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OpLog Research Group

Better decisions for more effective emergency medical care

The case of the Portuguese Emergency Medical Service

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Bochum, Nov 22, 2018

Agenda

- OpLog brief introduction
- Emergency medical services (EMSs) and the Portuguese EMS provider (INEM)
- Ambulance dispatching and relocation
- Integrated staff scheduling
- Final remarks

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Short background

BAC, Brussels

Maths Applied to Economics and Business

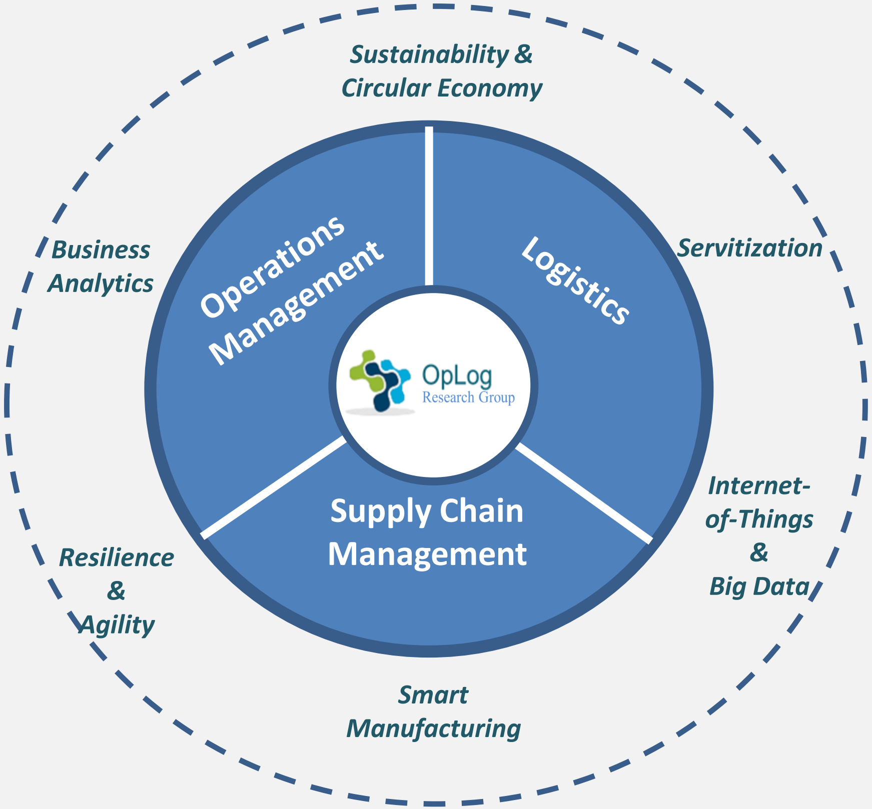
Operations Research

Statistics and Operations Research

Topic: Operating Room Planning & Scheduling

Assistant Professor at IST

OpLog main research pillars



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

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
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Senior Researchers
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Teresa Grilo
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+1

15 PhD Candidates
40+ Ongoing MSc Students

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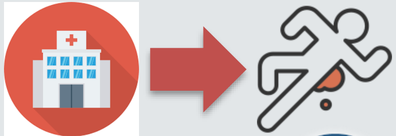
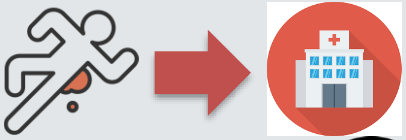
What is an EMS?

"a comprehensive system which provides the arrangements of personnel, facilities and equipment for the effective, coordinated and timely delivery of health and safety services to victims of sudden illness or injury"

Simulation, Optimization, Data Science and Artificial Intelligence (AI)

Improve decision making – more effective, coordinated and timely health delivery

Current international EMS systems evolved from two main models

	Franco-German model ***Stay and stabilize***	Anglo-American model ***Scoop and run***
Main idea		
Main provider		
Patients treated		
Destination for transported patients	 Ward	

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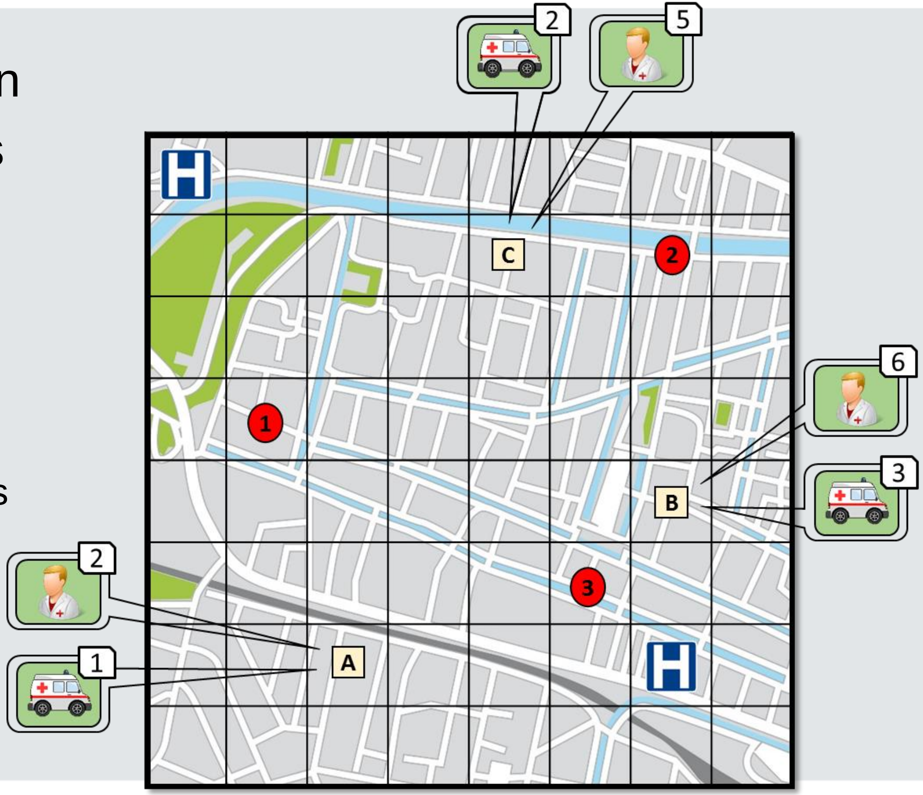
Why is EMS such an important health service?

- Main goal: provide **timely basic medical care** to victims or emergencies
- **Prevents** needless mortality or long-term morbidity
- Corresponds to the **pre hospital assistance**
- Has to manage and mobilize **several resources**
- Aims to serve as many emergencies as possible with an **effective response**

Response time: total time between an emergency call received by the system and the moment that an ambulance arrives at the scene

EMS environment

- **Sub zones**: Basic subdivisions of the region
- **Hospitals**: Health care facility that provides patient treatment
- **Ambulance Bases**: Structures or areas for storage of ambulances
  - **Depots**: A base where ambulances start and end their shift
  - **Potential standby sites**: Sites where ambulances can park during the day while waiting for emergencies
- **Emergency points**: Location where an emergency occurs



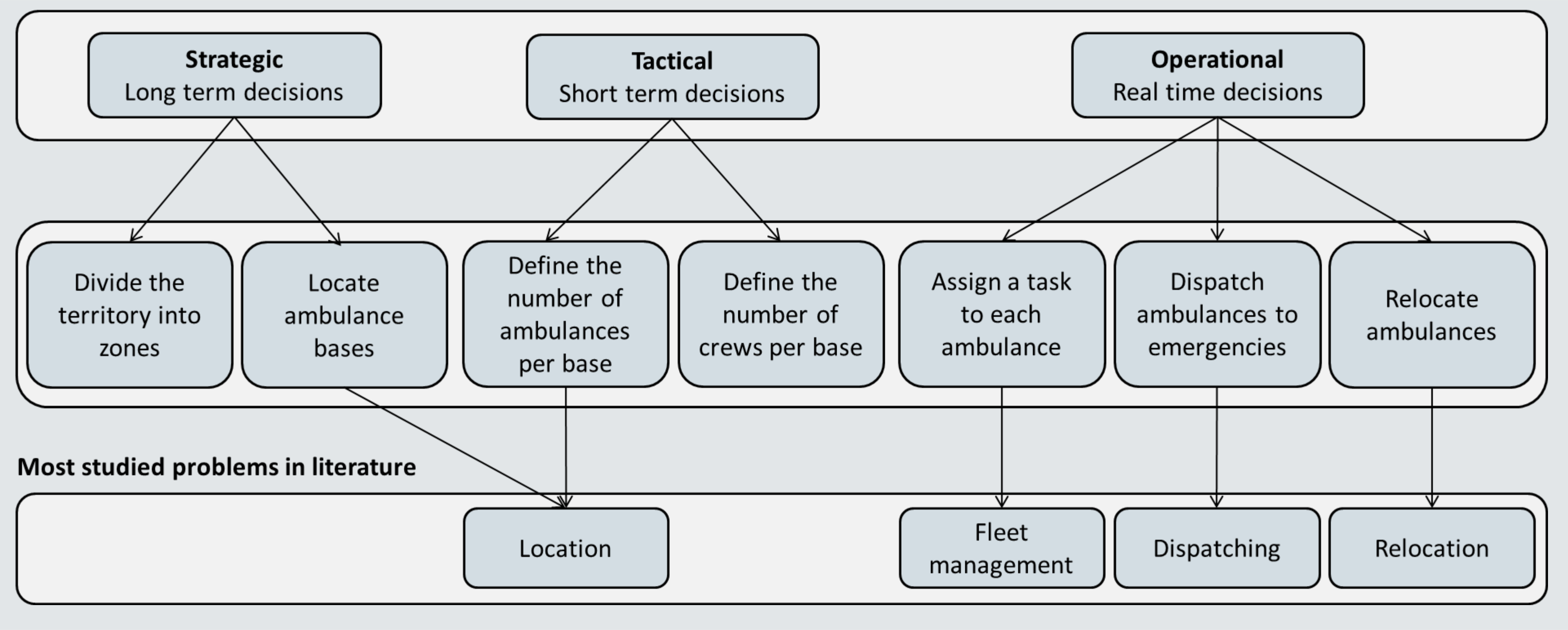
Open questions

- How many?
- Where?
- When?
- How severe?

