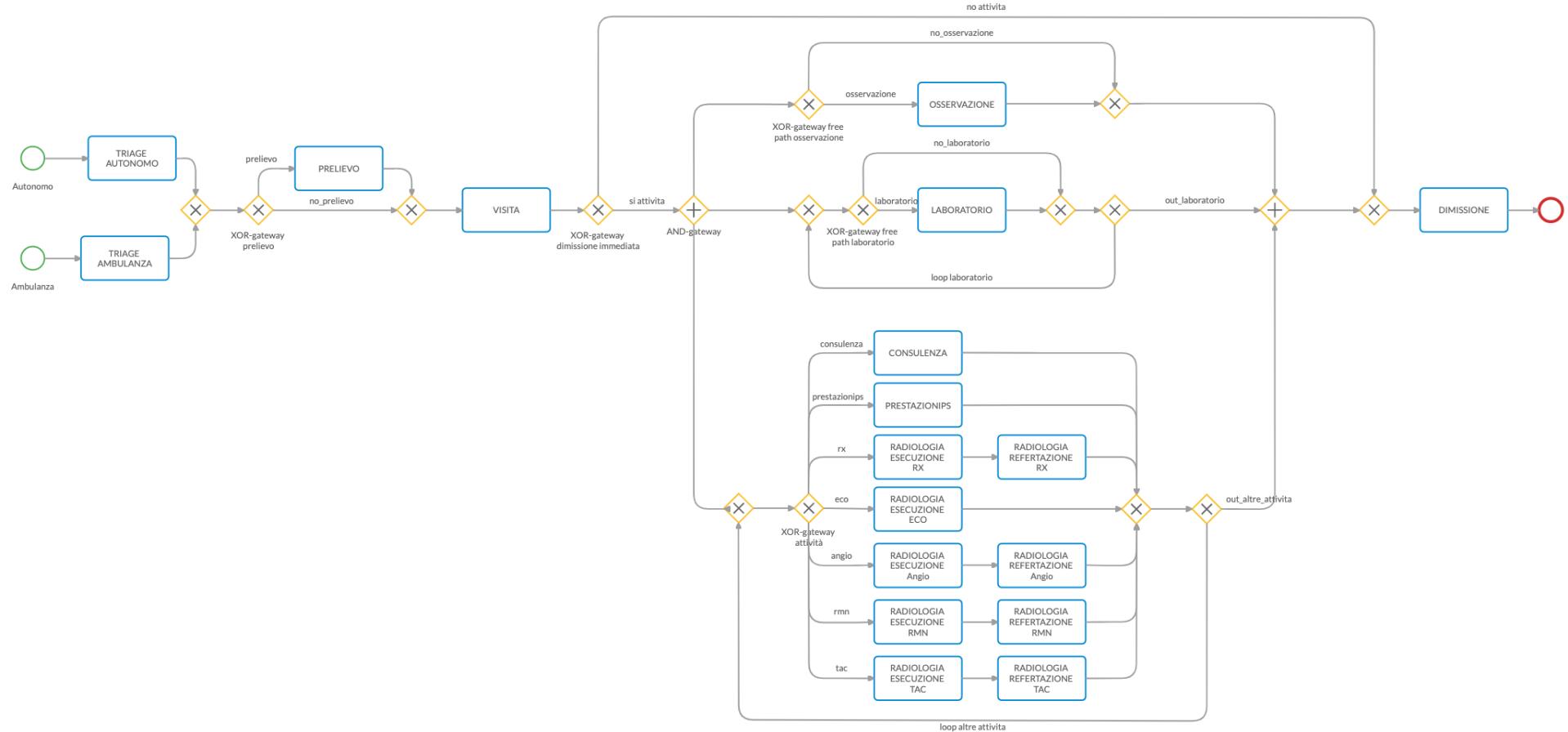
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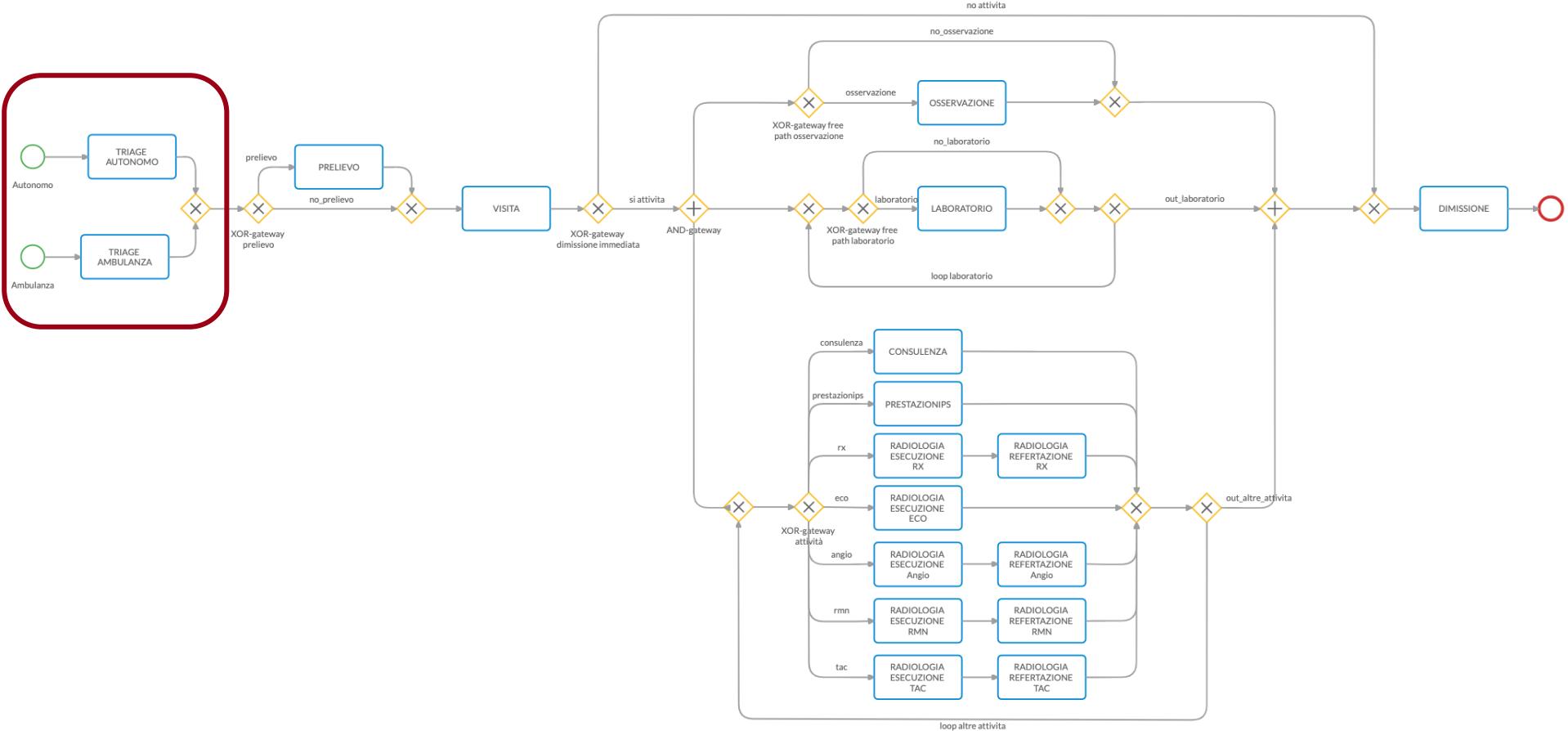
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! Construction of a fitting process model

