Better decisions for more effective emergency medical care
The case of the Portuguese Emergency Medical Service

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Agenda

OpLog brief introduction

Emergency medical services (EMSs) and the Portuguese EMS provider (INEM)

Ambulance dispatching and relocation

Integrated staff scheduling

Final remarks
OpLog brief introduction

Emergency medical services (EMSs) and the Portuguese EMS provider (INEM)

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Final remarks
Short background

Maths Applied to Economics and Business

Operations Research

Statistics and Operations Research

Assistant Professor at IST

Topic: Operating Room Planning & Scheduling

BAC, Brussels

Operations Research

Statistics and Operations Research

Assistant Professor at IST

Operation Room Planning & Scheduling
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

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Miguel Vieira

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40+ Ongoing MSc Students

Bochum, Nov 22, 2018
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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

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Current international EMS systems evolved from two main models

Franco-German model
*Stay and stabilize*

- Main idea
- Main provider
- Patients treated
- Destination for transported patients

Anglo-American model
*Scoop and run*

- Main idea
- Main provider
- Patients treated
- Destination for transported patients
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?
- Should standby sites be used?
Decision-making process

**Strategic**
Long term decisions

**Tactical**
Short term decisions

**Operational**
Real time decisions

- Divide the territory into zones
- Locate ambulance bases
- Define the number of ambulances per base
- Define the number of crews per base
- Assign a task to each ambulance
- Dispatch ambulances to emergencies
- Relocate ambulances

**Most studied problems in literature**

- Location
- Fleet management
- Dispatching
- Relocation
INEM: Resources and operational results in the media (August 2018, Público)

Presidente do INEM diz que falta de técnicos não afecta socorro
27 de Agosto de 2018

Sindicato pede abertura de mais concursos para técnicos de emergência pré-hospitalar
RITA MARQUES COSTA
27 de Agosto de 2018

<table>
<thead>
<tr>
<th></th>
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<td>19 203</td>
<td>20 940</td>
<td>23 967</td>
<td>3 027</td>
</tr>
</tbody>
</table>

Daily average: 66
Some figures 2017

- Daily average: 3.748
- Number of calls: 75,843 (5.5%)
- Number of calls: 208
- Number of calls: 3,477
- Percentage: 93%

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Data2Help: Data Science for Optimization of EMSs

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

Forecast the expected demand of vehicles and workload

Dispatching and relocation
Optimization, Simulation and AI
Staff scheduling
Vehicle location
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

**Ambulance dispatching and relocation**

**Time**

1. Detection
2. Reporting
3. Response
4. On scene care
5. Care in transit
6. Transfer to hospital

**Maximum response time**

**Response time**

- **Call 112**

**Which ambulance is more appropriate to send?**

**Available ambulances**

**Where to (re)locate the ambulance?**

**Patient’s health may be in danger**

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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)
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
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
MILP model

Decision 1
Dispatching problem

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

Decision 2
Relocation problem I

Decision 3
Relocation problem II

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

\[ r_{ij} = \text{extra response time for ambulance } i \text{ to reach emergency } j \]
MILP model

System capability to handle new emergencies in the future
→ Min system response time for future emergencies

\[
\begin{align*}
\text{min} & \quad \sum_{q \in Q} \lambda_q \left( \sum_{l \in B} d_{lq} \delta_{lq}^{\text{min}} + \text{INF}^{\text{Travel time}} w_q \right) \\
& + \sum_{j \in E} P^{\text{Uncovered}} u_j \\
& + P^{\text{Response}} \sum_{i \in A} \sum_{j \in E} r_{ij} \\
& + P^{\text{Target}} \sum_{i \in A^{\text{Target}}} z_i \\
\end{align*}
\]

- Number of uncovered emergencies
- Extra response times
- Changes in target bases

Response time for current emergencies

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### MILP model

#### Uncovered emergency definition

\[ u_j = 1 - \sum_{i \in A} x_{ij}, \quad \forall j \in E \]

#### Change target definition

\[ z_i = 1 - \left( y_{ib} + \sum_{j \in E} x_{ij} \right), \quad \forall i \in (A^B \cup A^R) \]

\[ z_i = 0, \quad \forall i \in \{A^B \cup A^R\} \setminus \{ATarget\} \]

#### Maximum number of changes in target bases

\[ \sum_{i \in ATarget} z_i \leq Target^{MAX} \]

#### Each available ambulance is dispatched to an emergency or assigned to a base

\[ \sum_{j \in E} x_{ij} + \sum_{l \in B} y_{il} = 1 \quad \forall i \in A \]

\[ \sum_{i \in A} x_{ij} \leq 1, \quad \forall j \in E \]
<table>
<thead>
<tr>
<th>MILP model</th>
<th>Ambulance dispatching and relocation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum response time</strong></td>
<td>( \sigma_j + d_{ij} x_{ij} \leq R^{MAX} + r_{ij}, \forall i \in A, j \in E )</td>
</tr>
<tr>
<td><strong>Whether a base is empty of ambulances or not</strong></td>
<td>( v_l \leq \sum_{i \in A} y_{il} \leq</td>
</tr>
</tbody>
</table>
| **Minimum time to reach a sub-zone** | \( d_{lq} \delta_{lq}^{min} \leq d_{l'q} + M \text{Travel time} (1 - v_{l'}), \forall l, l' \in B, q \in Z \)  
\( \delta_{lq}^{min} \leq v_l, \forall l \in B, q \in Z \)  
\( \sum_{l \in B} \delta_{lq}^{min} + w_q = 1, \forall q \in Z \) |
| **Defines the base that reaches the sub-zone in minimum time or no ambulance at all** | |
| **Binary-domain and real-domain variables** | \( x_{ij}, y_{il}, u_{ij}, v_l, z_{l'}, w_{q}, \delta_{lq}^{min} \in \{0, 1\}, \forall i \in A, i' \in \{A^B \cup A^R\}, j \in E, l \in B, q \in Z \)  
\( r_{ij} \geq 0, \forall i \in A, j \in E \) |
Heuristic: overview