- How many?
- Where?
- When?

- How many?
- Where?
- Should standby sites be used?

Decision-making process



INEM: Resources and operational results in the media (August 2018, Público)

SAÚDE

Presidente do INEM diz que falta de técnicos não afecta socorro

27 de Agosto de 2018

9

INEM

Sindicato pede abertura de mais concursos para técnicos de emergência pré-hospitalar

RITA MARQUES COSTA

27 de Agosto de 2018

INEM

INEM prevê renovar até 2021 frota de ambulâncias

26 de Agosto de 2018

2

SAÚDE

INEM demorou cerca de 30 segundos a atender chamadas nos primeiros sete meses do ano

ANA MAIA

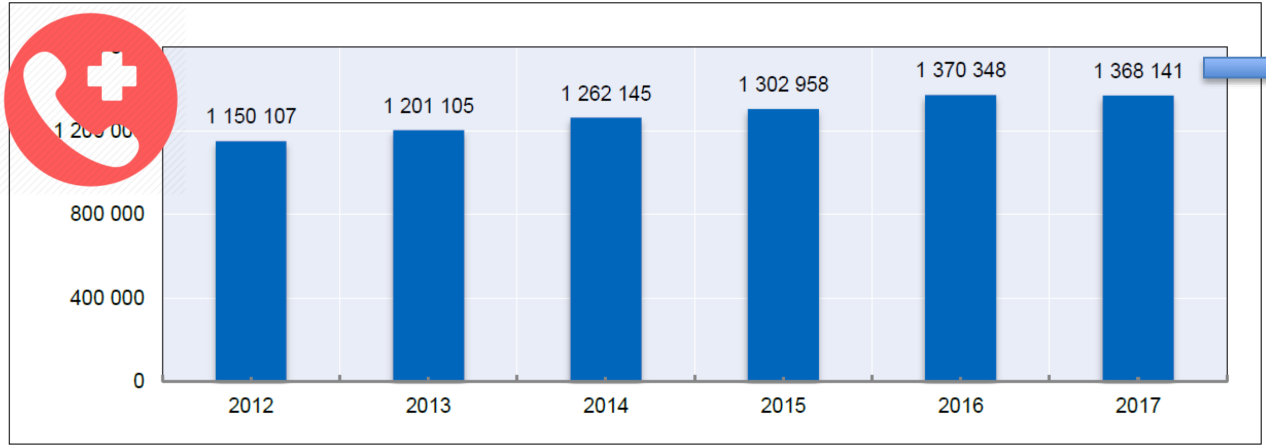
10 de Agosto de 2018

Atividade	2013	2014	2015	2016	2017	Var 2017/2016	
Notícias Setor da saúde	102 203	148 469	125 422	120 139	171 521	51 382	43%
Notícias c/ referência INEM (imprensa, televisão, rádio e internet)	15 061	22 341	19 203	20 940	23 967	3 027	14%

14%

Daily average: 66

Some figures 2017



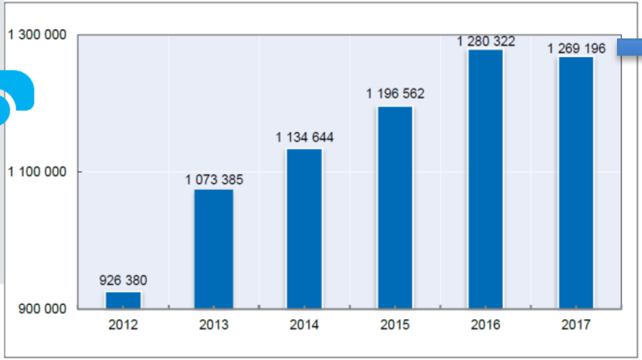
75.843 (5.5%)

Daily average:

3.748

208

3.477



93%

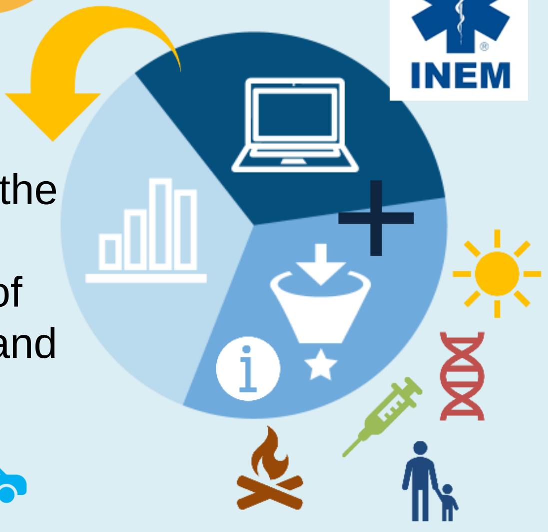
966

652

Data2Help: Data Science for Optimization of EMSs

Improve decision making – more effective, coordinated and timely health delivery

Data Science and Simulation



Forecast the expected demand of vehicles and workload

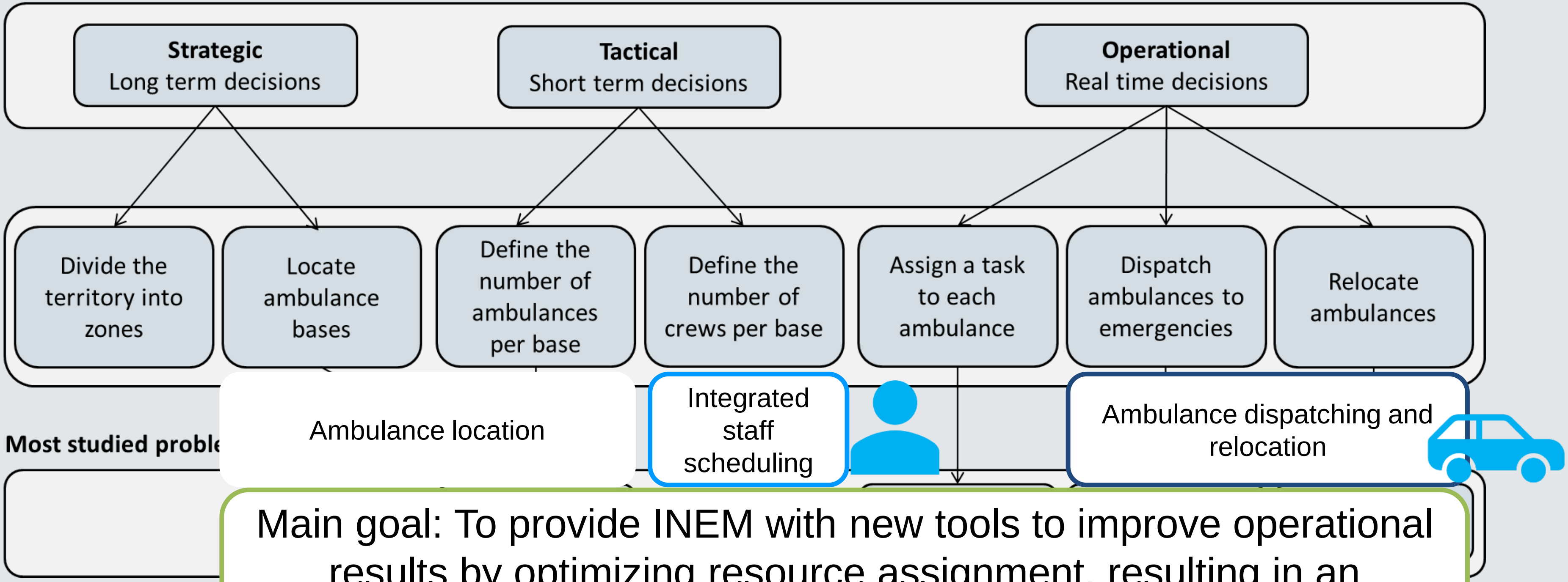
Optimization, Simulation and AI

Dispatching and relocation

Staff scheduling

Vehicle location

Data2Help and the Decision-making process



Main goal: To provide INEM with new tools to improve operational results by optimizing resource assignment, resulting in an improved and faster response to medical emergencies in Portugal.