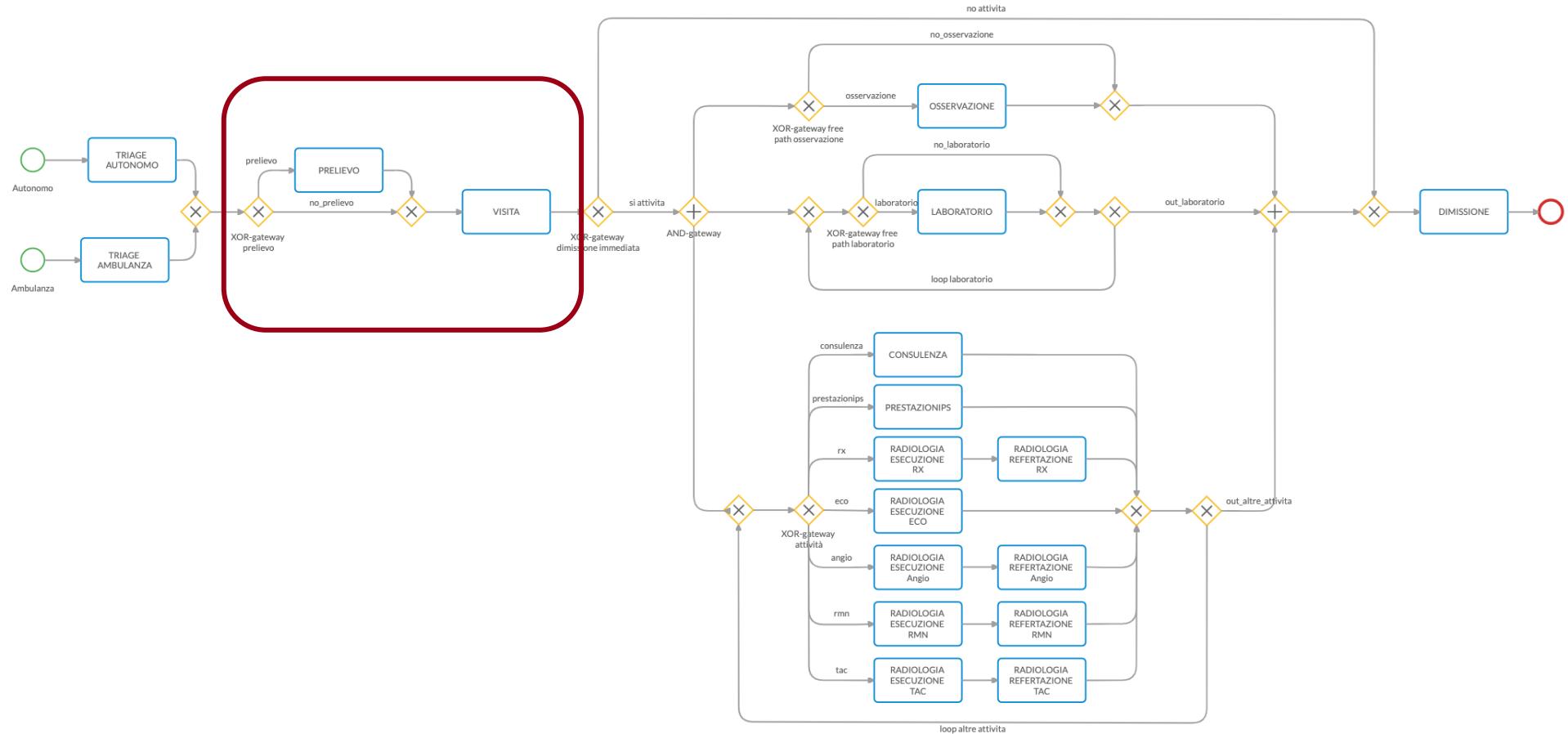
ED process model



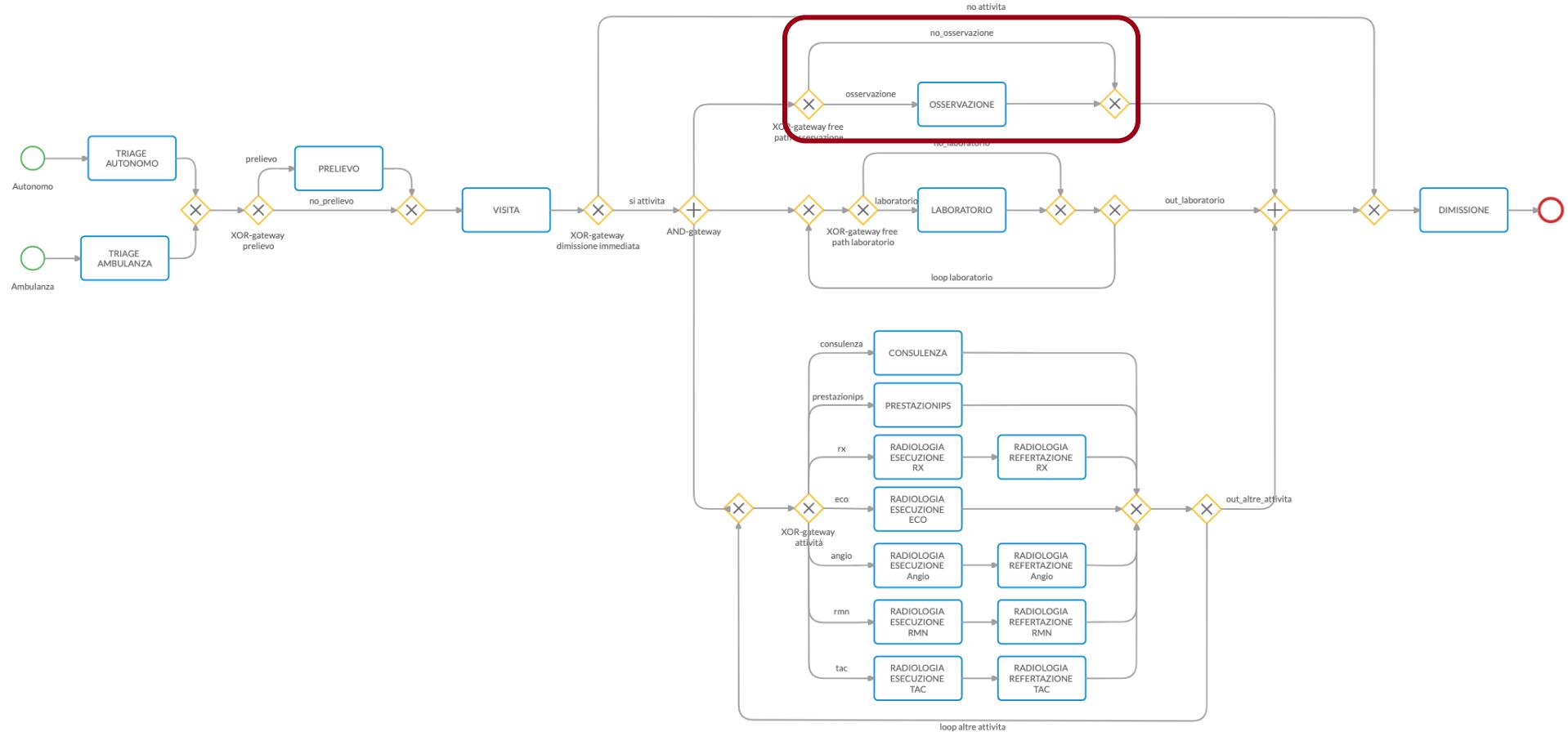
ED process model



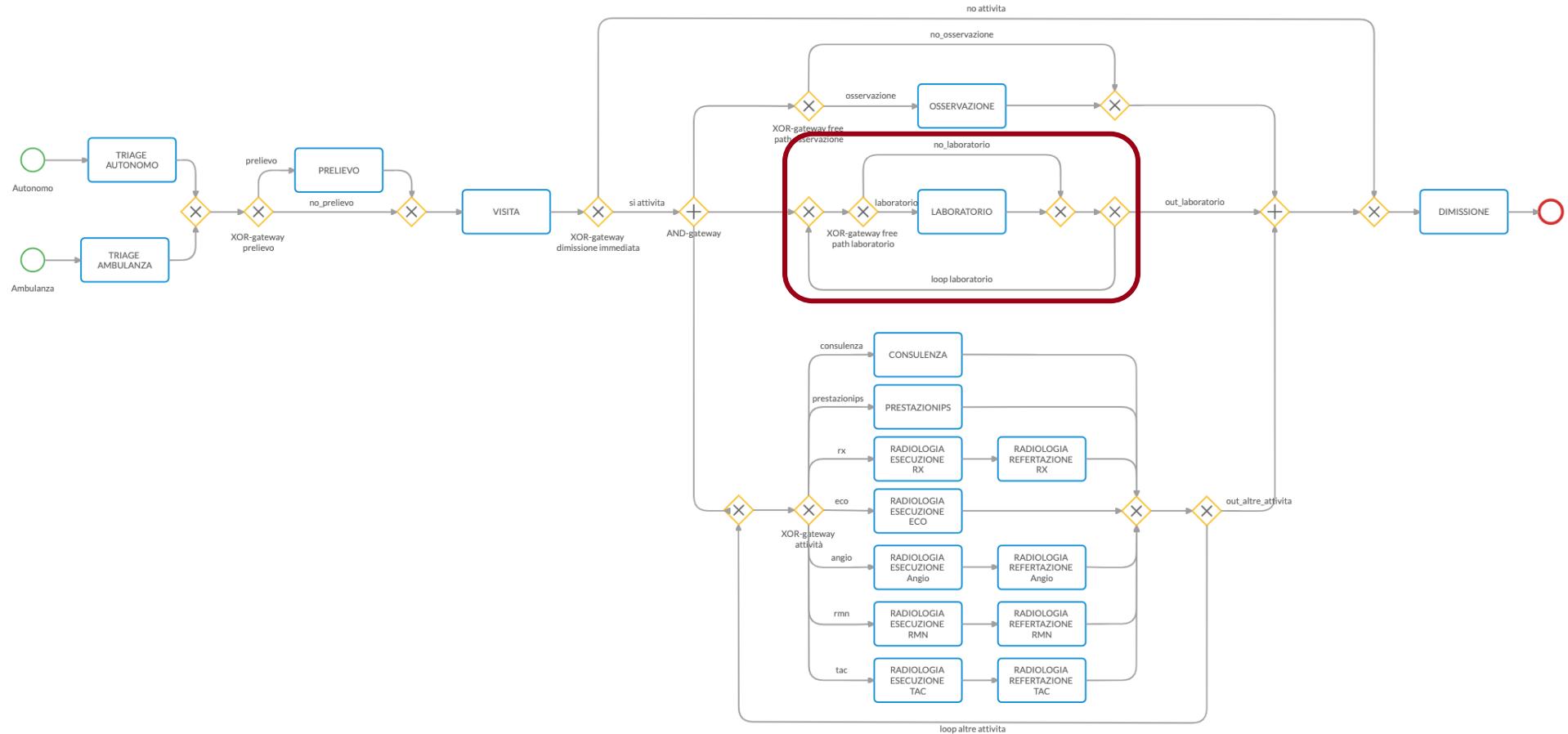
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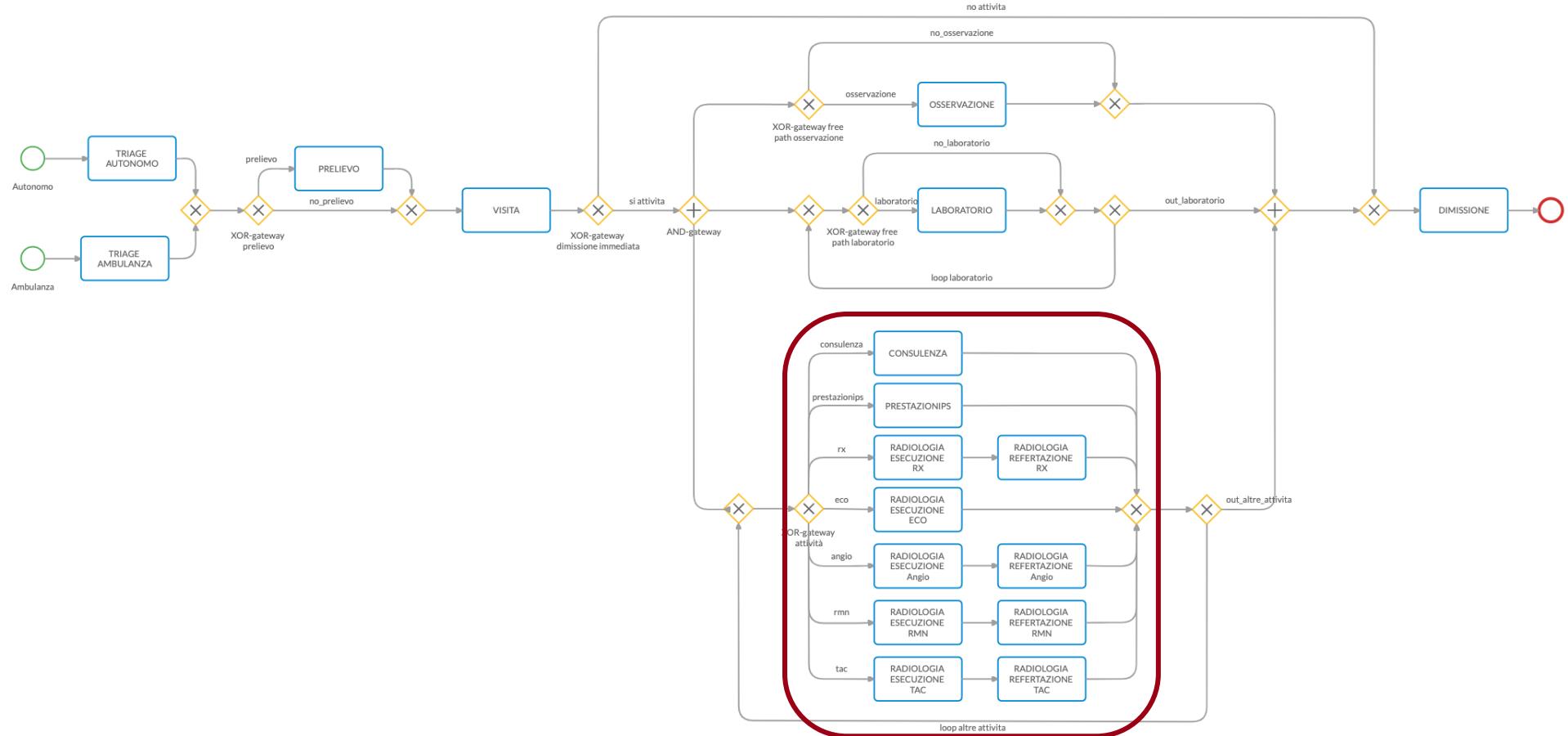
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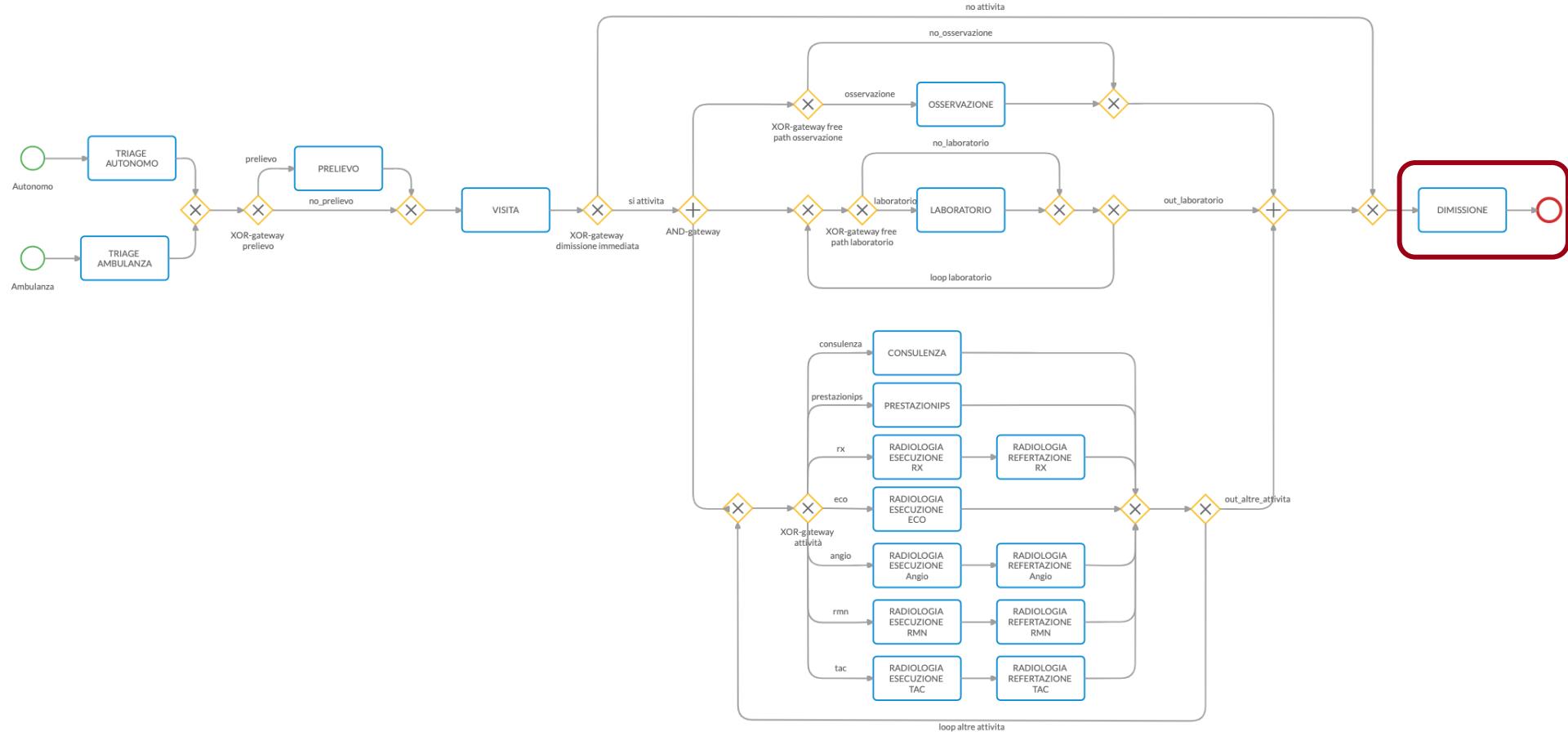
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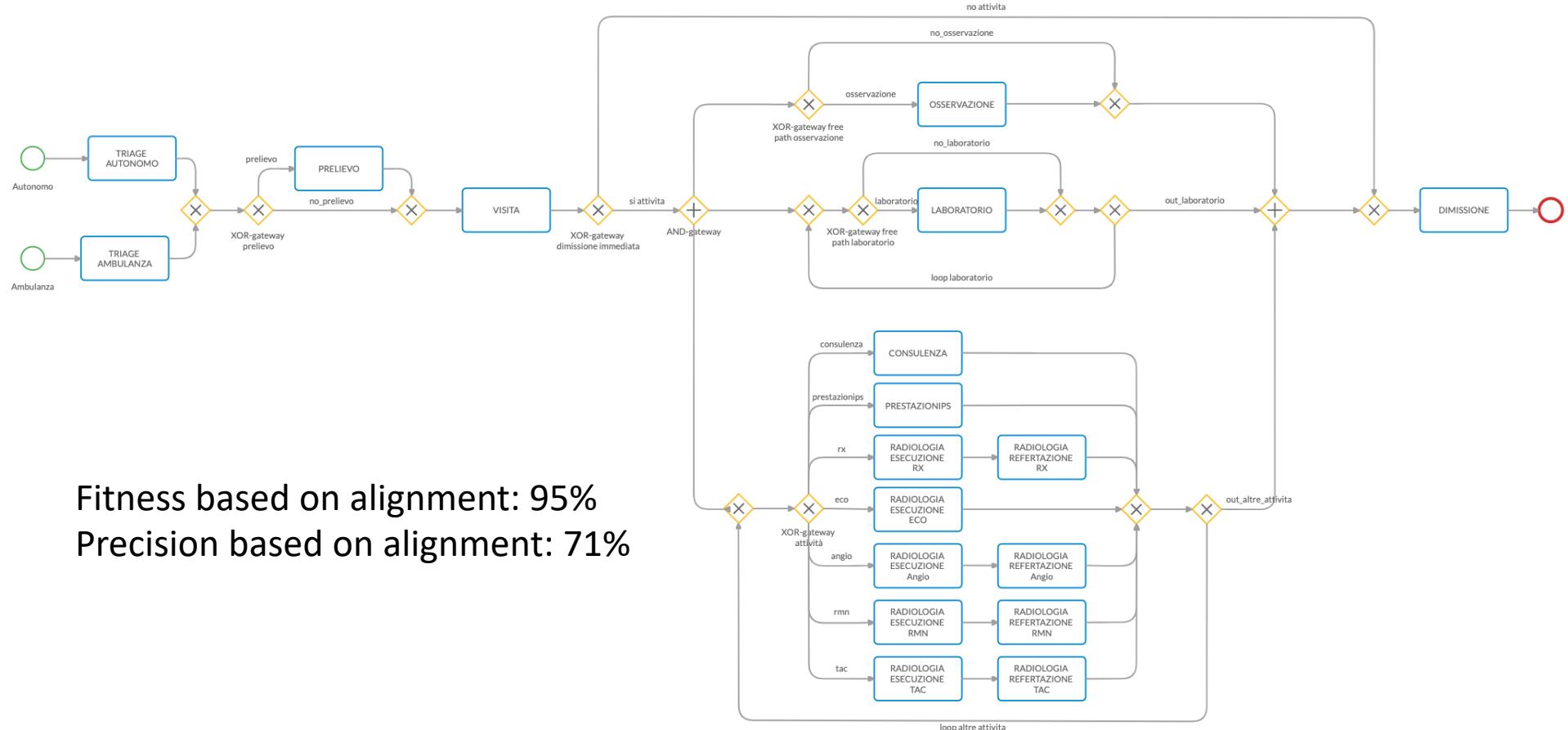
ED process model



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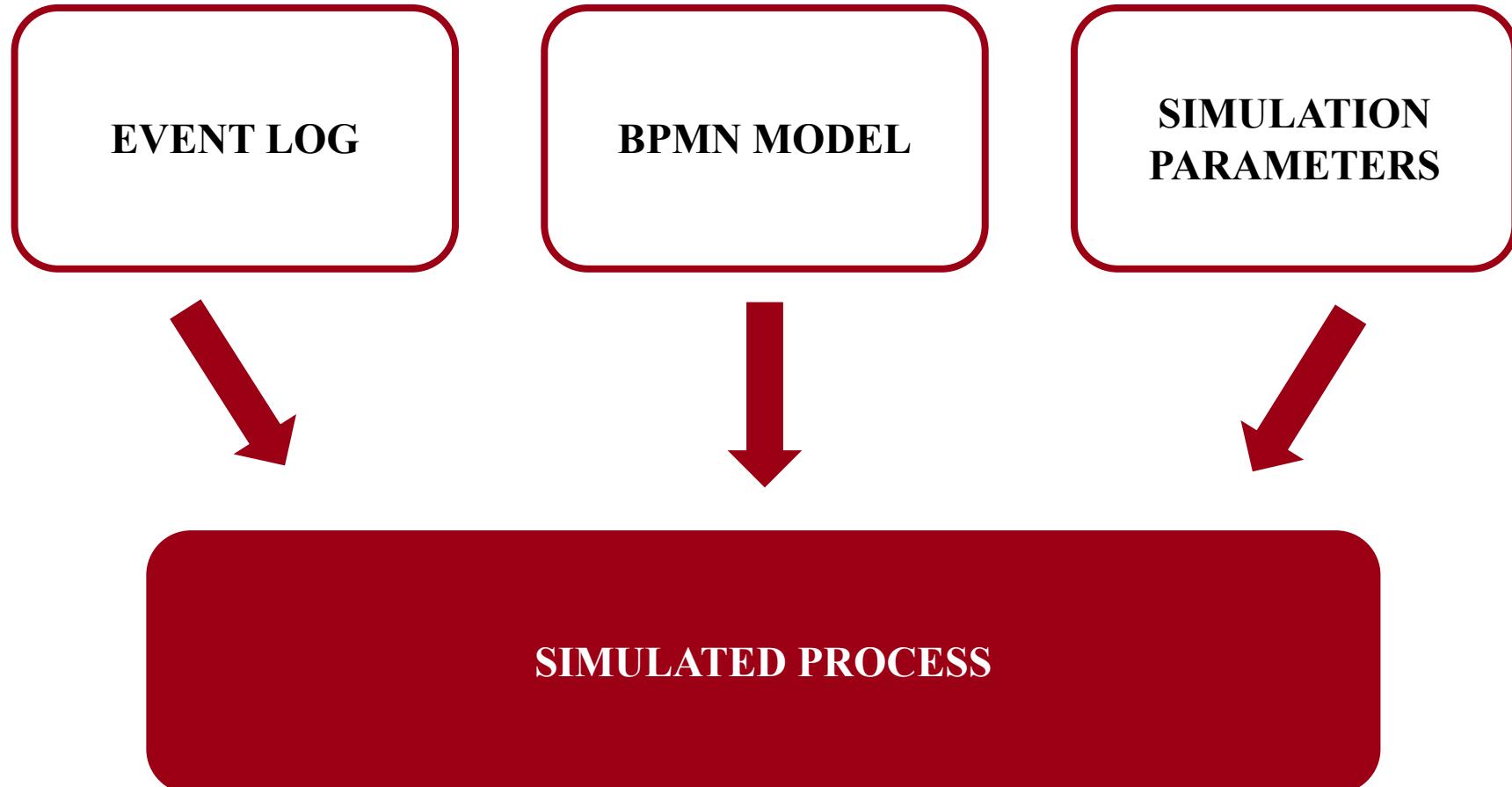
ED process model