Decision 1
Dispatching problem

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

Phase 2

Decision 2
Relocation problem I

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

Decision 3
Relocation problem II

Phase 1

Decision 2
Relocation problem I

Decision 3
Relocation problem II

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Phase 1: Dispatching problem

Algorithm 1 Heuristic phase 1 - dispatching decisions

1: for all emergencies $e \in E^*$ do
2: \hspace{1em} Calculate $p^{(t+1)}(A \setminus i)$
3: \hspace{1em} Dispatch available ambulance $i'$ such that $i' = \arg\max_{i \in A} \frac{p^{(t+1)}(A \setminus i)}{1 + d_{ie}}^\alpha$
4: end for
5: \* Emergencies are analyzed by descending order of the corresponding waiting time, i.e. emergencies that occurred earlier are considered first.

$\alpha$: calibration factor that weights on preparedness (closest-policy if $\alpha = 0$)
Phase 2: Relocation problem

Algorithm 2 Heuristic phase 2 - relocation decisions

1: Define $S$ as the master solution with an undefined initial cost, $Cost_S = +\infty$
2: Define $A^{Fixed}$ as the set of available ambulances fixed in $S$, $A^{Fixed} = \emptyset$
3: while $[(A - A^{Fixed}) \neq \emptyset]$ and
4: (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
5: for $a \in (A - A^{Fixed})$ do
6: Apply pilot heuristic (Algorithm 3) to obtain $Cost_a$ by fixing $a$
7: Update master solution $S$ if $Cost_a < Cost_S$
8: end for
9: 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

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Phase 2: Relocation problem

Algorithm 3 Pilot heuristic

1: Initial ambulance: $a$
2: while there are available ambulances to analyze and
3: (number of ambulances that changed target base $\leq \text{Target}^{MAX}$ or there
are ambulances at an emergency or at a hospital to return to a base) do
4:   i) Choose base $b$ to assign ambulance $a$
5:   if ambulance $a$ is at an emergency or at a hospital then
6:     Choose between all bases $b \in B$, the one that maximizes $p_A^{(t+1)}$
7:   else
8:     Choose between maintaining the current assigned base or changing
     to the closest base, the one that maximizes $p_A^{(t+1)}$
9:   end if
10:   ii) Choose the following ambulance $a^*$ to analyze
11:     $a^*$ is the furthest available ambulance from $a$
12:     $a = a^*$
13:   iii) Update solution cost and other info
14: end while

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

Lisbon region divided into sub-zones

Number of emergencies per hour in Lisbon (2nd half of 2016)
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
# Tests: Strategies

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Relocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest (available)</td>
<td>Any base, C/HB</td>
</tr>
<tr>
<td>Preparedness</td>
<td>P/AB</td>
</tr>
</tbody>
</table>

*MIP and heuristic adapted to consider INEM policies*

**Ambulance dispatching and relocation**

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Results: preparedness

P/AB allows a better preparedness of the system.
Results: response time

Average response time

There is no consistent pattern
Results: extra time

- P/AB reduces the number of ambulances dispatched with extra time

- P/AB reduces the average extra time per ambulance
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

Ambulance dispatching and relocation

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

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Final remarks
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
Problem statement

Integrated staff scheduling

Services → Teams → People → Tasks

Skills
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
Problem statement

• 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

• 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

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Variable Neighborhood Decomposition Search (VNDS)

Constructive method

Feasible solution

VNDS

Neighborhoods for local search
1. Fix-Days
2. Fix-Shifts
3. Fix-Tasks

Neighborhood for shaking
1. Fix-People

Randomly choose neighborhood
Fix current solution
Free variables neighborhood

Shake
Solution improved within max_iter?

Update solution if improved
Find local optimum using IP solver

Start

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Results: case study at INEM

Integrated staff scheduling

Dispatch center (CODU)

Emergency Vehicles (EVs)

Lisbon region

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Results: case study at INEM

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

<table>
<thead>
<tr>
<th>Instance</th>
<th>LP relaxation</th>
<th>CPLEX IP</th>
<th>Diving B</th>
<th>VNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>INEM</td>
<td>180</td>
<td>26,442</td>
<td>1,994,304</td>
<td>98.67</td>
</tr>
<tr>
<td>INEM MD</td>
<td>572</td>
<td>50,506</td>
<td>2,255,012</td>
<td>97.76</td>
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<tr>
<td>INEM MP</td>
<td>272</td>
<td>39,218</td>
<td>2,821,106</td>
<td>98.53</td>
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<tr>
<td>INEM LS</td>
<td>372</td>
<td>41,386</td>
<td>3,698,754</td>
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<tr>
<td>INEM HS</td>
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<td>25,128</td>
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<td>Test15</td>
<td>659</td>
<td>10,944</td>
<td>2,581,719</td>
<td>99.58</td>
</tr>
</tbody>
</table>

**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
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Final remarks
Conclusions and Future research

Real life features

Uncertainty
Integrated staff scheduling


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.

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Research teams and partners

Currently:
+ 2 MSc students

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

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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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