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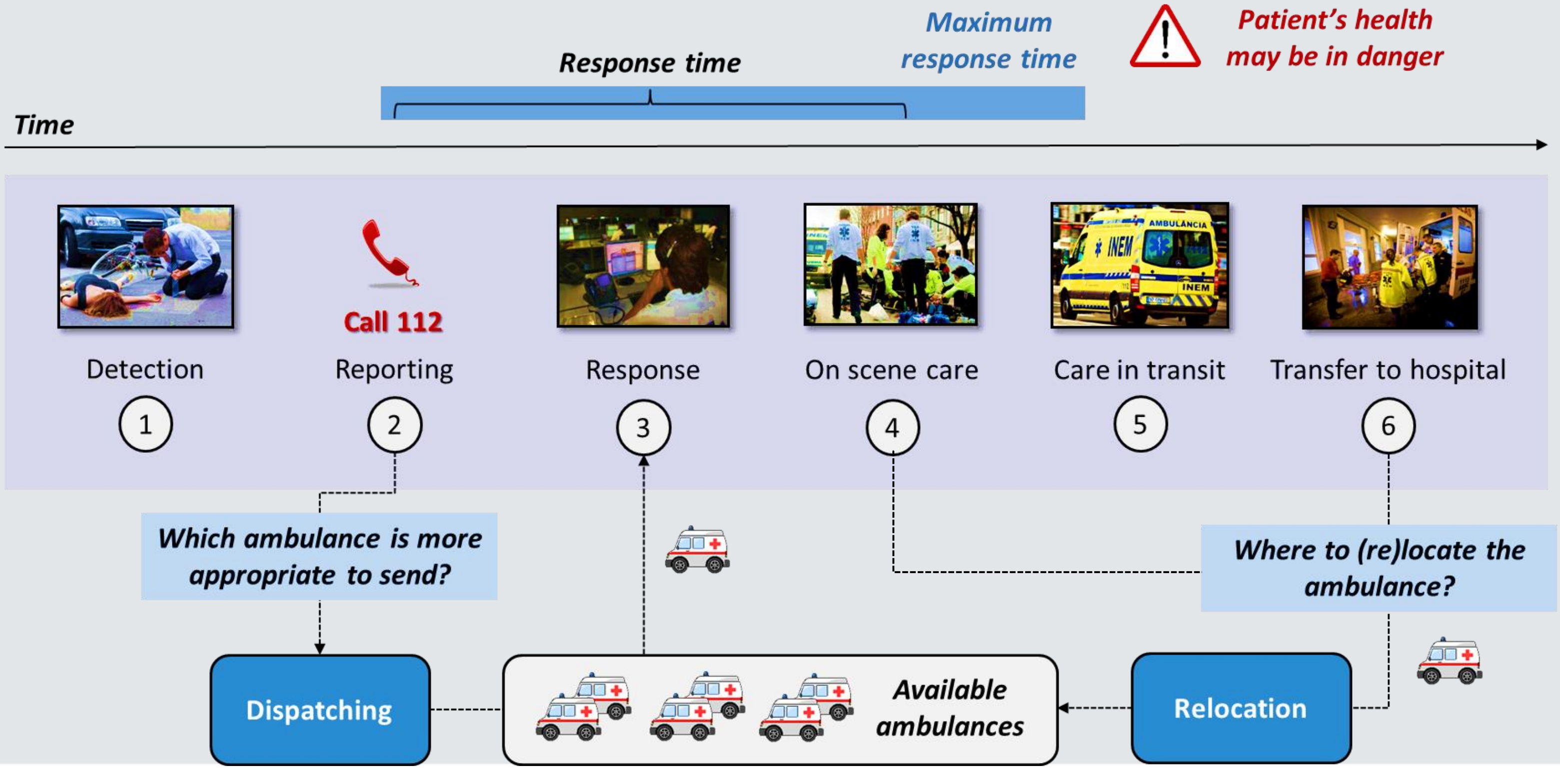
Chain of events



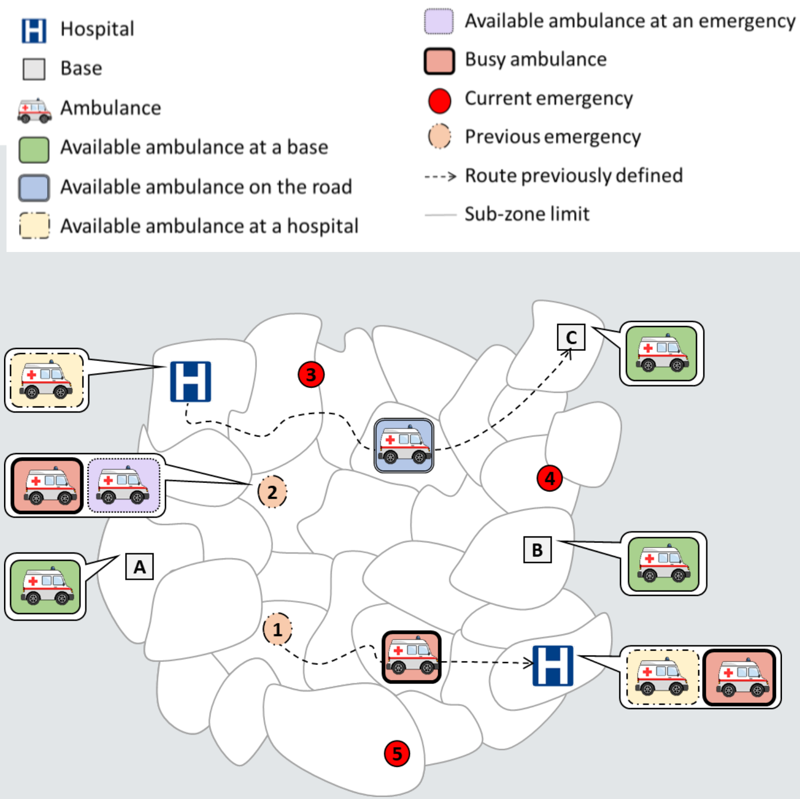
Motivation

- **Response time is** (sometimes) **too high** affecting patients' health state
- Effective and efficient emergency response is an **issue that concerns society**
- Emergency decisions are still based on **staff common sense**

➢ Aim: develop optimization tools to dispatch and relocate ambulances
  - analyze the importance of changing the current policies at INEM
    (Dispatch closest available ambulance and relocate ambulances to home base)

Ambulance dispatching and relocation

Decisions



Decision 1
Dispatching problem

Which (available) ambulance goes to each actual emergency point?

Decision 2
Relocation problem I

To which base the available ambulances go after completing the service?

Decision 3
Relocation problem II

Are additional relocations between bases needed?

Main goal: ensure a good system coverage to provide quick response times to current and future emergencies

Ambulance dispatching and relocation

Dynamic problem: coverage

How to analyze system coverage?

- **Preparedness** evaluates the ability to serve patients now and in the future
- *Time-preparedness metric*
  - Preparedness for a fleet of available ambulances in the area under study
  - Depends on the historical number of emergency calls and on the travel time
  - ➢ increases with available ambulances closer to a sub-zone
  - ➢ decreases with the call frequency and the travel time at each moment

Ambulance dispatching and relocation

MILP model

Decision 1
Dispatching problem

$$x_{ij} = \begin{cases} 1 & \text{if available ambulance i is dispatched to emergency j} \\ 0 & \text{otherwise} \end{cases}$$

Decision 2
Relocation problem I

Decision 3
Relocation problem II

$$y_{i\ell} = \begin{cases} 1 & \text{if available ambulance i is assigned to base } \ell \\ 0 & \text{otherwise} \end{cases}$$

+

$$r_{ij} = \text{extra response time for ambulance i to reach emergency j}$$

Ambulance dispatching and relocation

MILP model

System capability to handle new emergencies in the future

→ Min system response time for future emergencies

Response time for current emergencies

$$\min \sum_{q\in Z} \lambda_q \left(\sum_{l\in B} d_{lq}\ \delta_{lq}^{min} + INF^{Travel\ time}\ w_q \right) + \sum_{j\in E} \left(\sigma_j + \sum_{i\in A} d_{ij}\ x_{ij} \right)$$
$$+ P^{Uncovered} \sum_{j\in E} u_j + P^{Response} \sum_{i\in A} \sum_{j\in E} r_{ij} + P^{Target} \sum_{i\in A^{Target}} z_i \quad (2)$$

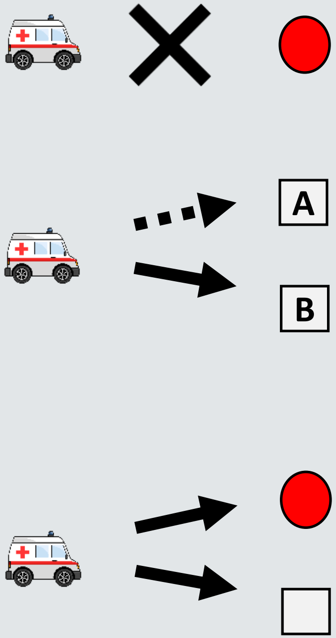
Number of uncovered emergencies

Extra response times

Changes in target bases

MILP model

Ambulance dispatching and relocation



Uncovered emergency definition	s.t.: $u_j = 1 - \sum_{i \in A} x_{ij}\ ,\ \forall\ j \in E$
Change target definition	$z_i = 1 - \left(y_{ib_i} + \sum_{j \in E} x_{ij} \right)\ ,\ \forall\ i \in (A^B \cup A^R)$ $z_i = 0\ ,\ \forall\ i \in \{A^B \cup A^R\} \setminus \{A^{Target}\}$
Maximum number of changes in target bases	$\sum_{i \in A^{Target}} z_i \leq Target^{MAX}$
Each available ambulance is dispatched to an emergency or assigned to a base	$\sum_{j \in E} x_{ij} + \sum_{l \in B} y_{il} = 1\ \ \forall\ i \in A$ $\sum_{i \in A} x_{ij} \leq 1\ ,\ \forall\ j \in E$