Fitness based on alignment: 95%
Precision based on alignment: 71%



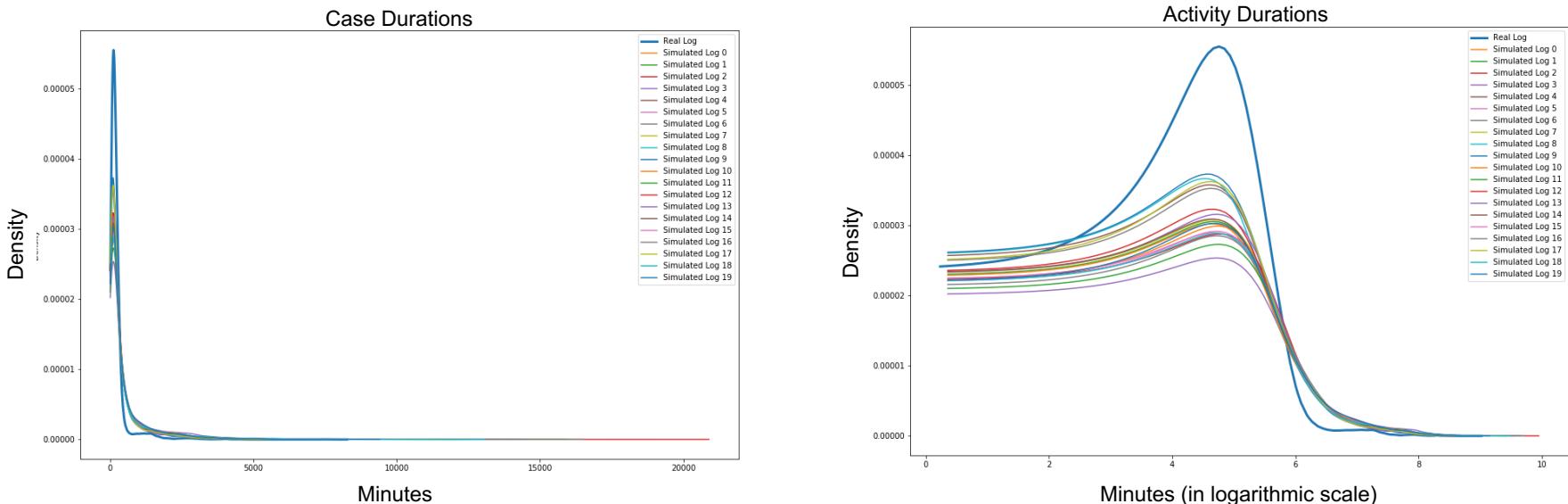
ED simulated process



ED simulated process: case durations



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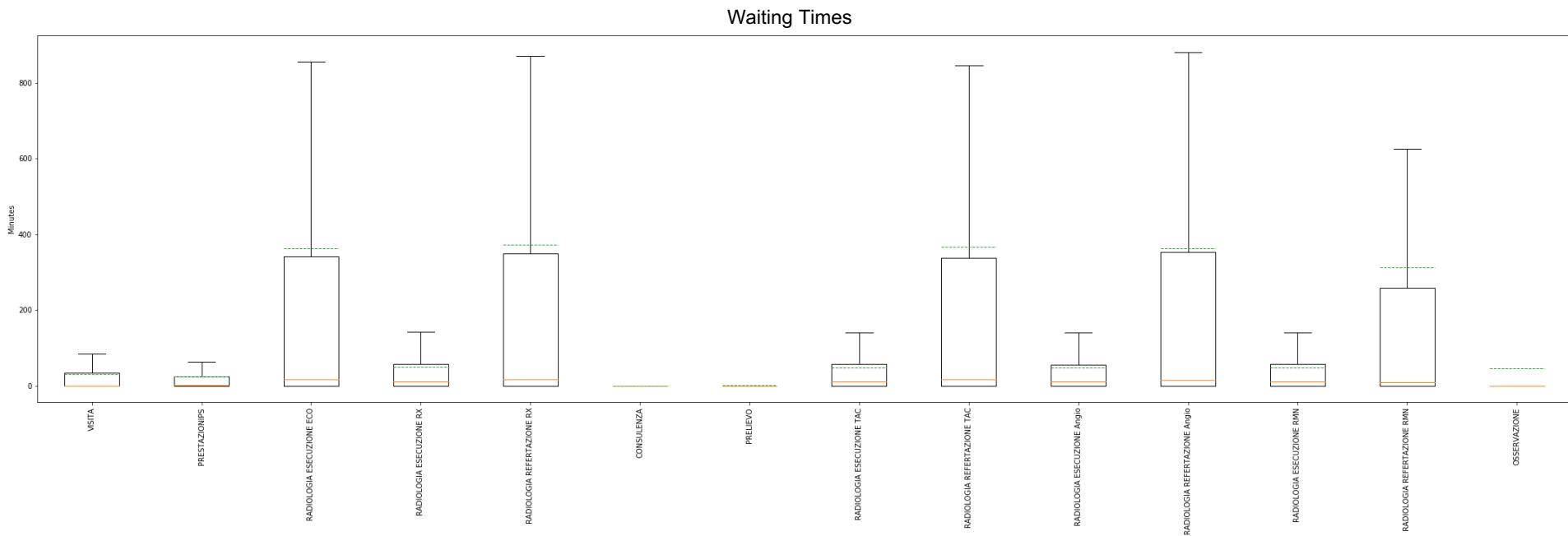
Median case durations:

- Real event log: 149 minutes
- Simulated event log: 186 minutes

ED simulated process: activities waiting times



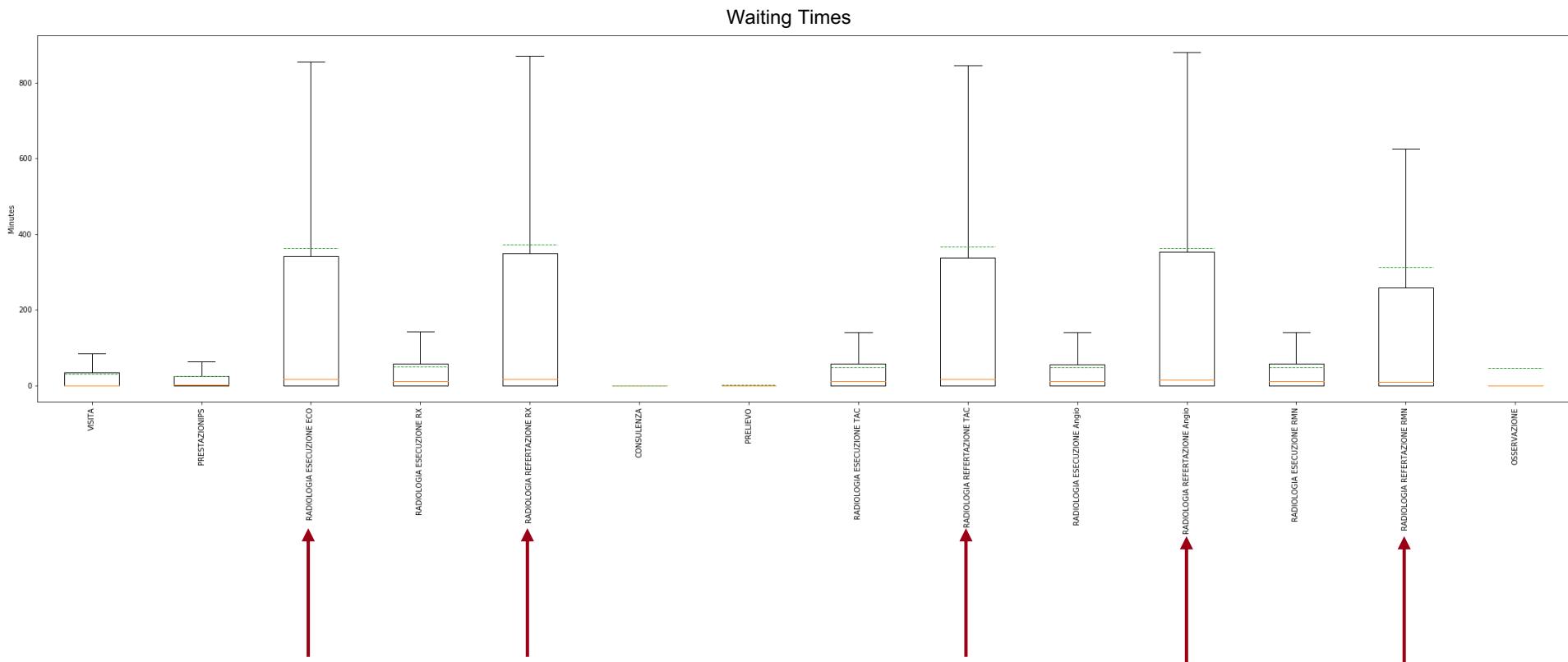
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ED simulated process: activities waiting times



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What-if scenarios

Two what-if scenarios:



Pediatric fast track



Optimization of costs and total waiting time as functions of resources

OBJECTIVE: propose approaches to counteract the main problems of healthcare

€ Tightening of government budgets

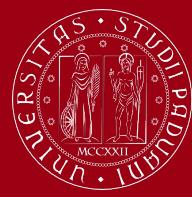


Scarce resource availability

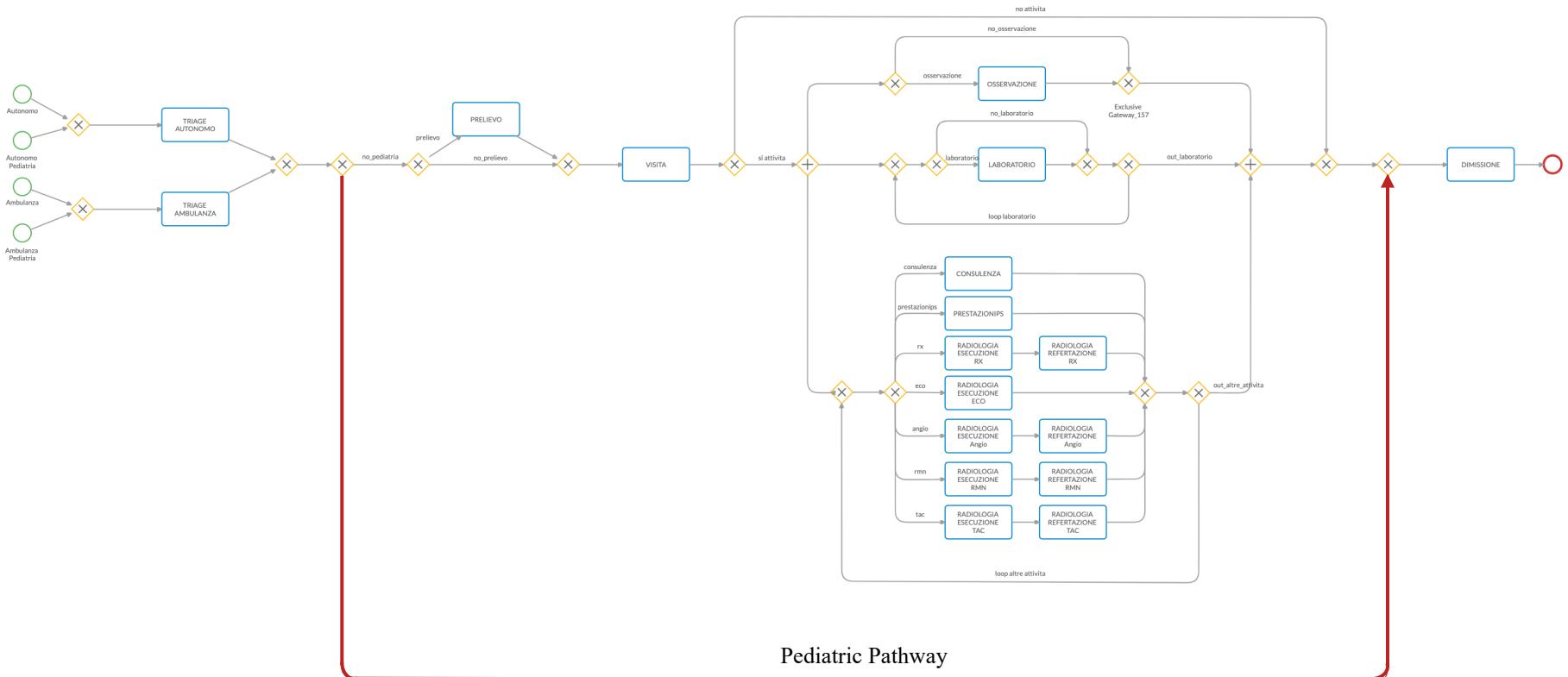


Offer efficient services to patients

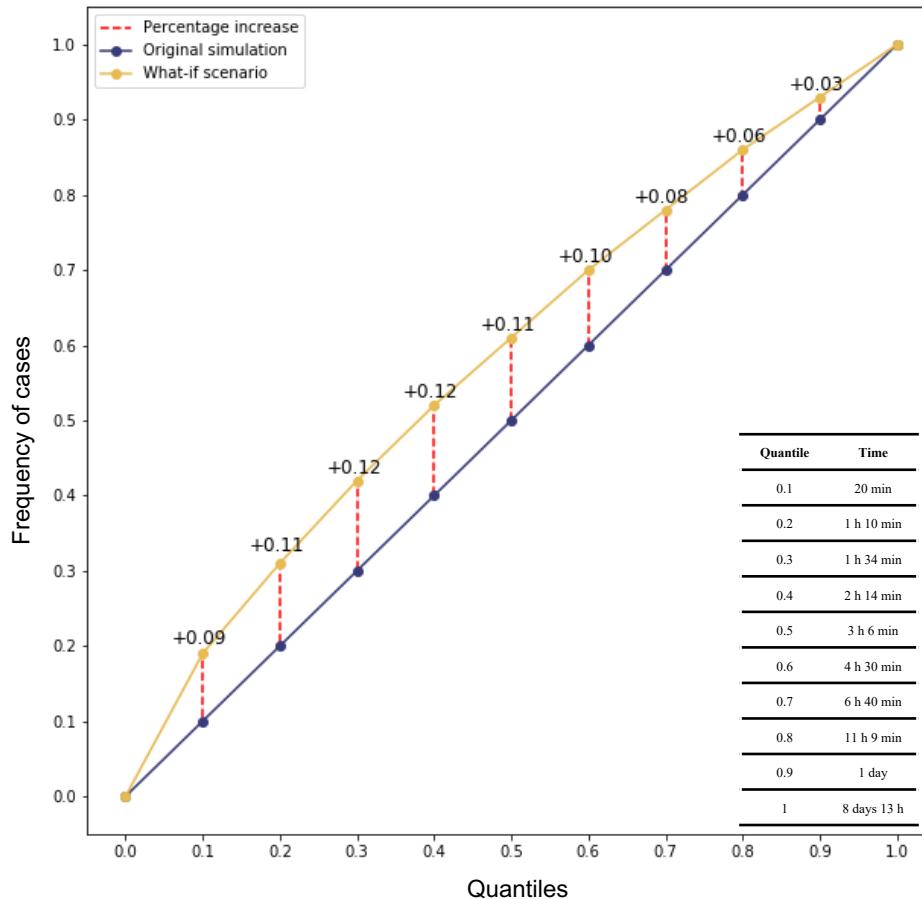
Pediatric fast track: process model



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Pediatric fast track: case duration quantiles comparison



Median case duration reduced by 35%.