MILP model

Maximum response time	$\sigma_j + d_{ij}\; x_{ij} \leq R^{MAX} + r_{ij}\;,\; \forall\, i \in A\;,\; j \in E$
Whether a base is empty of ambulances or not	$v_l \leq \sum_{i \in A} y_{il} \leq \lvert A \rvert\; v_l\;,\; \forall\, l \in B$
Minimum time to reach a sub-zone	$d_{lq}\;\delta_{lq}^{min} \leq d_{l'q} + M^{Travel\ time}\,(1 - v_{l'})\;,\; \forall\, l\;,\; l' \in B\;,\; q \in Z$ $\delta_{lq}^{min} \leq v_l\;,\; \forall\, l \in B\;,\; q \in Z$
Defines the base that reaches the sub-zone in minimum time or no ambulance at all	$\sum_{l \in B} \delta_{lq}^{min} + w_q = 1\;,\; \forall\, q \in Z$
Binary-domain and real-domain variables	$x_{ij}, y_{il}, u_j, v_l, z_{i'}, w_q, \delta_{lq}^{min} \in \{0,1\},$ $\forall\; i \in A, i' \in \{A^B \cup A^R\},\; j \in E,\; l \in B,\; q \in Z$ $r_{ij} \geq 0\;,\; \forall\, i \in A\;,\; j \in E$

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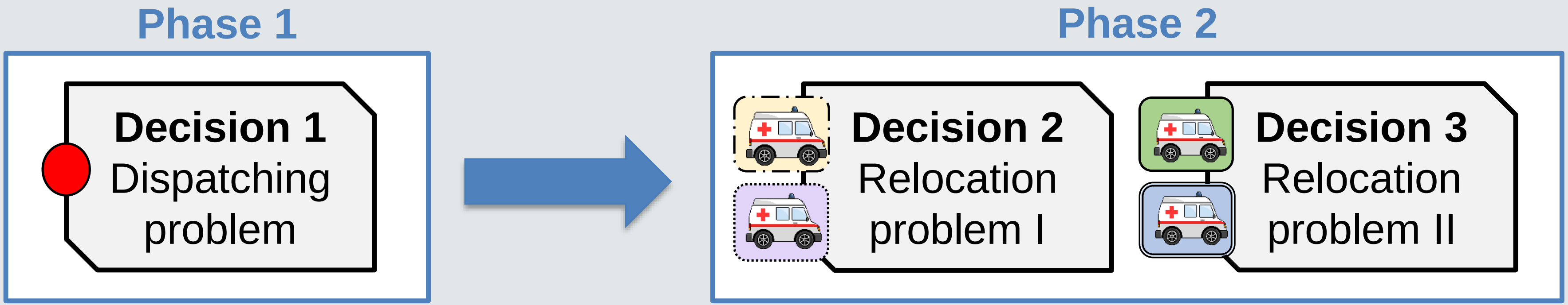
Ambulance dispatching and relocation

Heuristic: overview



needs to be solved within few seconds in order to ensure a quick response time

can be solved in slightly more time (not too much) as these are not immediate critical decisions

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Ambulance dispatching and relocation

Phase 1: Dispatching problem

Phase 1

Decision 1
Dispatching problem

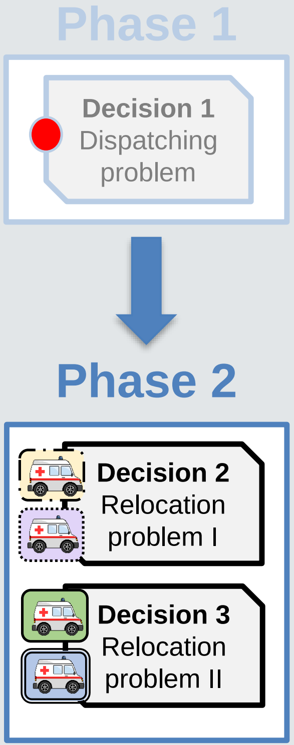
Algorithm 1 Heuristic phase 1 - dispatching decisions

for all emergencies $e \in E^*$ **do**
    Calculate $p^{(t+1)}_{(A\setminus i)}$
    Dispatch available ambulance i' such that $i' = argmax_{i\in A} \frac{\left[p^{(t+1)}_{(A\setminus i)}\right]^{\alpha}}{1+d_{ie}}$
end for
* Emergencies are analyzed by descending order of the corresponding waiting time, i.e. emergencies that occurred earlier are considered first.

α: calibration factor that weights on preparedness (closest-policy if $\alpha = 0$)

Ambulance dispatching and relocation

Phase 2: Relocation problem



Algorithm 2 Heuristic phase 2 - relocation decisions

Define S as the master solution with an undefined initial cost, $Cost_S = +\infty$

Define A^{Fixed} as the set of available ambulances fixed in S, $A^{Fixed} = \emptyset$

while [$(A - A^{Fixed}) \neq \emptyset$ **and**

(number of ambulances that changed target base $\leq Target^{MAX}$ **or** there are ambulances at an emergency or at a hospital to return to a base)] **do**

  for $a \in (A - A^{Fixed})$ **do**

    Apply pilot heuristic (Algorithm 3) to obtain $Cost_a$ by fixing a

    Update master solution S if $Cost_a < Cost_S$

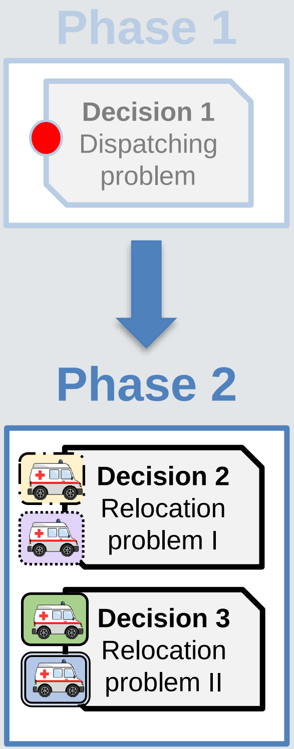
  end for

end while

- A **pilot heuristic** is used to generate and compare solutions (tempered greedy meta-heuristic - look-ahead method)
- A **master solution** is extended at the end of each iteration with the best pilot solution

Ambulance dispatching and relocation

Phase 2: Relocation problem



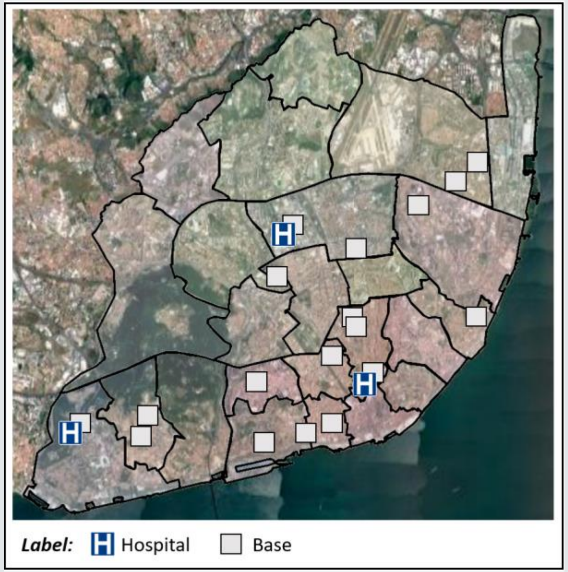
Algorithm 3 Pilot heuristic

```
Initial ambulance: a
while [ there are available ambulances to analyze and
(number of ambulances that changed target base ≤ Target^MAX or there
are ambulances at an emergency or at a hospital to return to a base) ] do
    i) Choose base b to assign ambulance a
    if ambulance a is at an emergency or at a hospital then
        Choose between all bases b ∈ B, the one that maximizes p_A^(t+1)
    else
        Choose between maintaining the current assigned base or changing
to the closest base, the one that maximizes p_A^(t+1)
    end if
    ii) Choose the following ambulance a* to analyze
    a* is the furthest available ambulance from a
    a = a*
    iii) Update solution cost and other info
end while
```

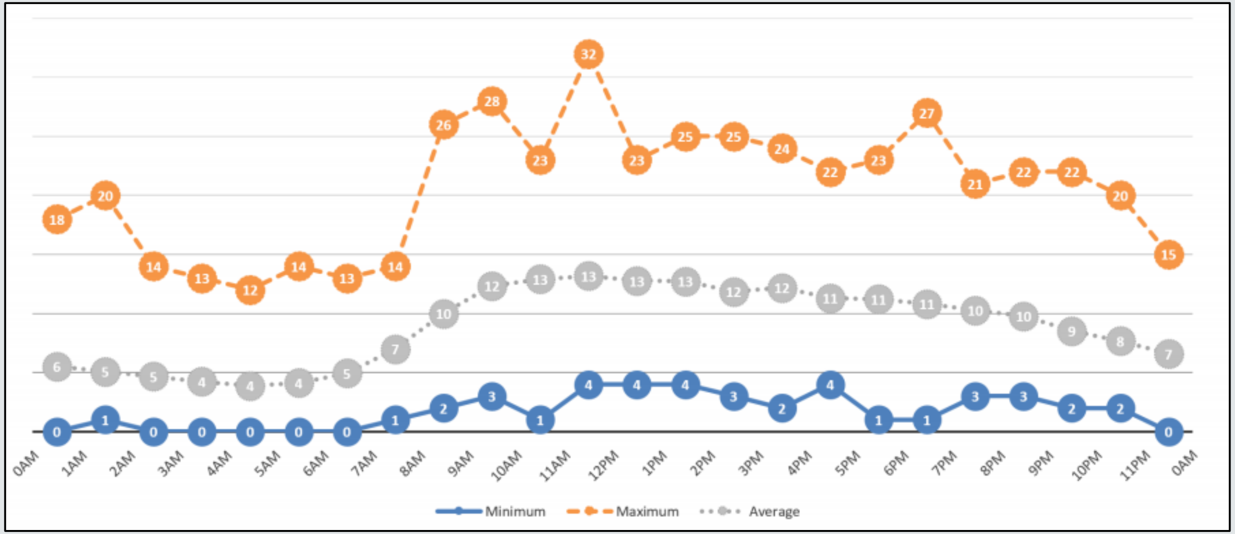
- Pilot heuristic: tempered greedy meta-heuristic (look-ahead method)

Ambulance dispatching and relocation

Tests: INEM data



Lisbon region divided into sub-zones



Number of emergencies per hour in Lisbon (2nd half of 2016)

Ambulance dispatching and relocation

Tests: Instances and scenarios

Input data (INEM case study)

- **Ambulances:** 37
- **Ambulance bases:** 19
- **Hospitals:** 3
- **Sub-zones:** 24
- **Maximum response time:** 900 seconds

Rolling-horizon scenario

- **1 day: 288 time periods (1 time period = 5 minutes)**
- **Random number of emergencies with random location at each time period**
- **20% of the emergencies does not require hospital-care**
- **Emergency service takes between 10-40 minutes**
- **1 hour is required to be available for a change to a different target base**

50 instances tested

Ambulance dispatching and relocation

Tests: Strategies

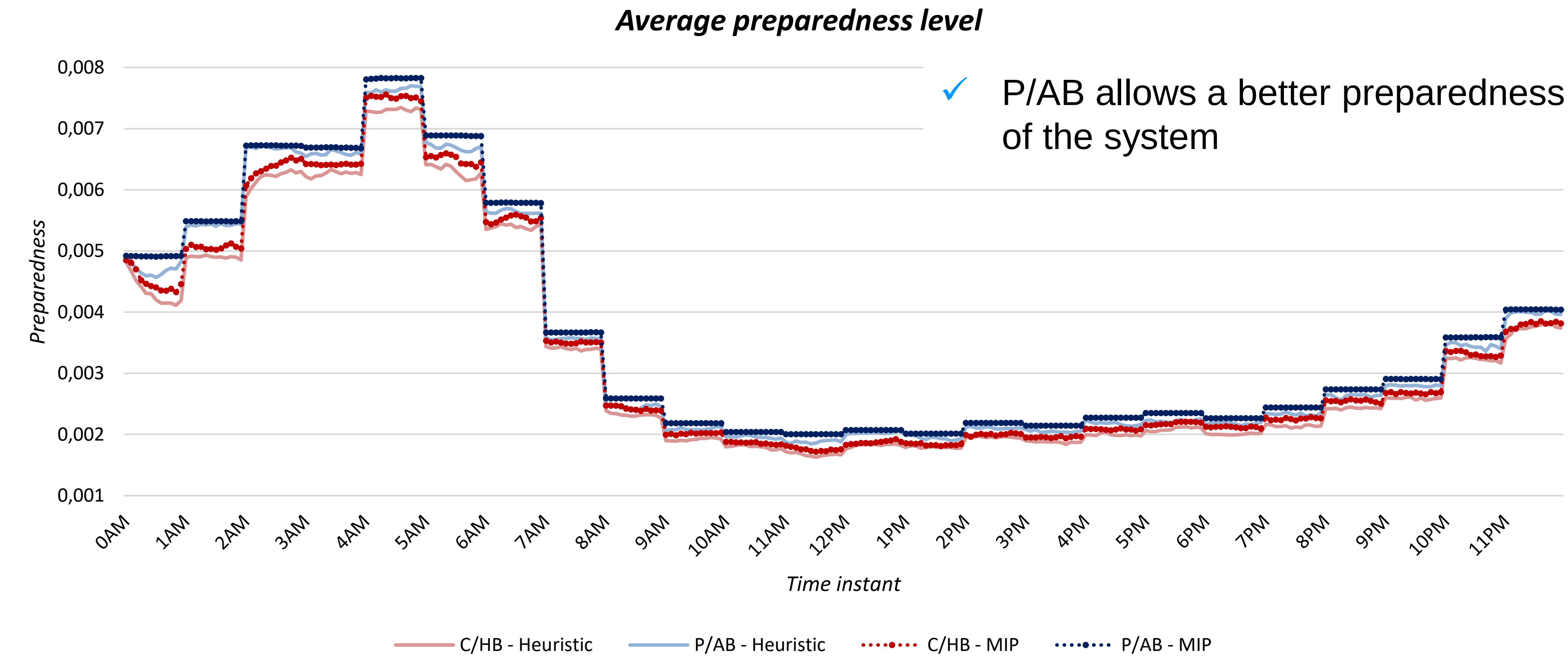
Strategies		Relocation	
		Any base	Home base
Dispatching	Closest (available)		C/HB
	Preparedness	P/AB	