Optimization Scenario

Multi-objective optimization problem:

$$\begin{cases} \varepsilon_1 = G \sum_{m=0}^n h(m) * c(m) \\ \varepsilon_2 = \sum_{k=0}^i w(i) \end{cases}$$

Objective

Find resource configurations
able to:

- Minimize total costs
- Minimize total waiting time

where:

- ε_1 : total costs
- ε_2 : total activities waiting times
- G : number of total days of the simulation
- $h(m)$: daily work-shift of resource m
- $c(m)$: hourly cost of resource m
- $w(i)$: total waiting time activity i



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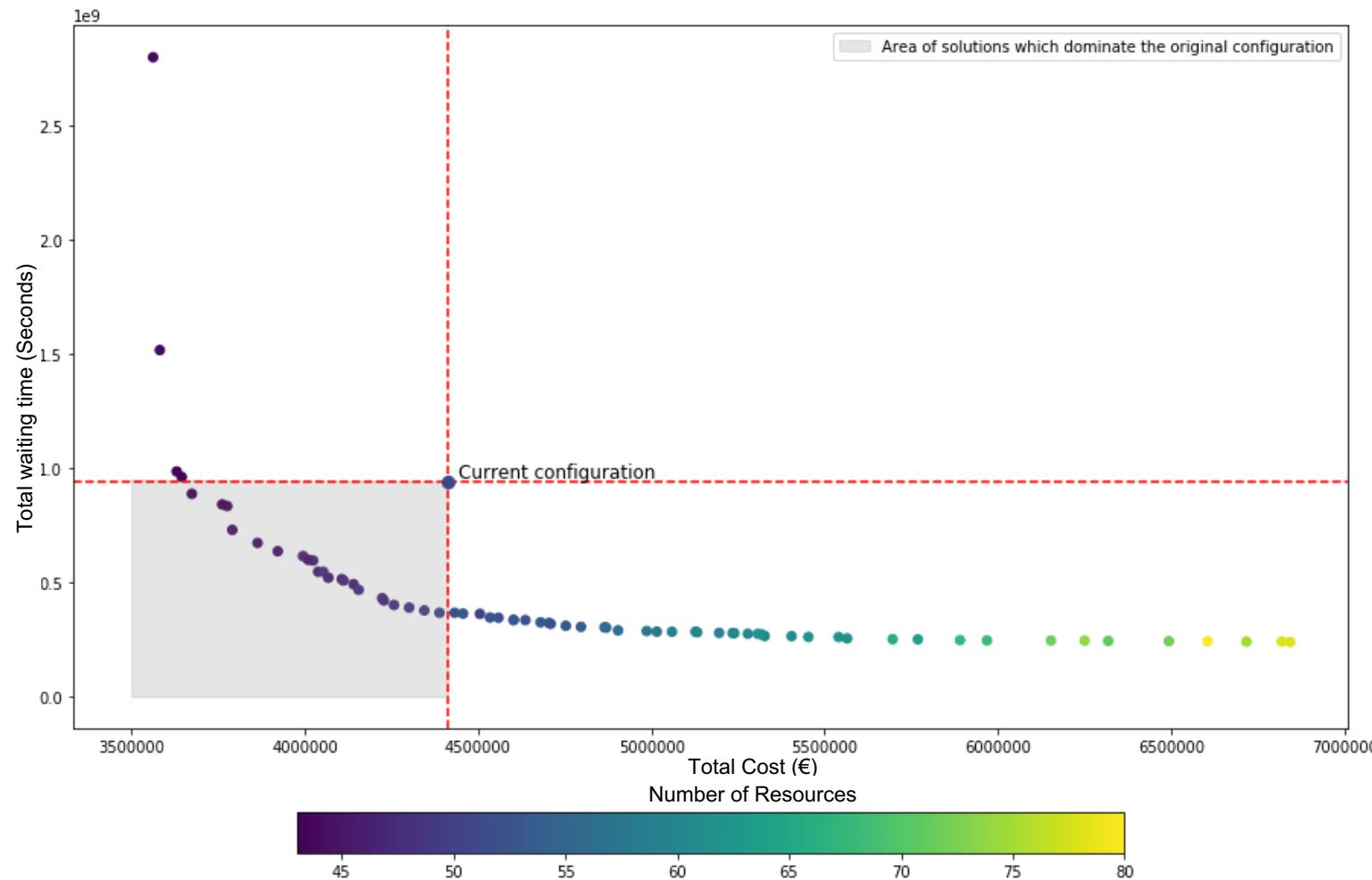
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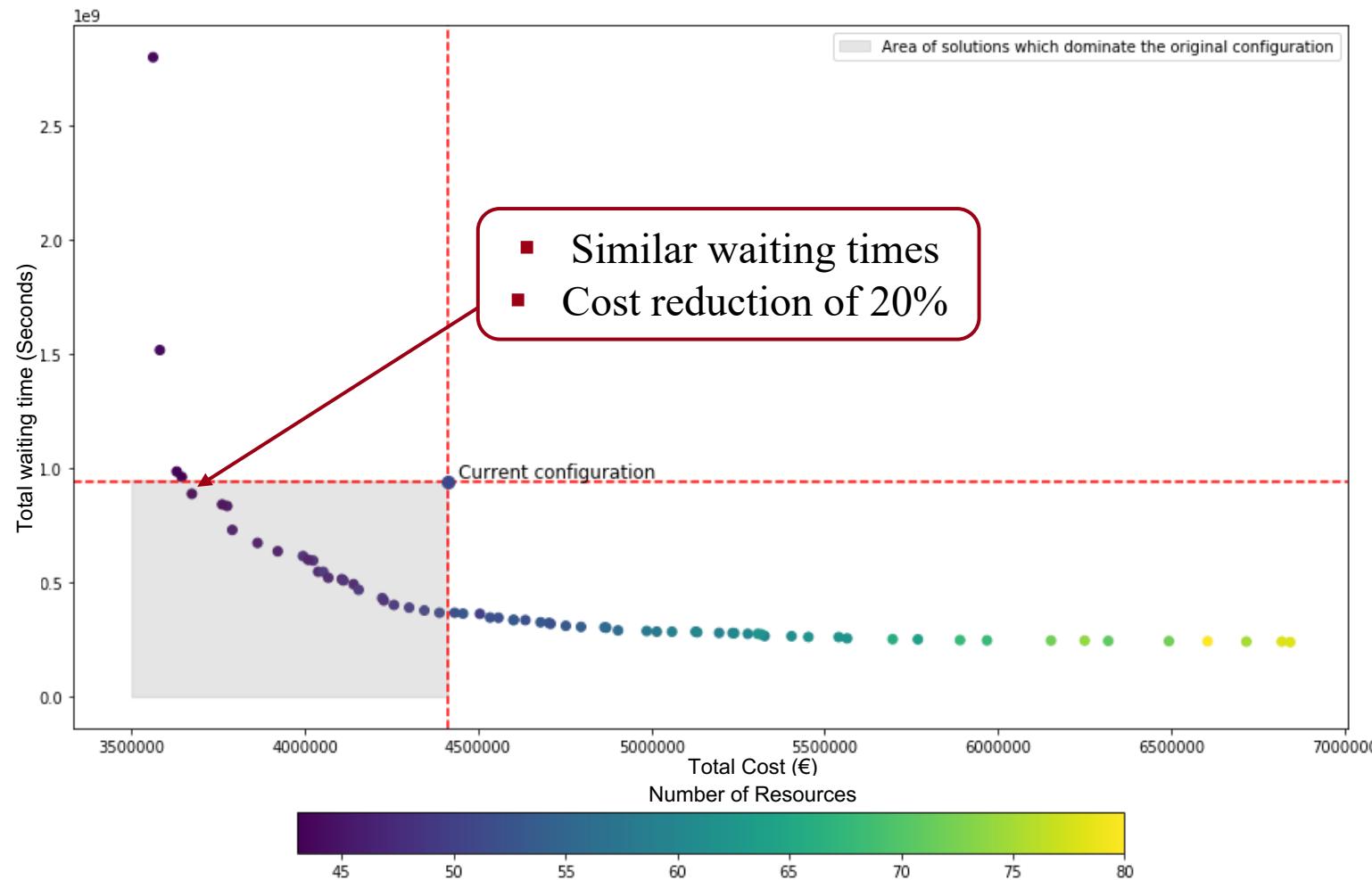
Optimization Scenario: non-dominated solutions



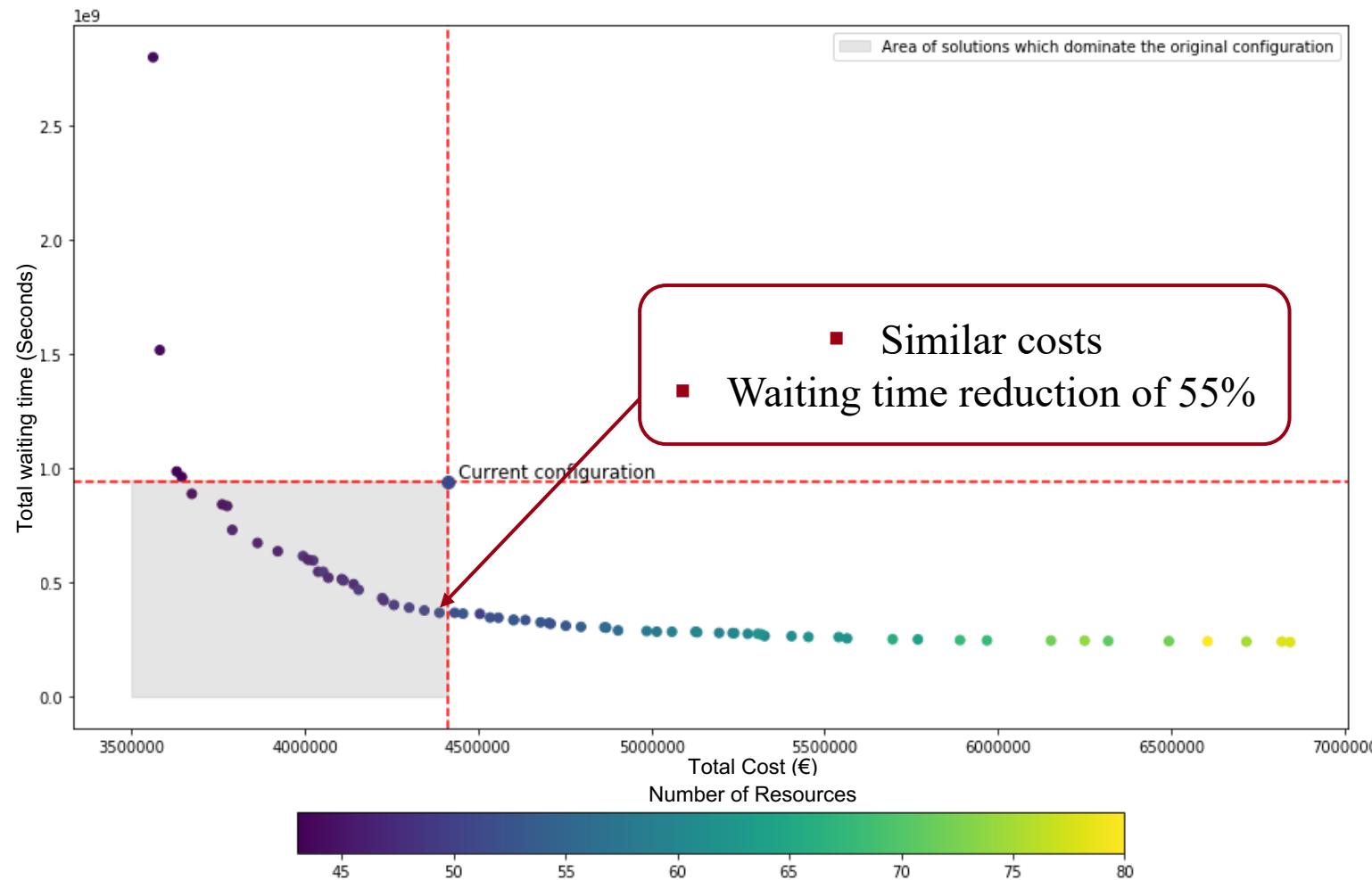
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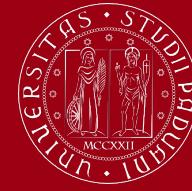


Optimization Scenario: non-dominated solutions



Optimization Scenario: non-dominated solutions





Optimization Scenario with boundary conditions

Multi-variable optimization problem with boundary conditions on the average waiting time of each activity:

$$\left\{ \begin{array}{l} \varepsilon_1 = G \sum_{m=0}^n h(m) * c(m) \\ \varepsilon_2 = \sum_{k=0}^i w(i) \\ \bar{w}(i) \leq 10800 \quad \forall i \end{array} \right.$$

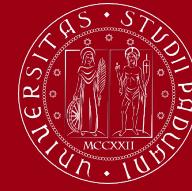
where:

- ε_1 : total costs
 - ε_2 : total activities waiting times
 - $\bar{w}(i)$: average waiting time activity i
 - G : number of total days of the simulation
 - $h(m)$: daily work-shift of resource m
 - $c(m)$: hourly cost of resource m
 - $w(i)$: total waiting time activity i
- 10800 seconds is the boundary condition

Objective

Find resource configurations able to:

- Minimize total costs
- Minimize total waiting time



Optimization Scenario with boundary conditions

Multi-variable optimization problem with boundary conditions on the average waiting time of each activity:

$$\begin{cases} \varepsilon_1 = G \sum_{m=0}^n h(m) * c(m) \\ \varepsilon_2 = \sum_{k=0}^i w(i) \\ \bar{w}(i) \leq 10800 \quad \forall i \end{cases}$$

where:

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Objective

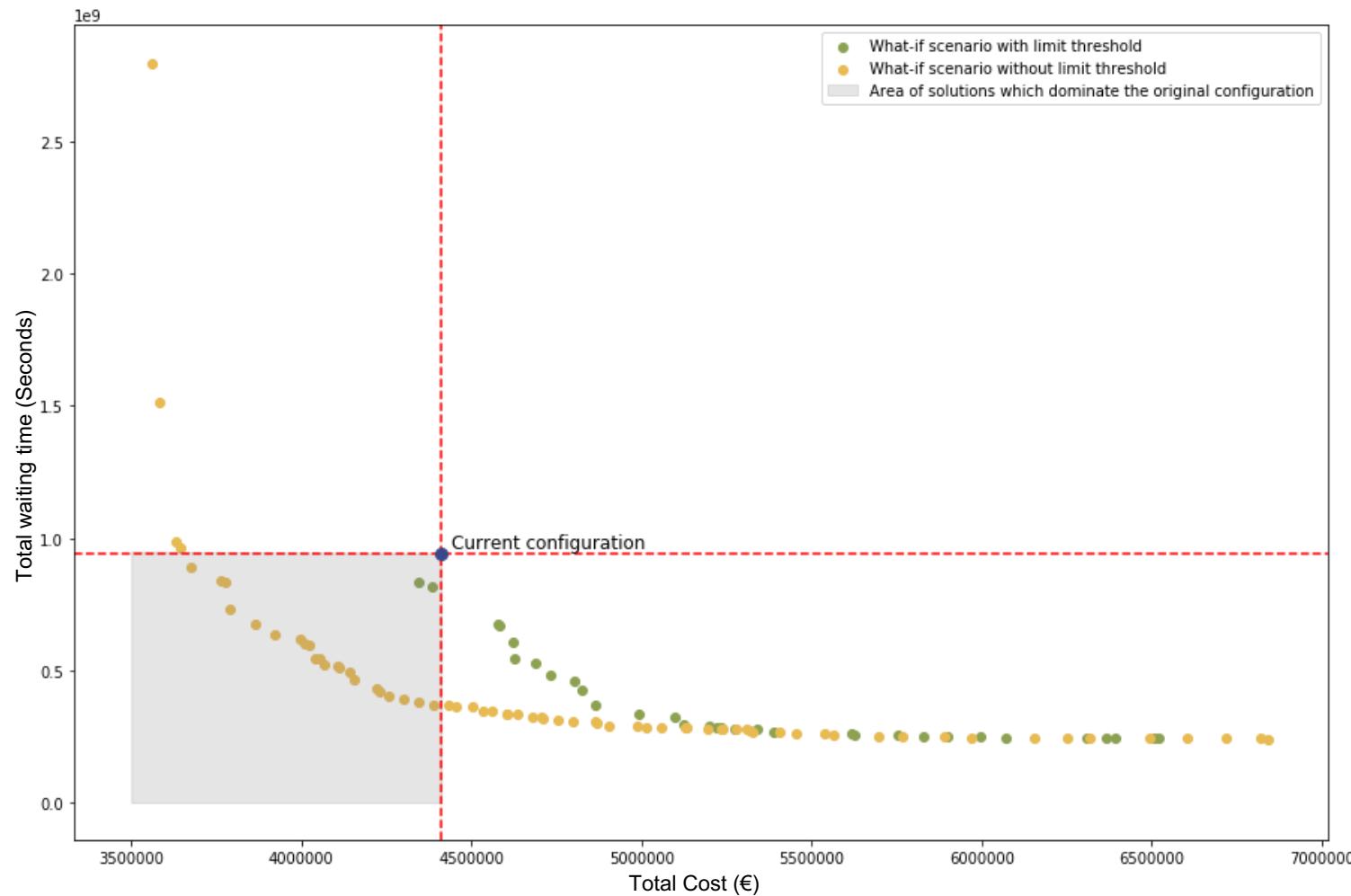
Find resource configurations able to:

- Minimize total costs
- Minimize total waiting time

Optimization Scenario with boundary conditions non-dominated solutions



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Conclusion



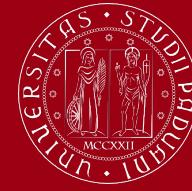
Conclusion

- ✓ Enhanced the activity missing start timestamps technique



Conclusion

- ✓ Enhanced the activity missing start timestamps technique
- ✓ Shown the effectiveness of process simulation to deal with healthcare problems



Conclusion

- ✓ Enhanced the activity missing start timestamps technique
- ✓ Shown the effectiveness of process simulation to deal with healthcare problems
- ✓ Proposed plausible what-if scenario able to:
 - ✓ Pediatric fast track
 - ✓ Reduce case durations by 35%
 - ✓ Multi-objective optimization
 - ✓ Reduce costs by 16% maintaining similar case durations
 - ✓ Reduce case durations by 55% maintaining similar costs

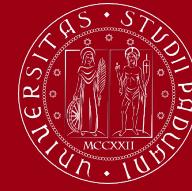


Conclusion

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Next steps

- 💡 Multi-objective optimization for start timestamp estimation



Conclusion

- ✓ Enhanced the activity missing start timestamps technique
- ✓ Shown the effectiveness of process simulation to deal with healthcare problems
- ✓ Proposed plausible what-if scenario able to:
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Next steps

- ⌚ Multi-objective optimization for start timestamp estimation
- ⌚ Introduce patients' priority information



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Thanks for your
kind attention!





Insights on alpha parameters computation

Students' credential recognition process

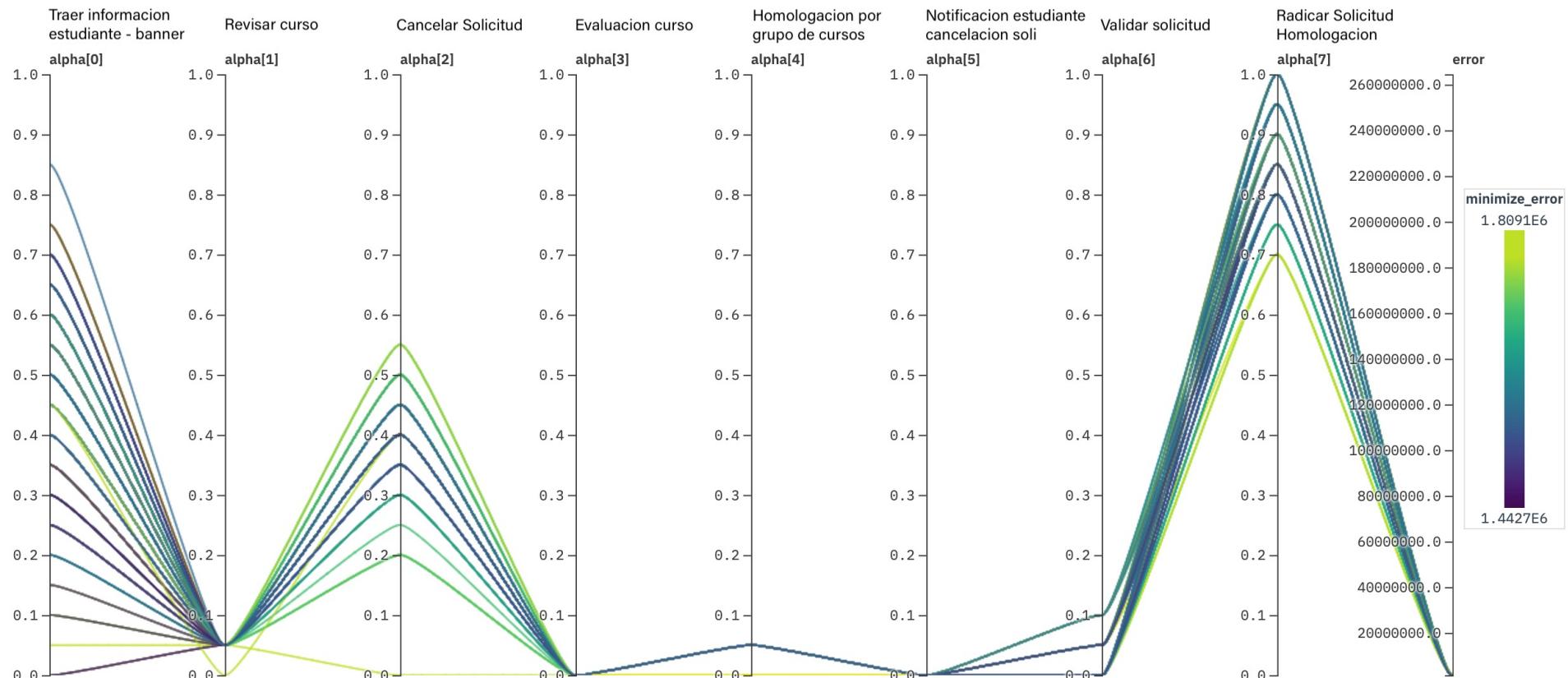


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Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

MOGAI^I



Students' credential recognition process



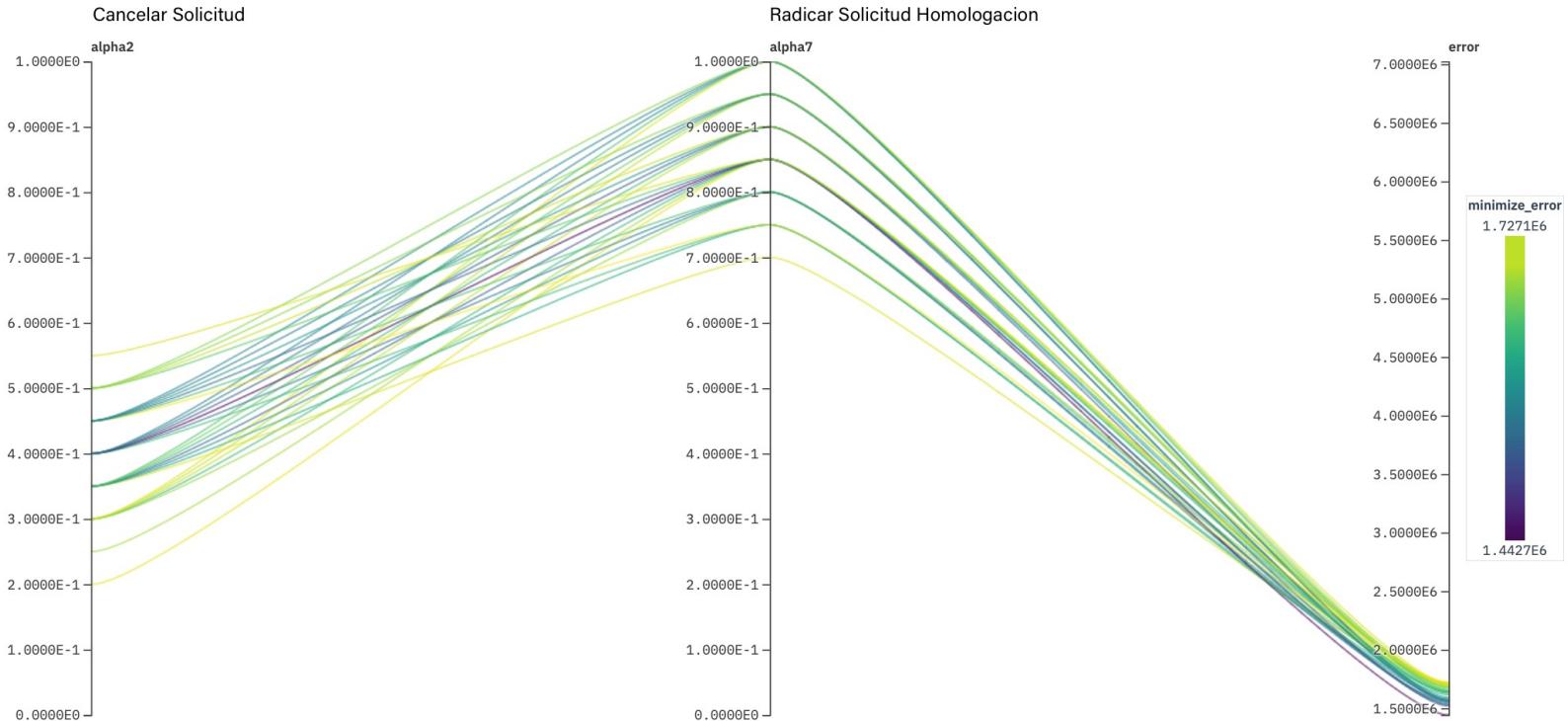
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Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

MOGAI

Second optimization on α_2, α_7
keeping fixed all the other
parameters to their best value.



Students' credential recognition process

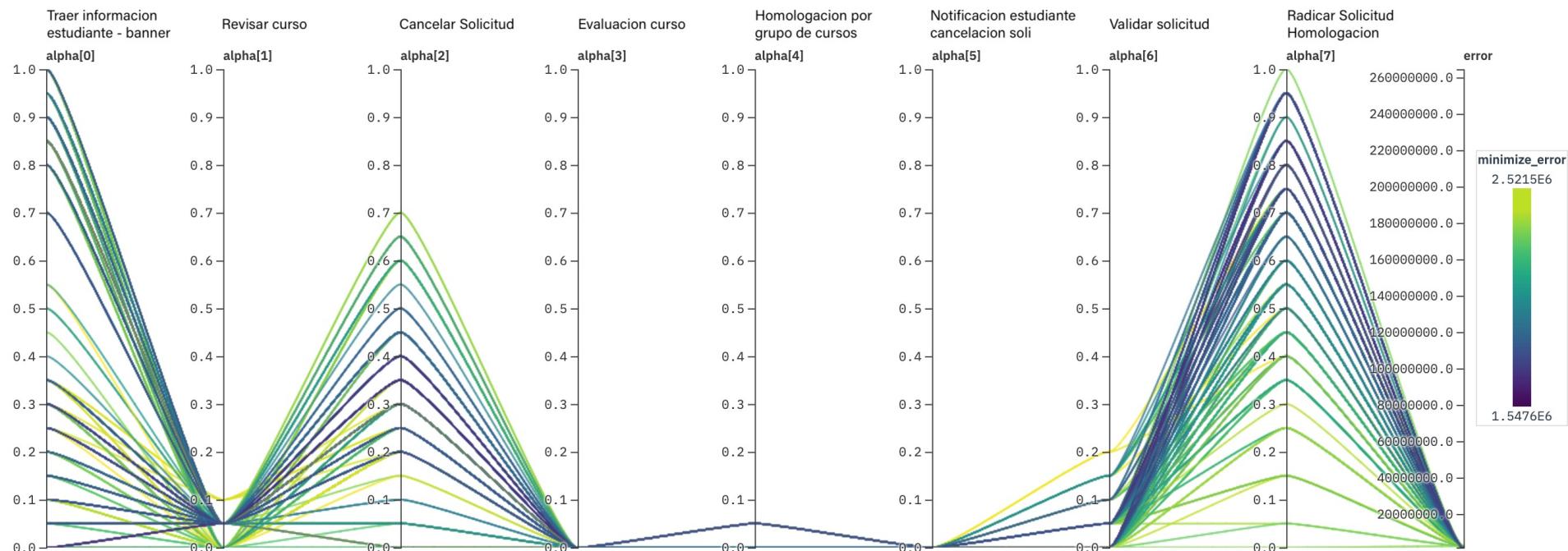


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Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