MIP and heuristic adapted to consider INEM policies

MIP and heuristic

Ambulance dispatching and relocation

Results: preparedness

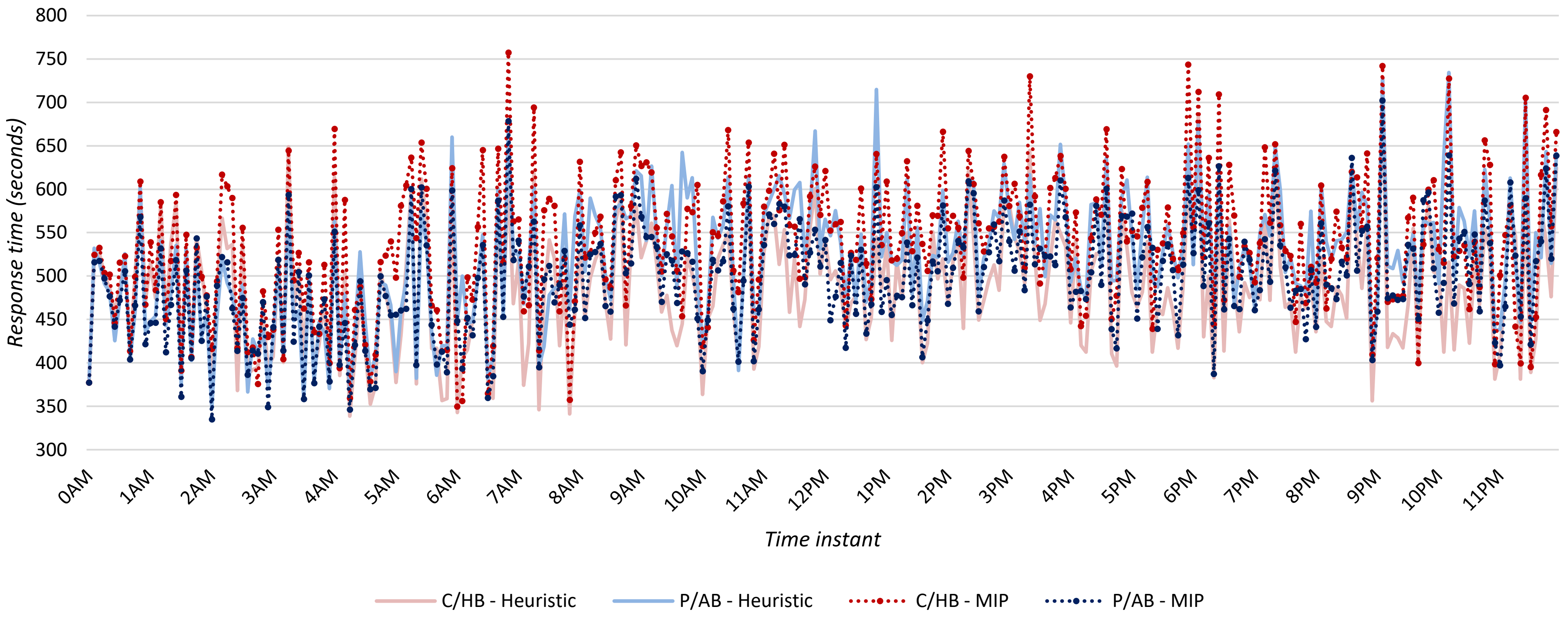


✓ P/AB allows a better preparedness of the system

Ambulance dispatching and relocation

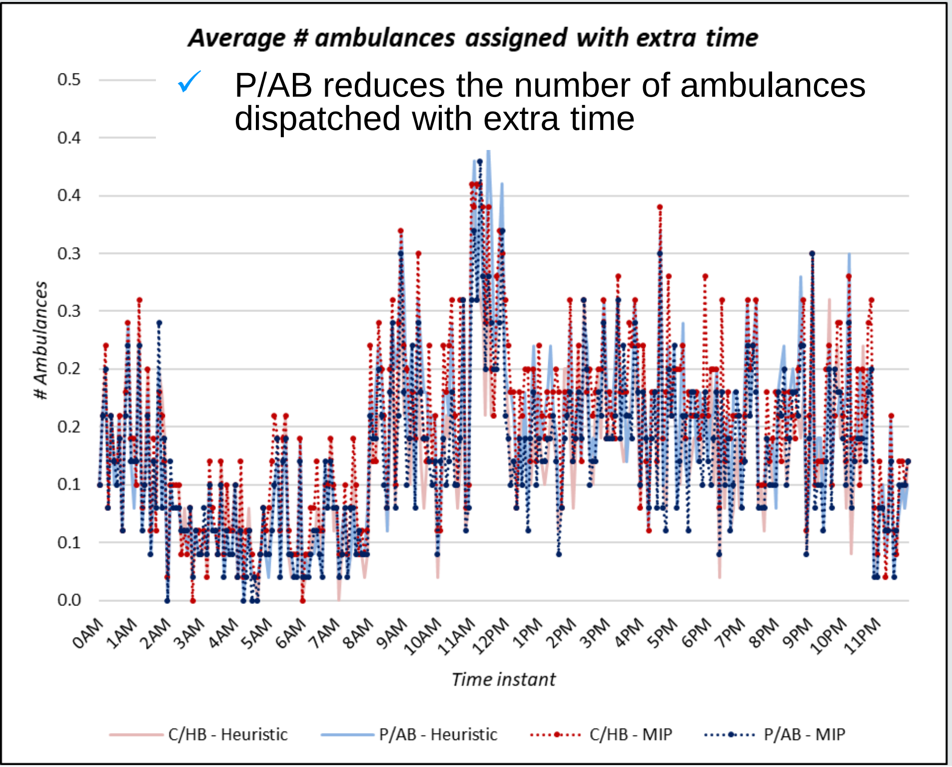
Results: response time

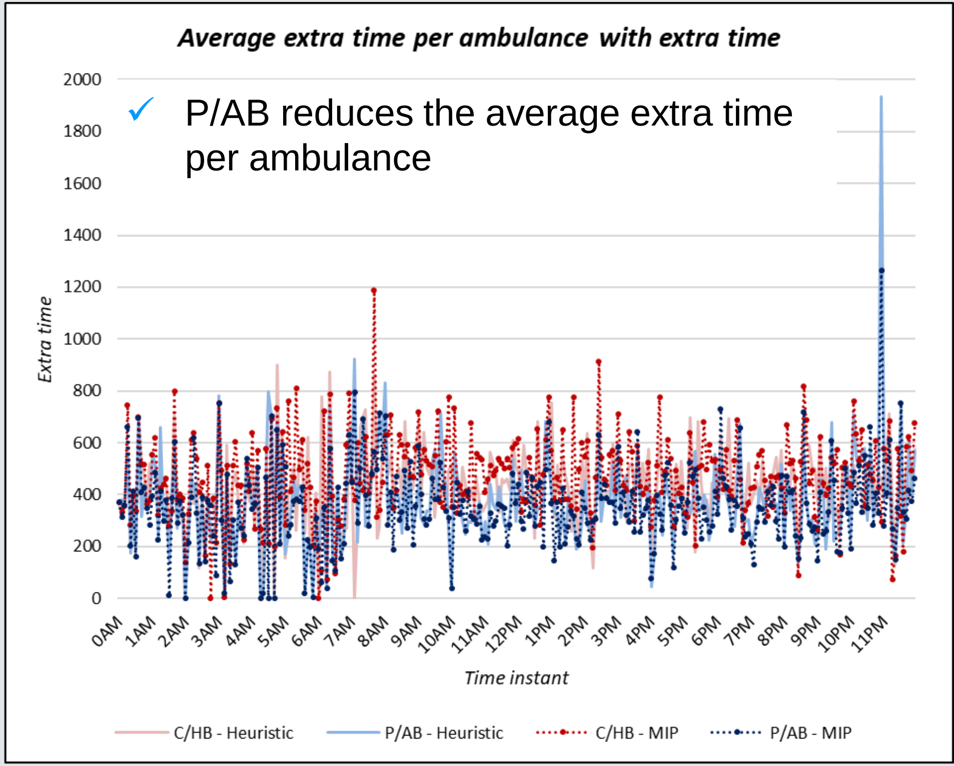
Average response time ✓ There is no consistent pattern



Ambulance dispatching and relocation

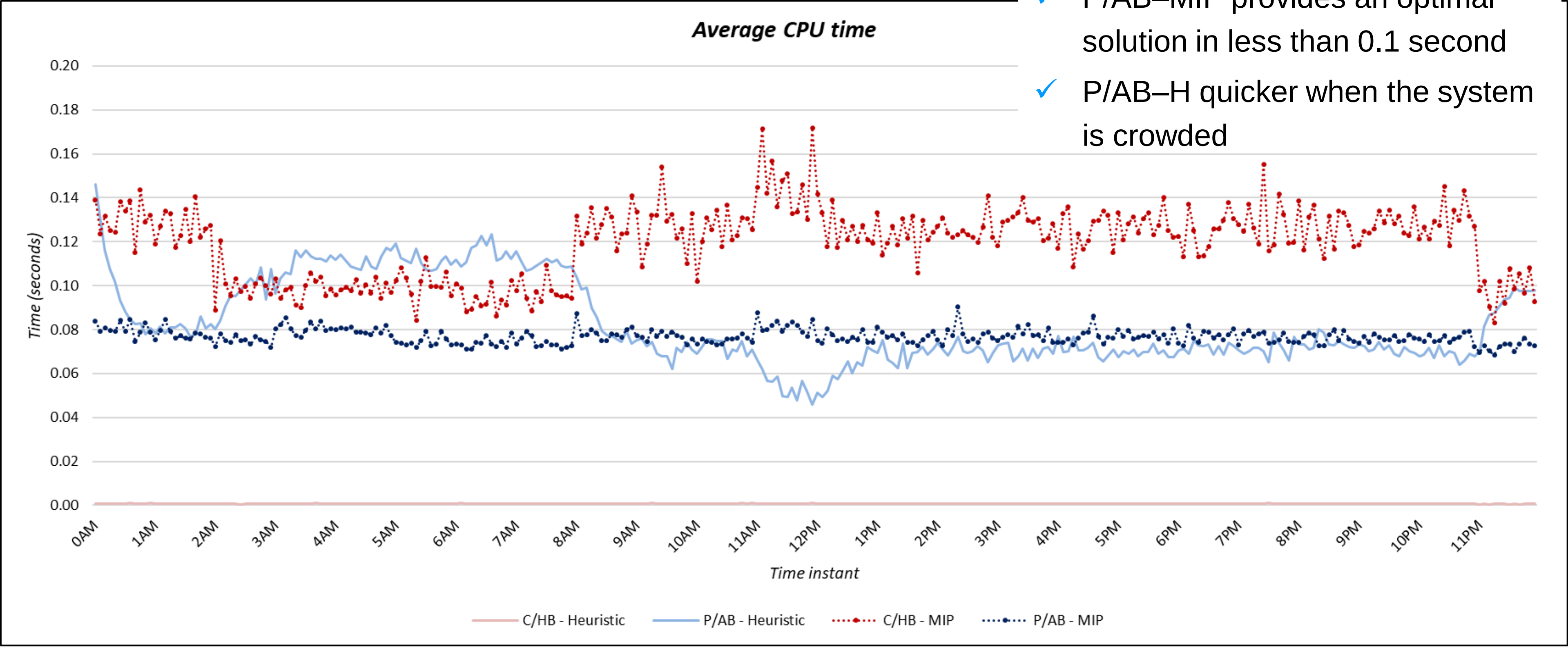
Results: extra time





Ambulance dispatching and relocation

Results: CPU time



- ✓ P/AB–MIP provides an optimal solution in less than 0.1 second
- ✓ P/AB–H quicker when the system is crowded