NSGAII

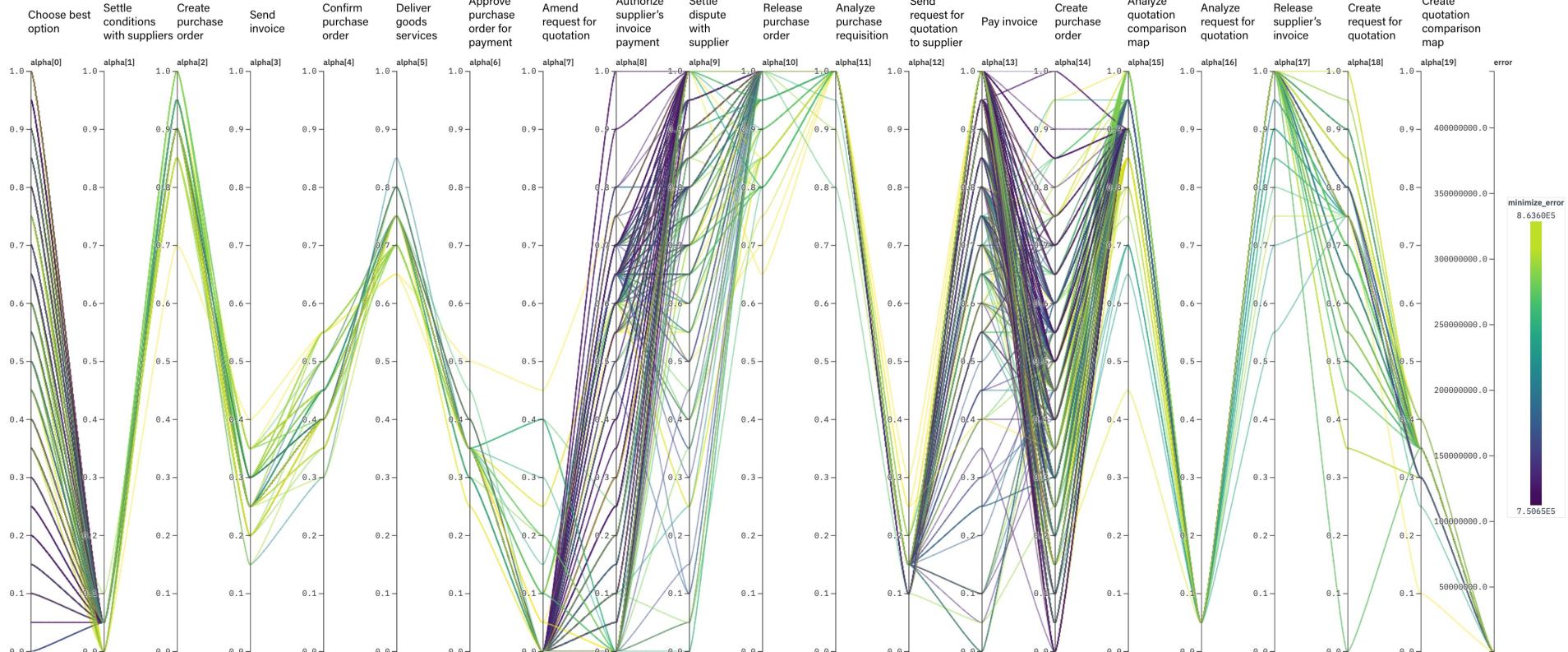


Purchase process

Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

MOGAI

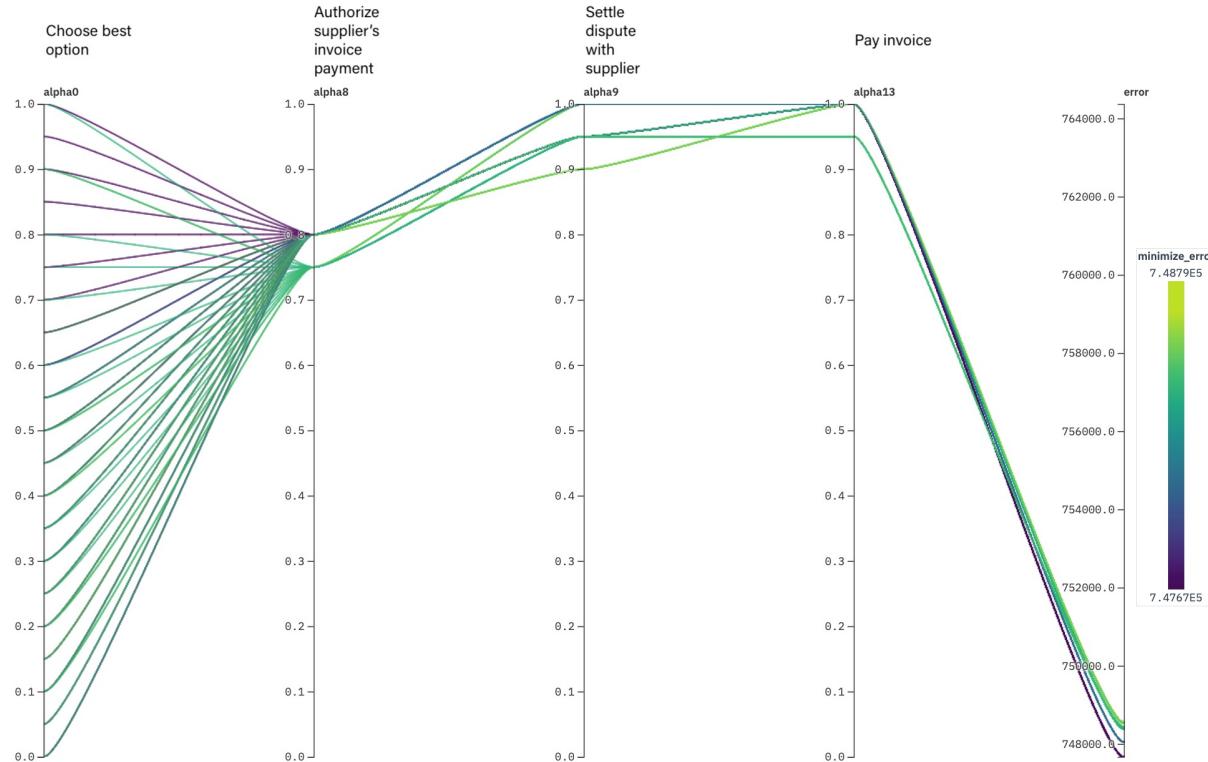


Purchase process

Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

MOGAI
Second optimization on
 $\alpha_0, \alpha_8, \alpha_9, \alpha_{13}$ keeping fixed all the
other parameters to their best
value.

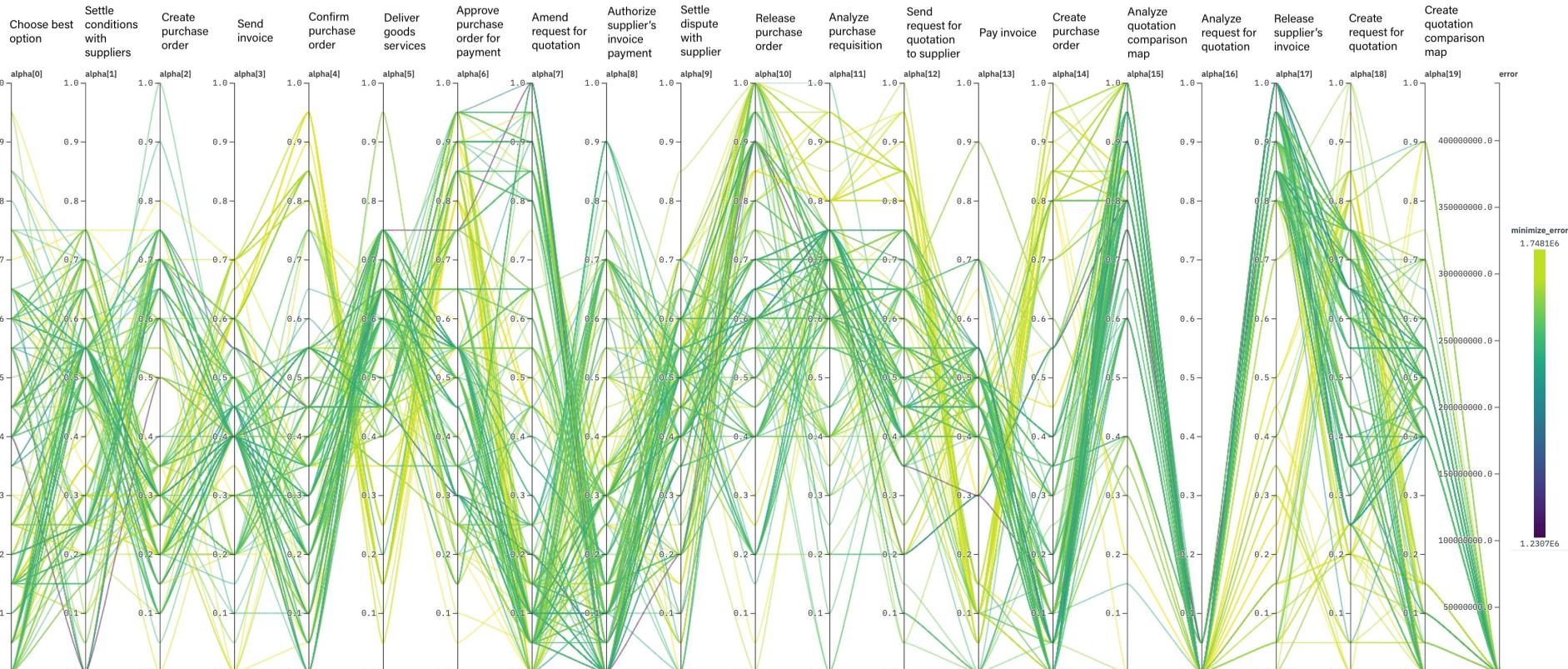


Purchase process

Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

NSGAII



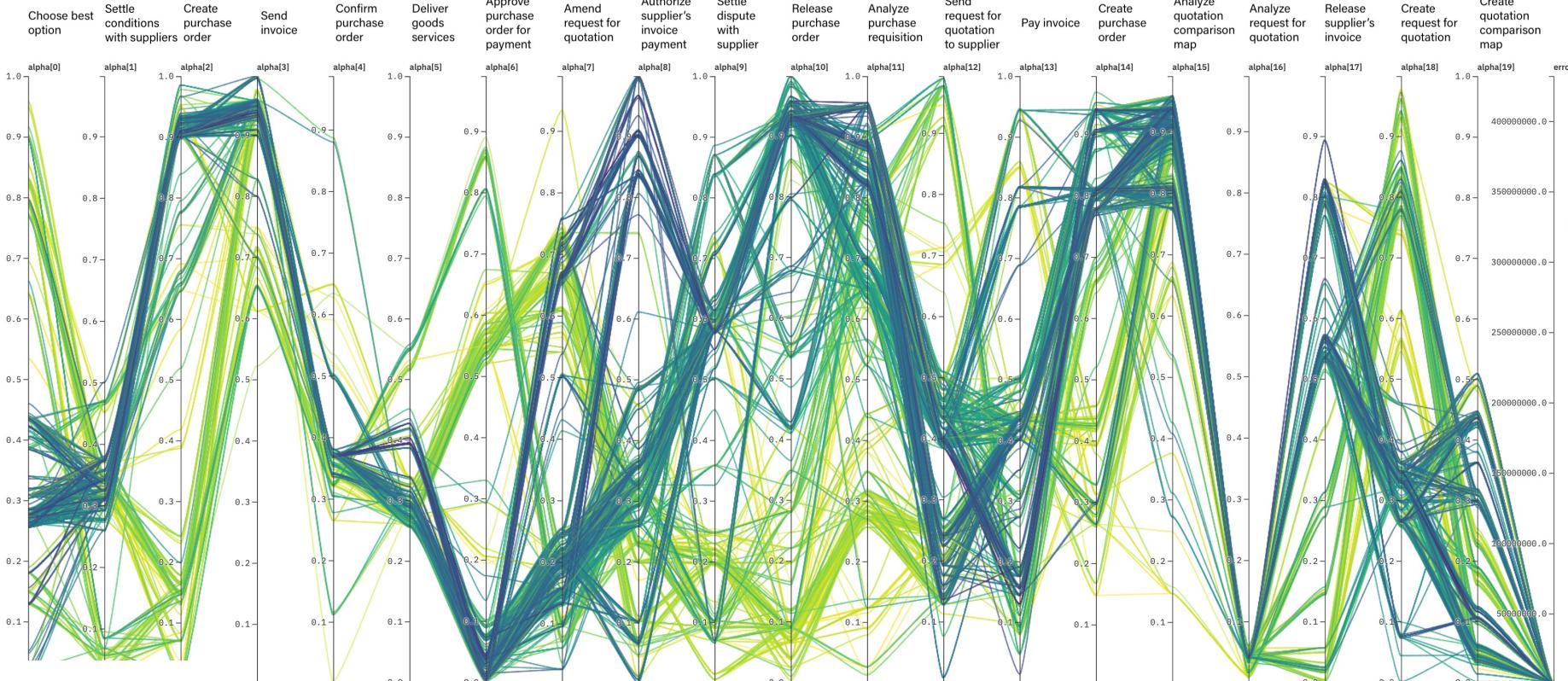
Purchase process

Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

NSGAI

$\delta = 0.001$



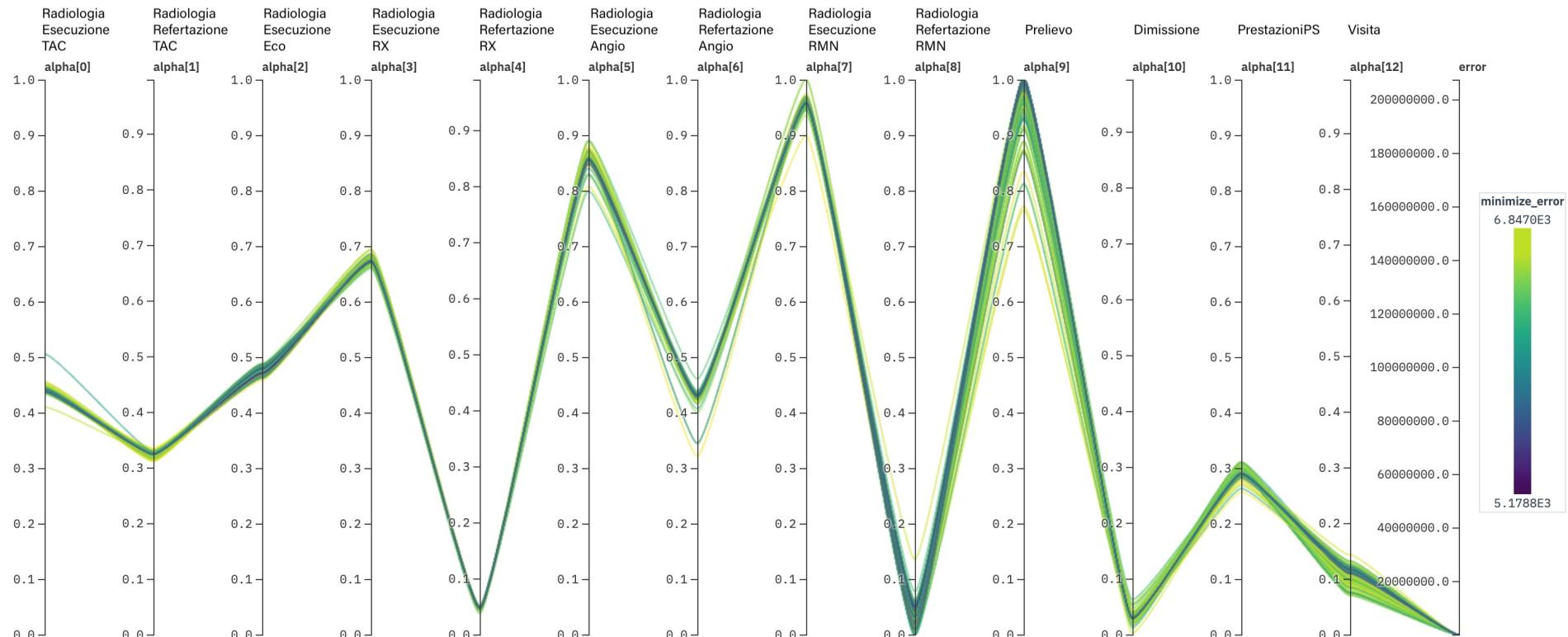
ED process

Parallel coordinate graph:

- Each line corresponds to a specific configuration of the alpha vector
- Color of the line indicates the resulting error

MOGAI

$\delta = 0.001$



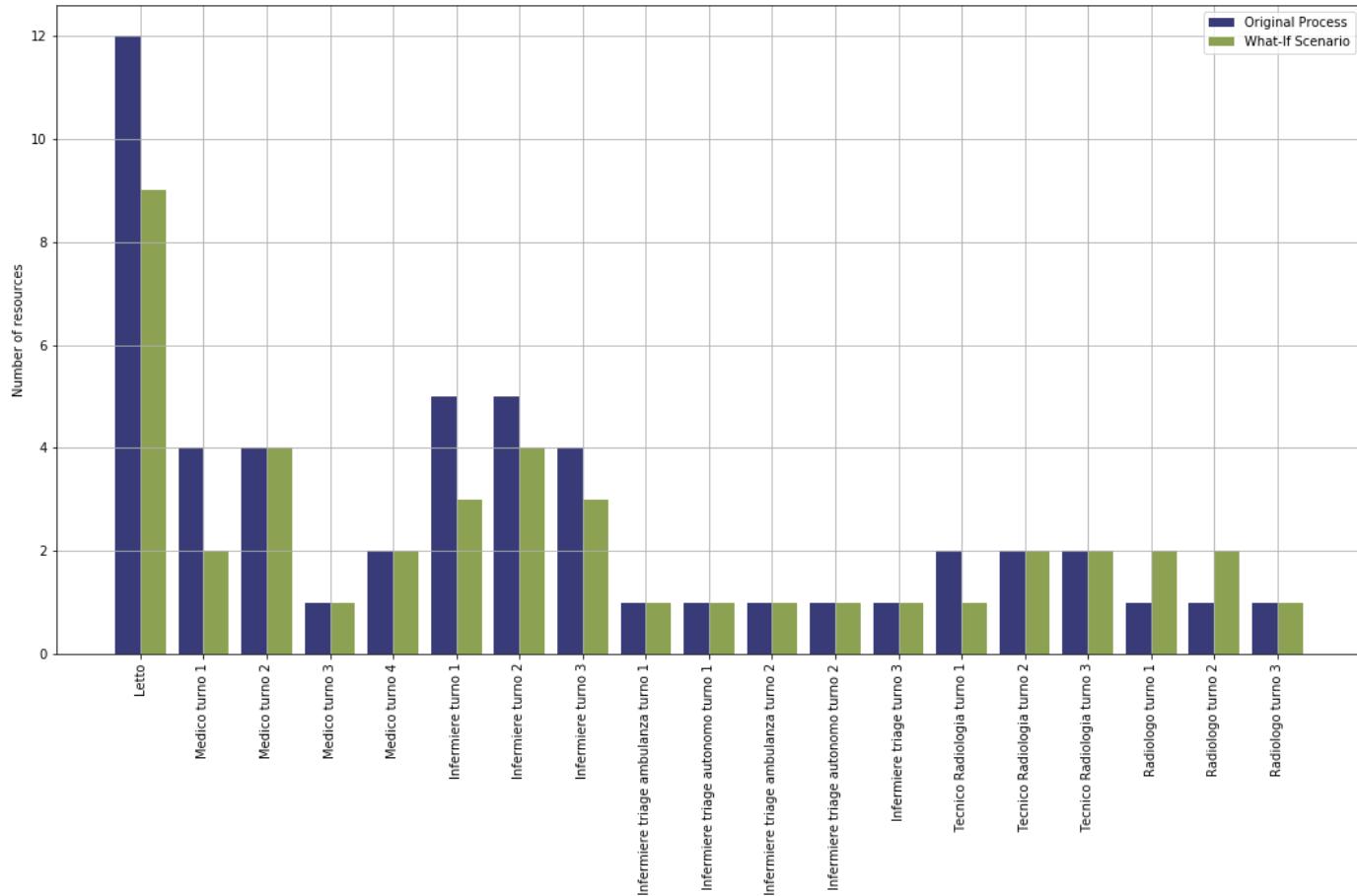


Insights on similar total waiting times solution

Similar total waiting times solution



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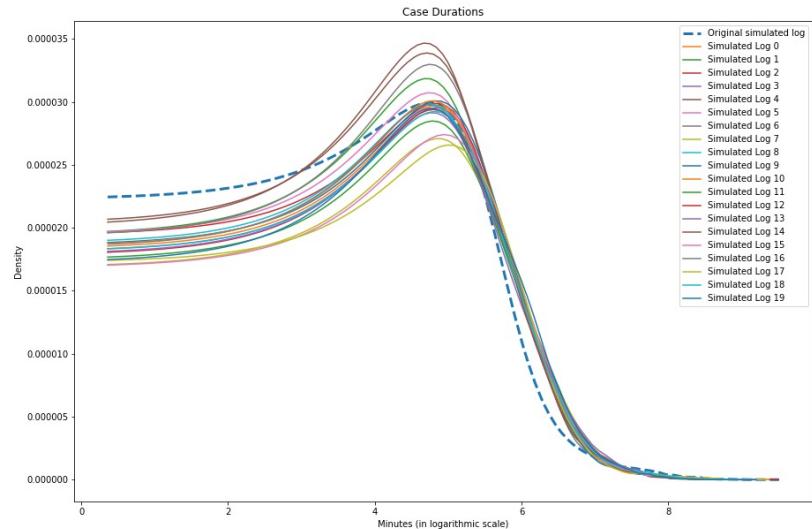
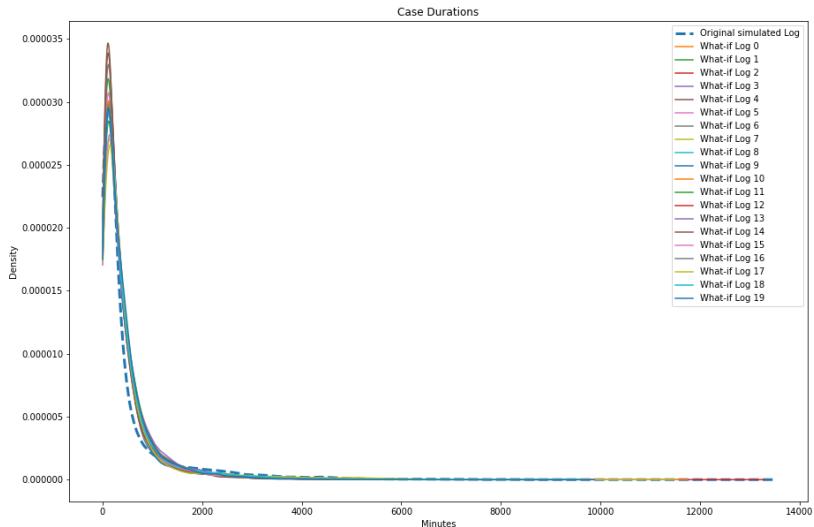


Similar total waiting times solution

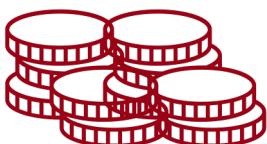


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Similar waiting time reflected also in similar case duration.



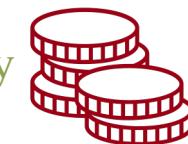
Current resource configuration



18080 €/day

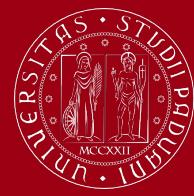


15120 €/day



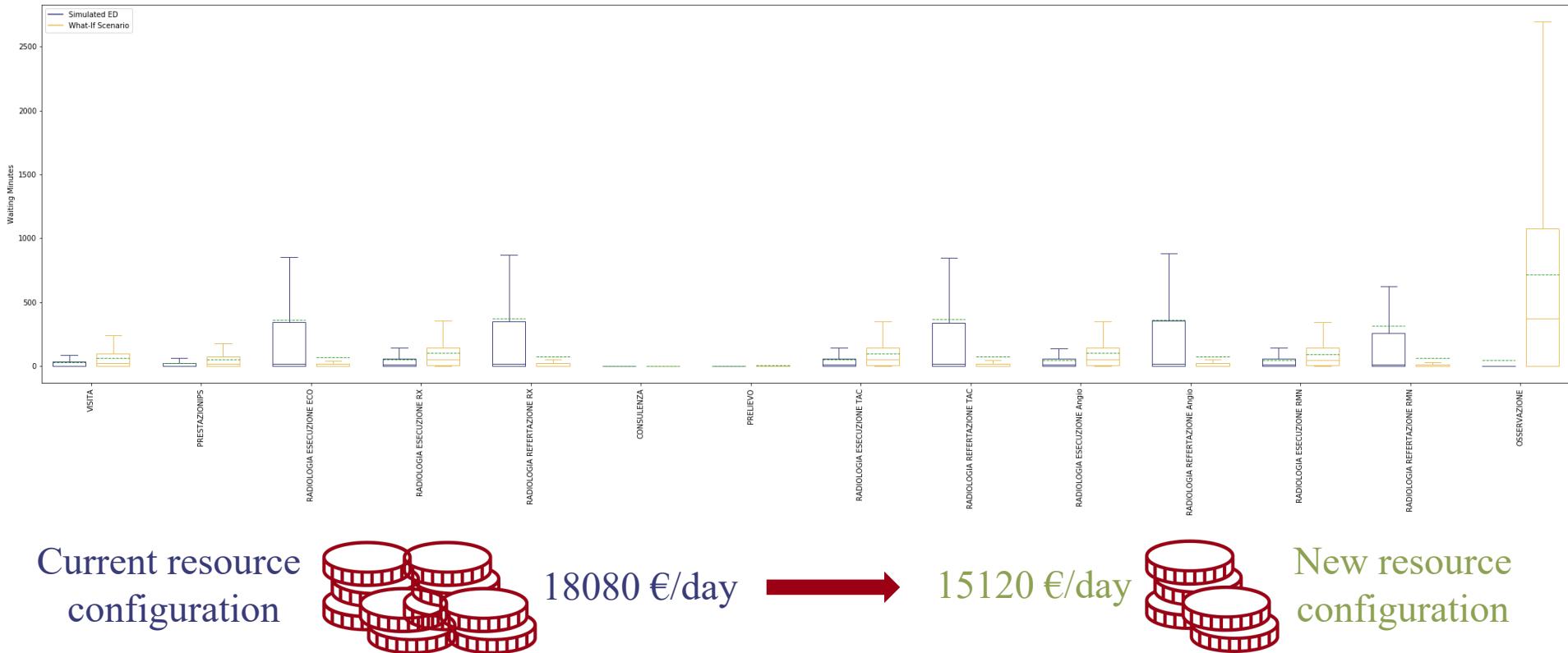
New resource configuration

Similar total waiting times solution

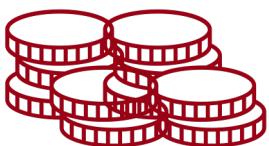


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Problem: waiting time *osservazione*



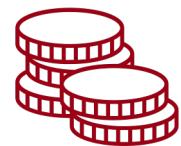
Current resource
configuration



18080 €/day

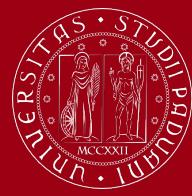


15120 €/day



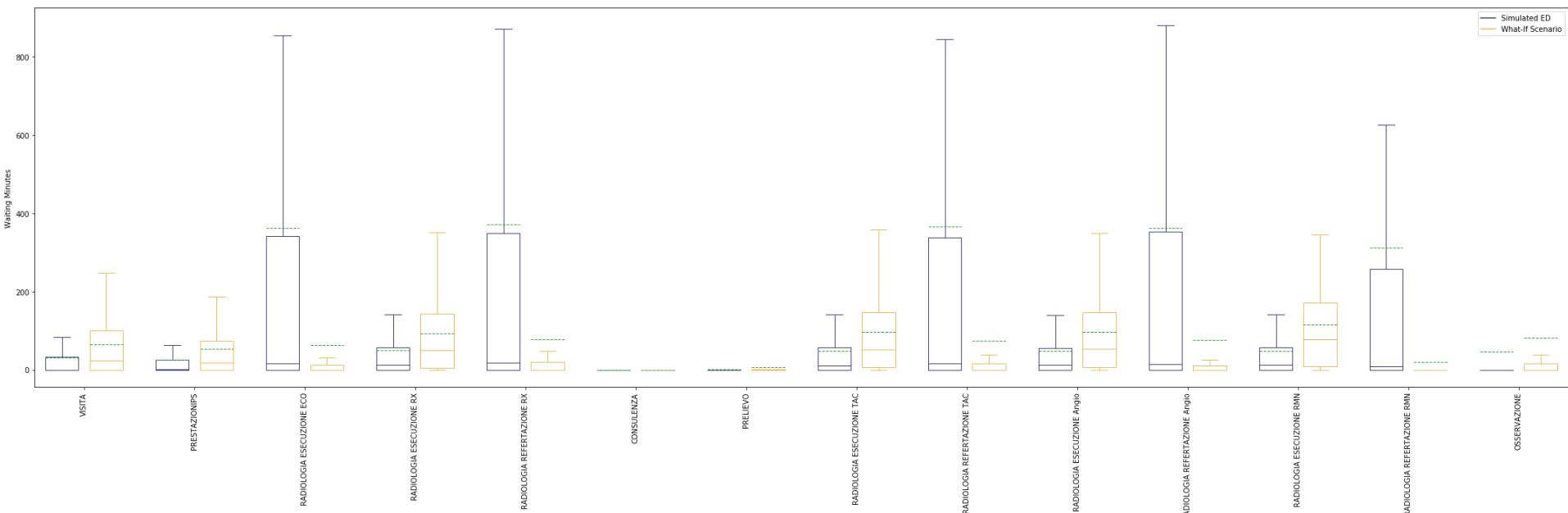
New resource
configuration

Similar total waiting times solution



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Solution: increase number of beds from 9 to 11



Current resource
configuration



18080 €/day



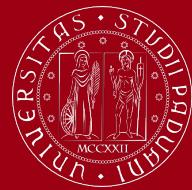
16560 €/day



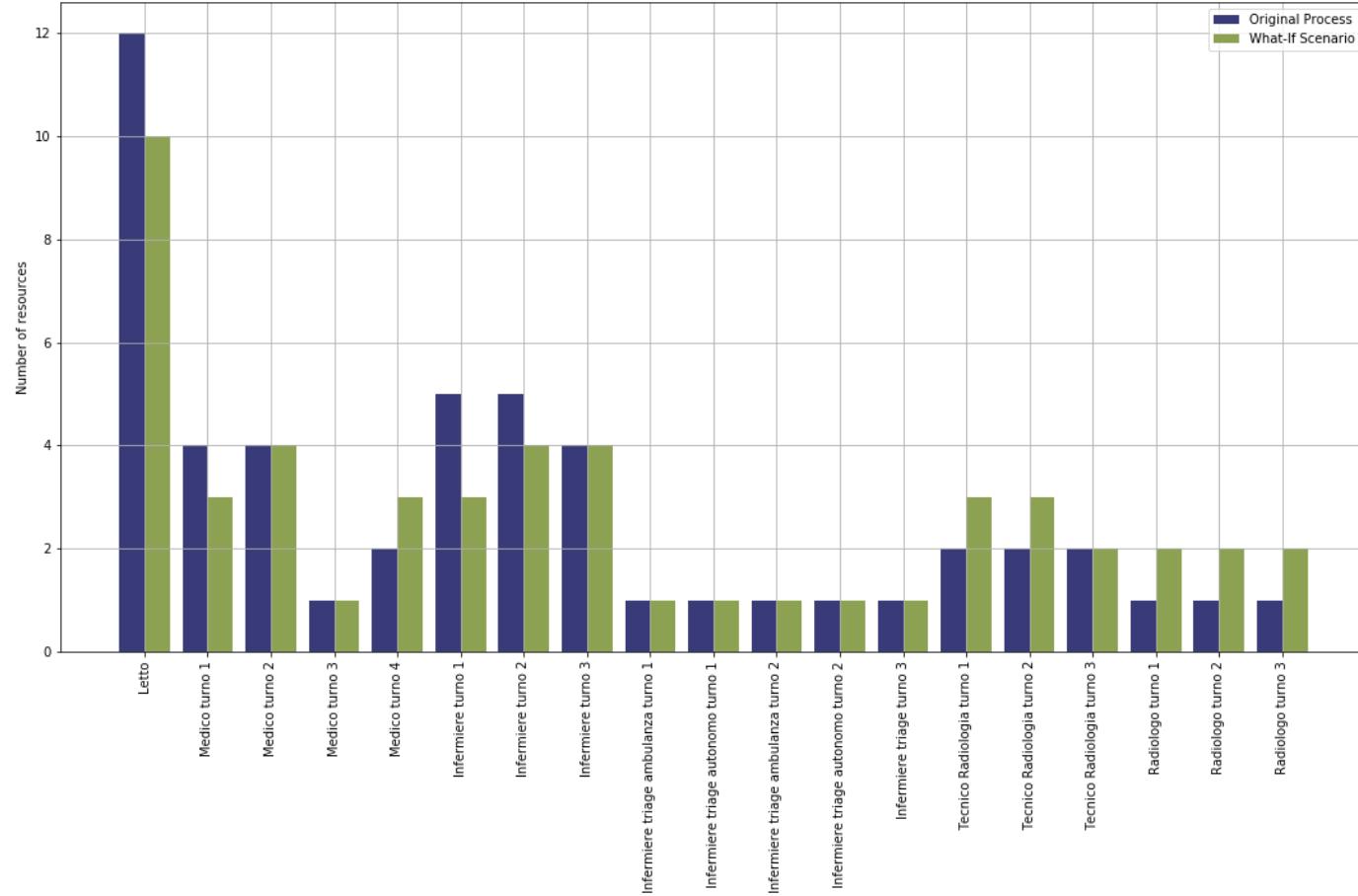
New resource
configuration



Insights on similar costs solution

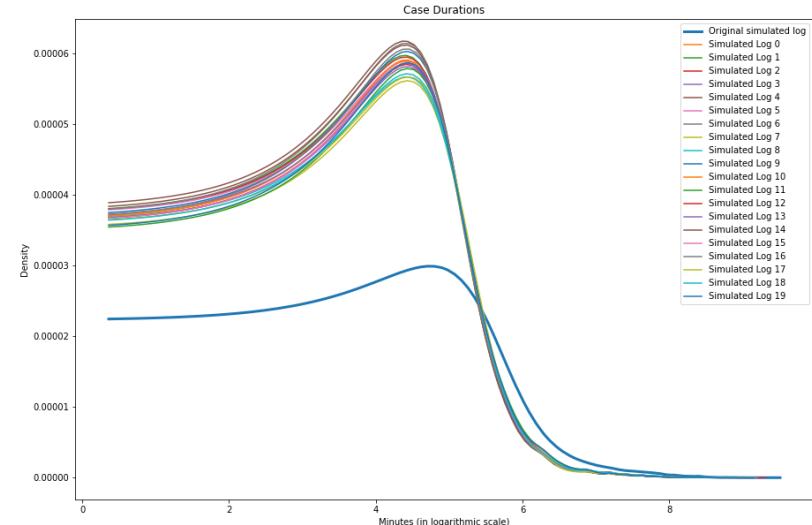
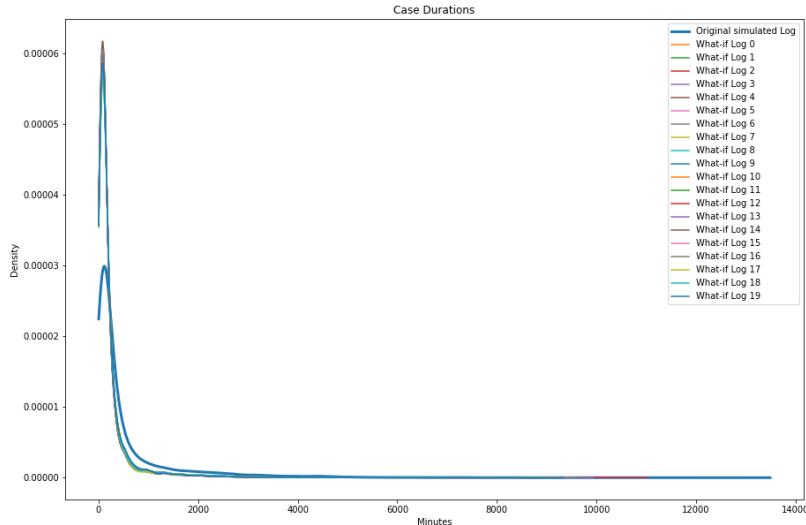


Similar costs solution



Similar costs solution

Maintaining similar costs re-allocating resources to different tasks it is reached a total waiting time reduction of ca. 55% reflected also in case durations.