Intel® Core™ i7-5500U CPU @ 2.40GHz, 8 GB RAM

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Integrated staff scheduling

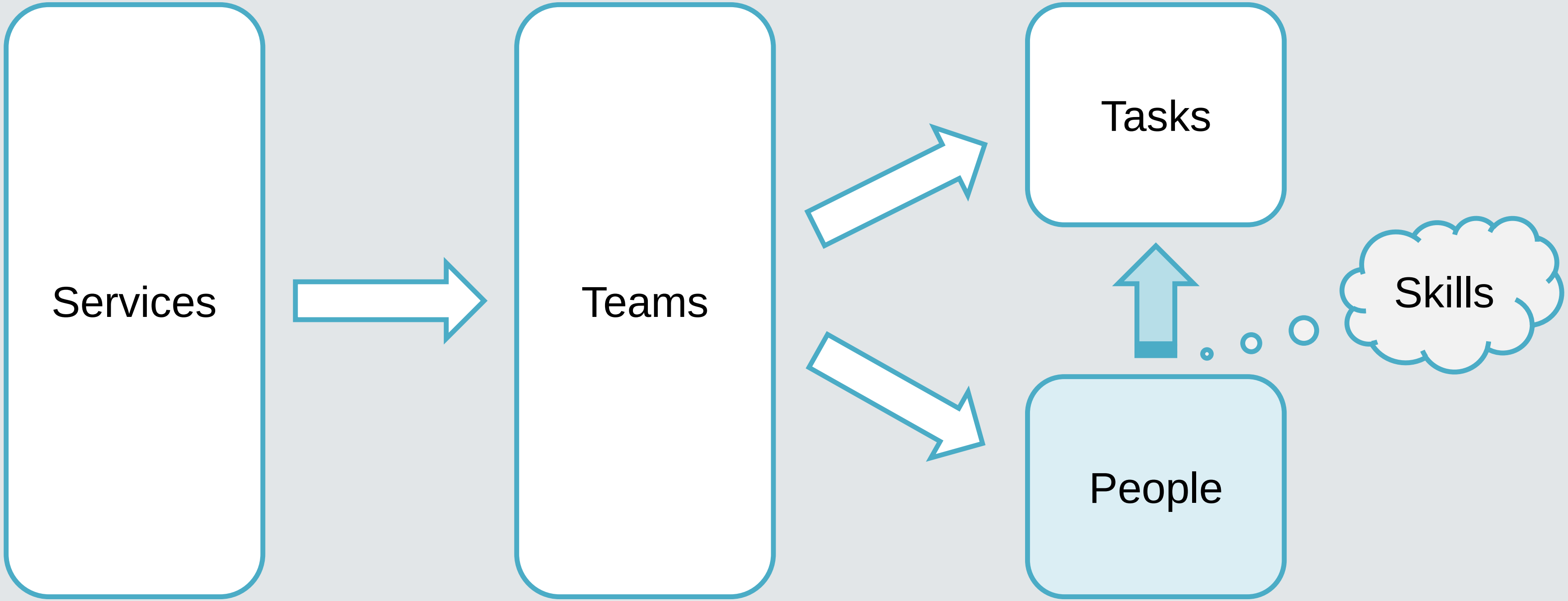
Motivation

- Quality of the schedule impacts the quality of the emergency care
- Employee preferences is directly related to on-job performance
- Timetables are still manually constructed
- Few research in staff scheduling in EMSs

- ➢ Aim: novel solution approach and automated scheduling tool
  - ➢ Provide staff schedules in significantly less time
  - ➢ Improve quality and transparency of the schedules
  - ➢ Increase employee perception about fairness
  - ➢ Focus on functionality of the services and equity among the staff

Integrated staff scheduling

Problem statement



Integrated staff scheduling

Problem statement

- Services operate 24/7
- Fixed shifts
- Required personnel coverage for each task, day and shift
- Legal regulations
- Organizational and contractual issues

➢ Integrated staff scheduling for a set of services that share the same workforce

Integrated staff scheduling

Problem statement

MASTER

SUBPROBLEMS

- Hard constraints
  1. Required skills for each assigned task
  2. Minimum rest between working shifts
  3. Maximum number of consecutive working days
  4. Maximum number of consecutive days off
  5. Minimum number of Sundays off
  6. Minimum number of each shift type

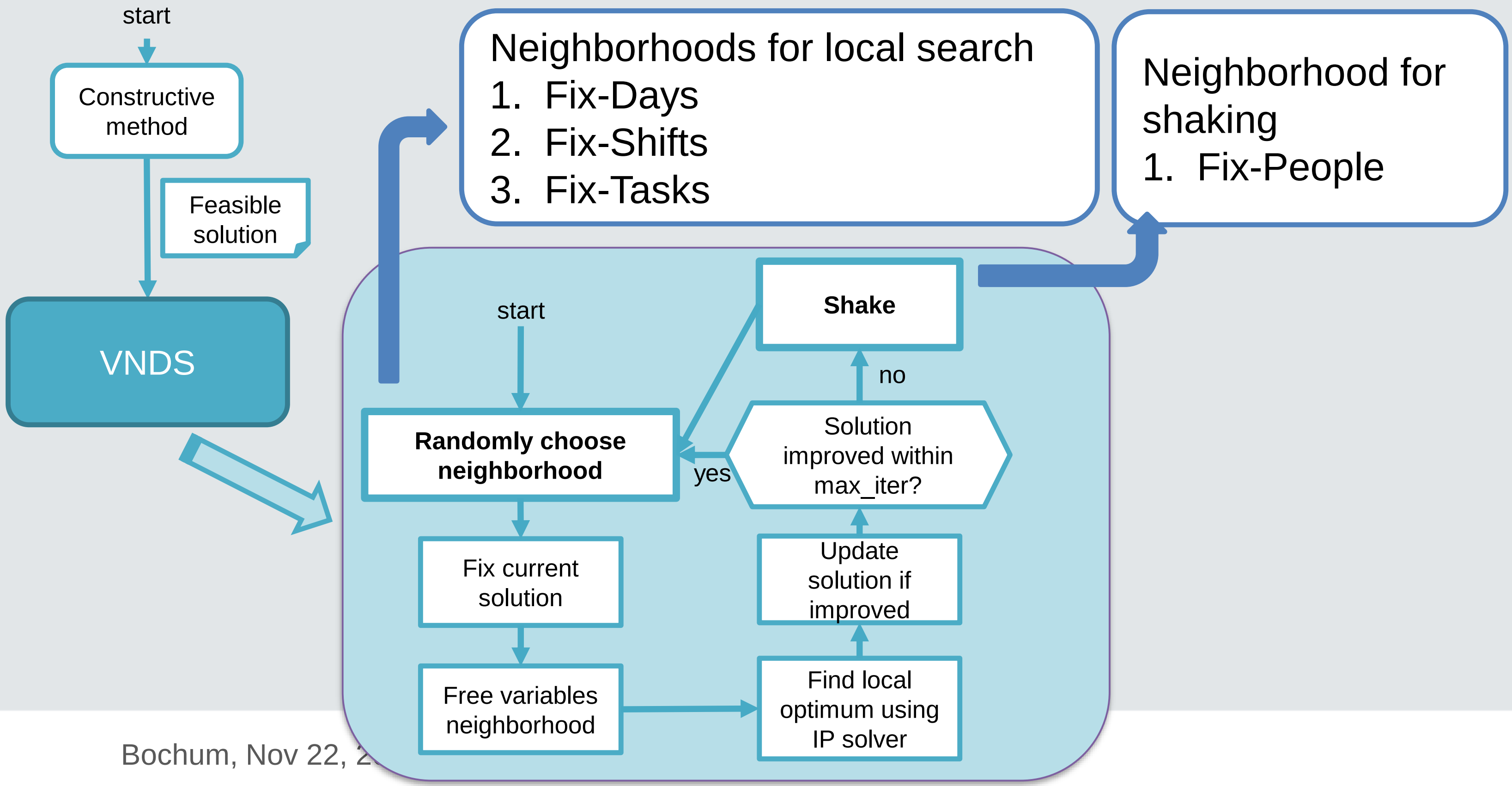
Functionality of services

- Soft constraints
  1. Coverage requirement (understaffing and overstaffing allowed)
  2. Full weekends off
  3. Working time equal to contract hours
  4. Assign to tasks of own team as much as possible

Equity among staff

Integrated staff scheduling

Variable Neighborhood Decomposition Search (VNDS)



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Integrated staff scheduling

Results: case study at INEM

INEM

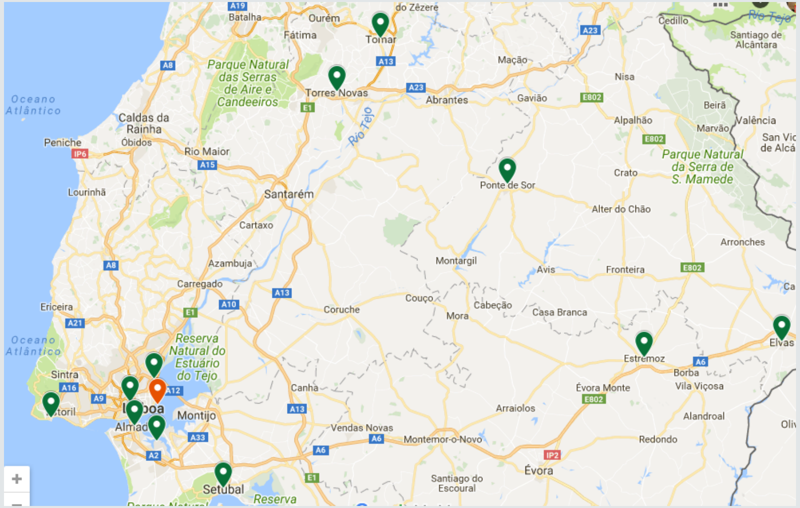
Lisbon region

Dispatch center (CODU)

Emergency Vehicles (EVs)

- CODU

- Lisboa
- Almada
- Cascais
- Elvas
- Estremoz
- Ponte de Sor
- Sacavém
- Setúbal
- Seixal
- Tomar
- Torres Novas



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Integrated staff scheduling

Results: case study at INEM

	CODU		EVs					
Task type	CODU Shift Responsible	CODU Task	AEM Driver	AEM Team Responsible	SIV Task	TIP Task	UMIPE Task	MEM Task
Task duration	8 hours							12 hours

- Overall dataset
  - 289 people
  - 22 teams (5 CODU, 17 EVs)
  - 61 tasks (10 CODU, 51 EVs)
  - 28 days (3 shifts per day)

Integrated staff scheduling

Results: test sets

- Start from INEM base case (289 people, 61 tasks)
- Change certain parameter
- Adjust demands and other requirements

1. TestMD: 56 days instead of 28
2. TestMP: 417 people instead of 289
3. TestLS: 103 tasks instead of 61 (to reduce symmetry)
4. TestHS: every person can do every task (to maximize symmetry)

+ 15 randomly generated instances

Results

Integrated staff scheduling

Instance	LP relaxation		CPLEX IP		Diving B		VNDS		
	Time (s)	Opt.	Obj.	Gap	Obj.	Gap	Avg. obj.	SD obj.	Avg. gap
INEM	180	26,442	1,994,304	98.67	76,556	65.46	27,024	42	2.15
INEM MD	572	50,506	2,255,012	97.76	367,952	86.27	51,488	55	1.91
INEM MP	272	39,218	2,821,106	98.53	100,314	60.91	40,797	16	3.87
INEM LS	372	41,386	3,698,754	98.94	191,966	78.44	42,452	136	2.51
INEM HS	304	25,128	441,896	94.31	100,720	75.05	26,062	351	3.58
Test01	505	19,892	253,624	92.16	58,638	66.08	20,389	20	2.44
Test02	1557	61,949	737,112	91.60	298,520	79.25	74,090	6	16.39
Test03	638	47,486	417,742	88.63	214,088	77.82	53,113	191	10.59
Test04	1227	55,322	557,332	90.07	307,248	81.99	61,845	7	10.55
Test05	829	26,711	251,460	89.38	81,446	67.20	27,465	31	2.74
Test06	375	15,140	3,887,199	99.61	32,247	53.05	15,542	4	2.59
Test07	1596	18,337	1,251,654	98.53	125,758	85.42	18,799	115	2.46
Test08	251	10,386	89,688	88.42	41,824	75.17	10,462	0	0.73
Test09	1852	38,398	1,251,960	96.93	121,378	68.36	41,258	21	6.93
Test10	2573	25,120	5,157,815	99.51	110,027	77.17	25,604	195	1.89
Test11	3254	22,065	1,454,516	98.48	144,192	84.70	23,269	20	5.18
Test12	689	15,742	4,022,071	99.61	45,007	65.02	16,501	23	4.60
Test13	563	6452	883,480	99.27	68,164	90.53	6944	66	7.09
Test14	626	14,193	4,580,454	99.69	52,846	73.14	14,625	4	2.95
Test15	659	10,944	2,581,719	99.58	42,821	74.44	11,408	7	4.07

Good performance of the VNDS heuristic

- Gaps of 0.7 to 16.4 percent w.r.t. LP lowerbound
- Within 1 hour CPU

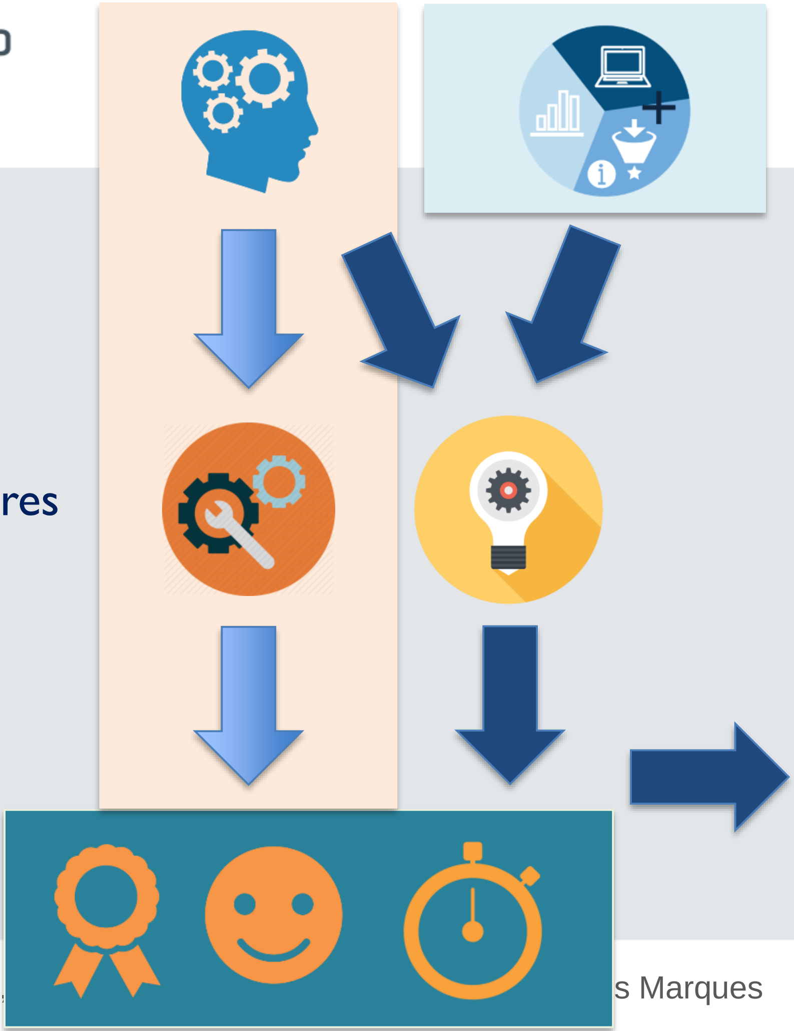
Further required developments…

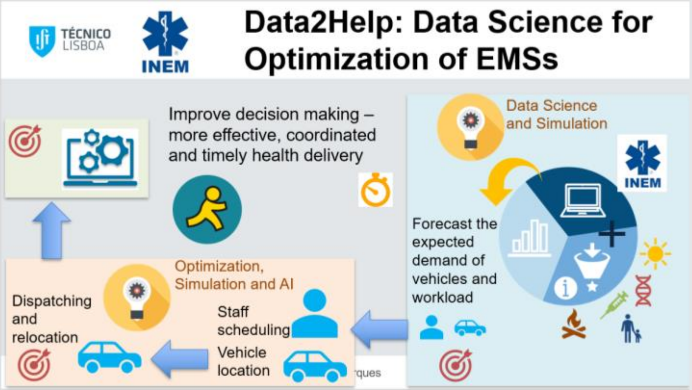
- Extend the scheduling tool
  - Holidays
  - Staff preferences
  - Requests for specific days-off and days-on
  - Uncertainty on unexpected absences
  - Changes between staff members
- Rescheduling in the course of the planning period

Agenda

- OpLog brief introduction
- Emergency medical services (EMSs) and the Portuguese EMS provider (INEM)
- Ambulance dispatching and relocation
- Integrated staff scheduling
- Final remarks

Conclusions and Future research





+
Real life features
Uncertainty

Integrated staff scheduling

Vermuyten H, Rosa JN, Marques I, Beliën J, Barbosa-Póvoa A (2018). Integrated staff scheduling at a medical emergency service: an optimization approach. Expert Systems with Applications 112: 62-76.

Ambulance dispatching and relocation

Carvalho AS, Captivo ME, Marques I. Integrating the ambulance dispatching and relocation problems to maximize system's preparedness. Submitted.

Ambulance location

Project 2019-2021 - DSAIPA/AI/0044/2018
Data2Help: Data Science for Optimization of Emergency Medical Services
Goal: To provide INEM with new tools to improve operational results by optimizing resource assignment, resulting in an improved and faster response to medical emergencies in Portugal.

Research teams and partners










Currently:
+ 2 MSc students

For the next 3 years:
+ 1 PostDoc
+ 2 PhD students
+ 5 MSc students

Post-Doc position announcement

- ImproveOR project

i. Developing comprehensive and innovative methods to improve operating room responsiveness to increasing surgical demand and to better coordinate surgical capacity and demand. Decision support tools are to be developed combining optimization approaches (based on multi-objective mathematical programming models, heuristics and simulation) to assist resource capacity planning decisions in the operating room, with structured participatory approaches to capture stakeholders' views and preferences regarding the surgical patient flows and the planning and scheduling of surgeries. The developed methods will be tested and validated in two central hospitals of the Portuguese National Health Service.

ii. Support in the management of the ImproveOR: Building Decision Support Tools for Improved Operating Room Management project and in the scientific supervision of masters and doctoral students associated with the different research tasks to be developed in the project.

Monthly remuneration:
2,128.34€

Duration:
3 years

Candidates with degree abroad:
Recognition of the degree by the Portuguese Directorate-General for Higher Education

To appear through:
ORAHS, APDIO, other OR societies

Better decisions for more effective emergency medical care

The case of the Portuguese Emergency Medical Service

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Bochum, Nov 22, 2018