Current resource
configuration



Median case duration:
186 minutes

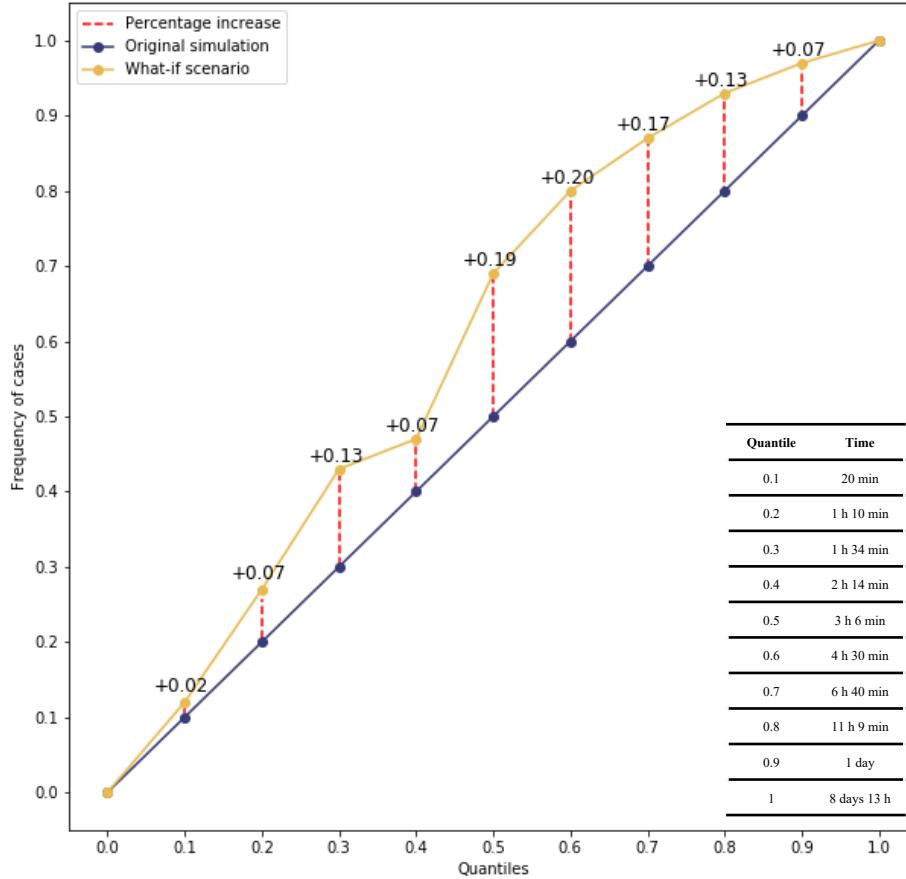


Median case duration:
102 minutes

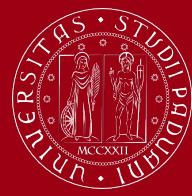


New resource
configuration

Similar costs solution

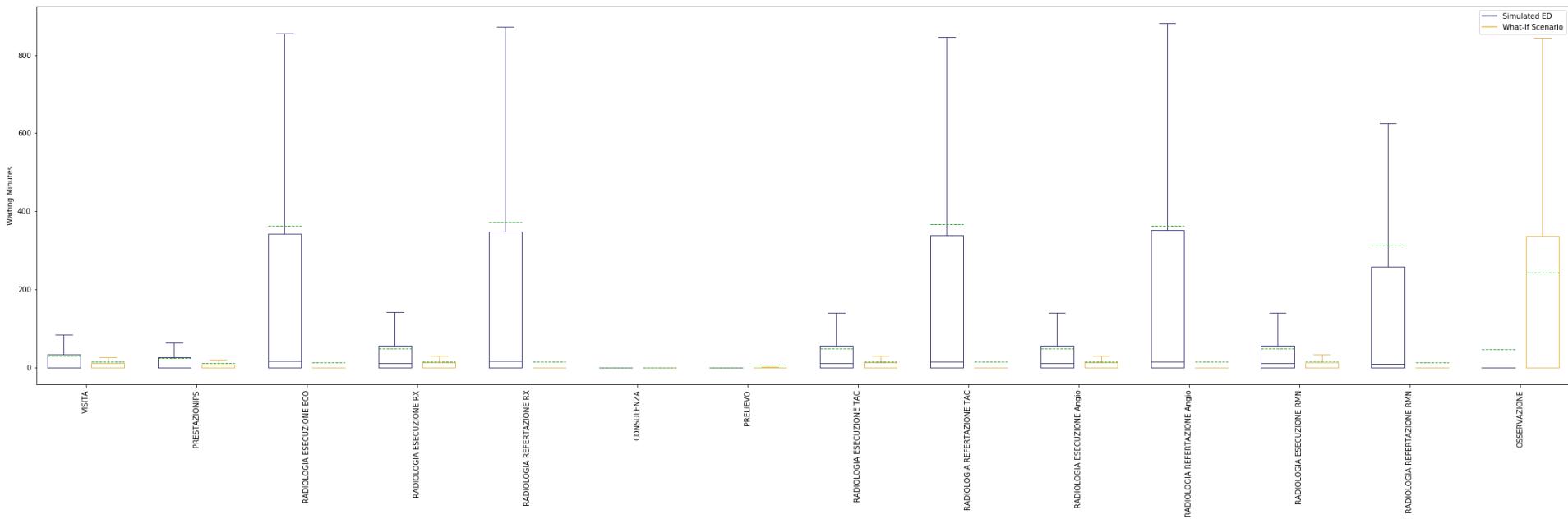


Similar total waiting times solution



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Problem: waiting time *osservazione*



Solution: increase number of beds or set boundary conditions

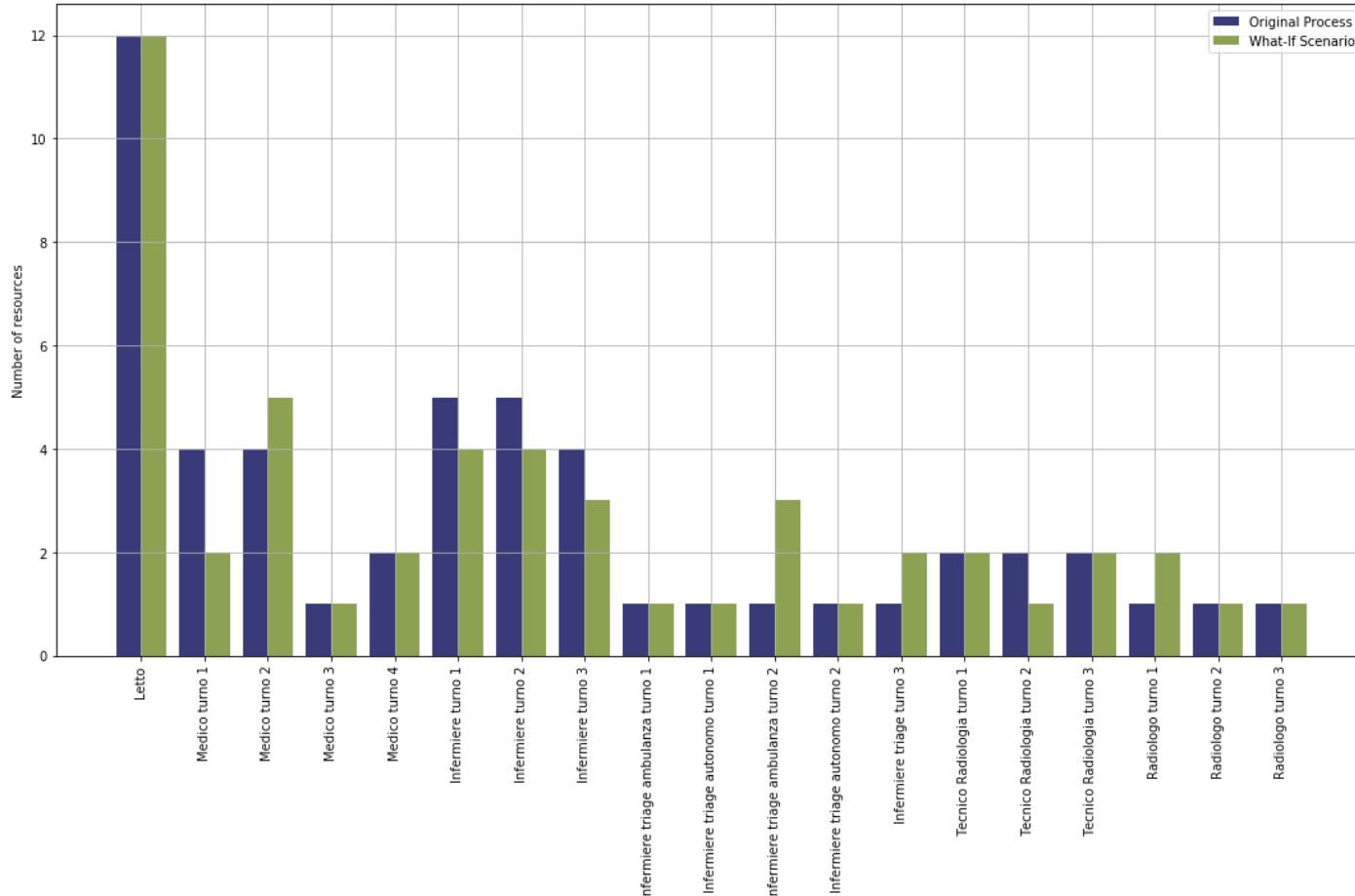


Insights on optimization scenario with boundary conditions

Optimization Scenario with boundary conditions



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Optimization Scenario with boundary conditions



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Current resource
configuration



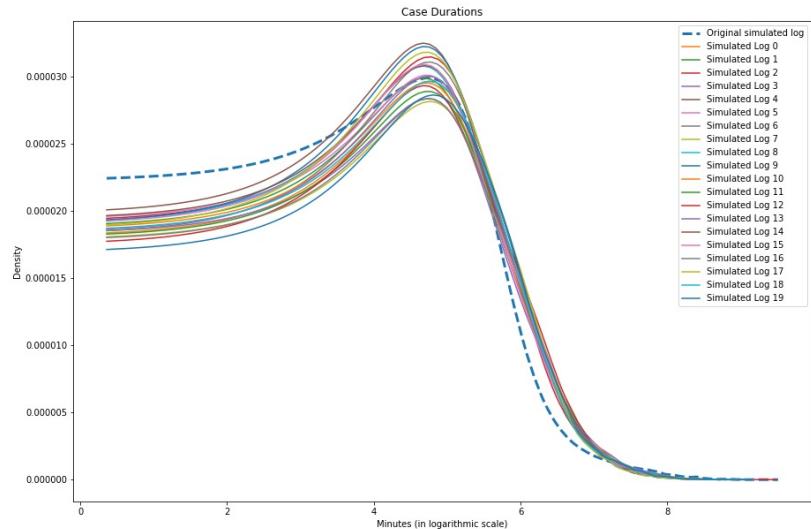
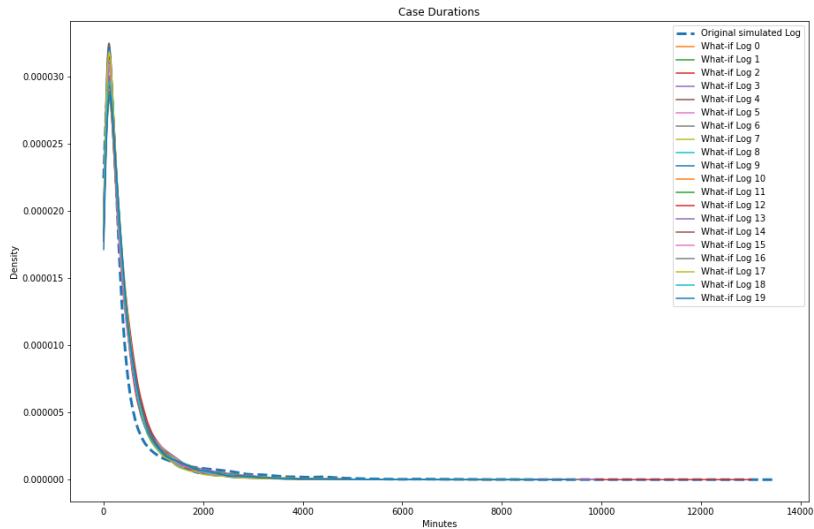
Median case duration:
186 minutes



Median case duration:
170 minutes



New resource
configuration



Current resource
configuration



18080 €/day



17880 €/day

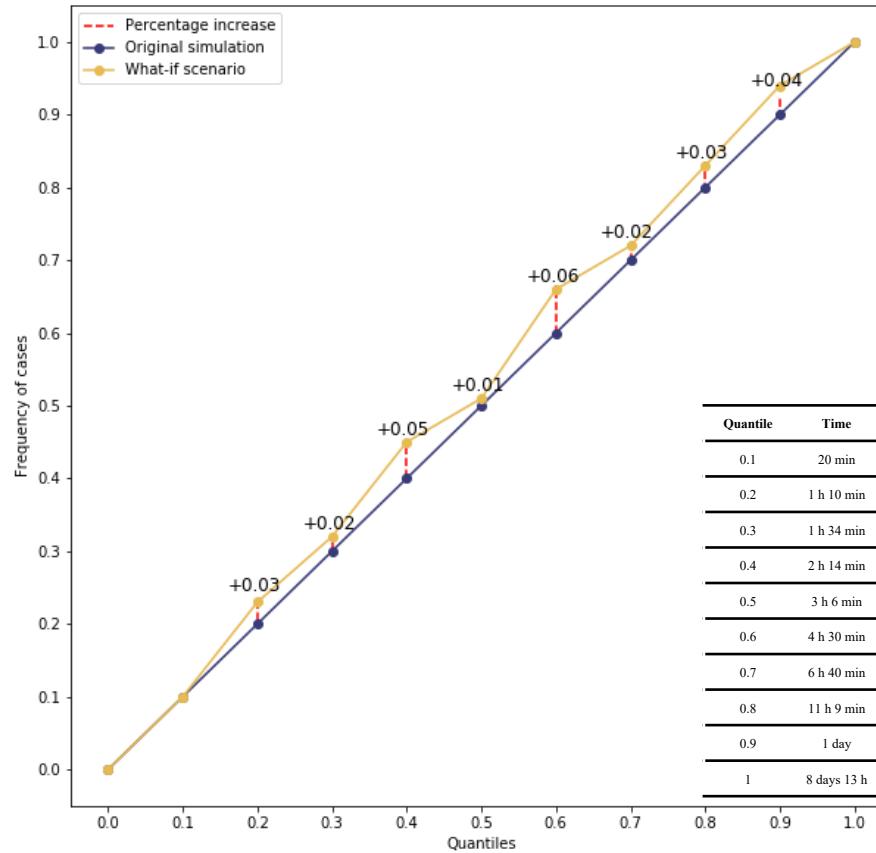


New resource
configuration

Optimization Scenario with boundary conditions



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Optimization Scenario with boundary conditions



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