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Optimization of surgery allocation to operating rooms in a post-pandemic context

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Part 1 - Project Introduction

1. Context of the Application Domain

Currently, the world, is going through the COVID-19 pandemic, which has resulted in many services being reduced to a minimum. Surgeries are included in this group, having most of them been postponed, except in urgent cases. The pandemic is starting to slow down and each country is getting ready to slowly go back to normal. But when we do go back to normal, the surgeries that were postponed during the pandemic need to be rescheduled, which results in a very high volume of surgeries that need scheduling. To reduce casualties to a minimum, it is critical to properly allocate a hospital's resources such as operating blocks to surgeries, minimizing the surgeries' waiting time.

In this context, a hospital has rooms designed specifically for the purpose of performing specific surgeries. Taking into consideration that there are more urgent cases in some medical specialties than in others, in this critical time, there might be a need to allocate operating blocks from a given specialty to another. In many cases, this allocation will have an associated adaptation cost, since operating rooms need to be adapted to other types of surgeries.

In addition, given the high volume of surgeries, the possibility of transferring some cases from one hospital to another needs to be considered. In this case, there is also an associated transferring cost.

With this simulation project, we will test different heuristics to schedule surgeries, allocating them to operating rooms of different medical specialties and even different hospitals, in a post-pandemic situation where there is a high volume of surgeries to be scheduled. We will consider the different levels of urgency that can be associated to a surgery.

Each surgery is conducted by a head surgeon. In a real life scenario, there is also a medical team composed of anaesthetists, other surgeons and nurses, however, for simplicity purposes, we will assume in our system that all this staff doesn't need to be allocated specifically to a surgery. There will always be enough staff available during the operating rooms' hours.

2. Problem Statement

The return to normality after a pandemic, which has temporarily shut down services such as surgeries, is characterized by a high volume of surgeries that need to be scheduled. Since some surgeries were postponed for 1 month or more, they might have become more urgent than when they were first recommended, which means that a big part of the surgeries is urgent. As such, it is critical to optimize the allocation of resources to these surgeries and the respective scheduling, with the goal of minimizing waiting time.

As such, methods such as the allocation of operating rooms across different medical specialties and even different hospitals should be studied.

3. Motivation to Tackle the Problem

The COVID-19 pandemic has been a real challenge for society. The process of going back to normal is reassuring, but scary since many things can go wrong if the population is not careful. One of these things includes the scheduling of surgeries.

If this process is not carefully considered, there might be casualties that could be avoided. In this context, we want to provide a mechanism to test what are the best procedures to apply to surgeries scheduling and respective resource allocation that will allow minimizing waiting time and casualties.

4. Research/Simulation Questions & Hypothesis

- Which is the best scheduling procedure, with the goal of minimizing waiting time?
- Does an increase in operating rooms help hospitals increase their capacity to respond to patients' surgery needs in a desirable time frame? What about an increase in surgeons?

5. Expected Contributions

Our project should contribute to:

- Society, by optimizing the surgery scheduling process which results in a reduction in waiting time which is critical in the context of post-pandemic.
- Hospitals, by optimizing resource allocation.

6. Aim and Goals of the Project

With the stated problems in mind, we devised this simulation project with the purpose of optimizing the allocation of surgeries to operating rooms and with the more specific goal of minimizing waiting time for surgery.

Part 2 - Problem Formalization

7. VARIABLES AND RESPECTIVE DOMAINS

The **system** will have the following overall variables:

- Number of hospitals.
- Number of operating blocks of each specialty per hospital.
- Number of surgeons of each specialty in each hospital.

Each **surgery** will contain the following variables:

- Urgency Degree: integer between 1 and 4, where the higher the number, the more urgent the surgery.
- Duration: in minutes.
- Medical specialty: string representing the name of the specialty.
- Head Surgeon: string representing the name of the surgeon.
- Operating room, which will be allocated during the execution of the simulation system.

Each **operating room** will contain the following variables:

- Identifier: unique string.
- Operating hours per day: integer.
- Medical Specialty: string representing the name of the specialty.
- Schedule: bidimensional array, where each row represents a day and inside each day, there are the surgeries scheduled for the day.
- Hospital: string with the unique identifier of the hospital.

Each **surgeon** will contain the following variables:

- Name: unique string.
- Medical Specialty: string representing the name of the specialty.
- Schedule: bidimensional array, where each row represents a day and inside each day, there are the surgeries scheduled for the day.
- Hospital: string with the unique identifier of the hospital.

Each **hospital** will contain the following variables:

- Identifier: unique string.
- Type: public or private.
- Coordinates: pair of integers that denote the hospital's position.

8. ASSUMPTIONS AND PREMISES

- The surgeries to be scheduled are known a priori.
- Other than the head surgeon, all the medical staff needed for surgery does not need to be allocated specifically to a surgery, there is always enough staff available during the operating rooms' hours.
- There are always enough beds in the hospital for the patients to stay after the surgeries.
- The cost of adapting an operating room of a specialty for another specialty only happens once in a day. If there are two surgeries of the same specialty on the same day in the operating room, the operating room does not need to be adapted for the second one.
- The cost of transferring a surgery to a private hospital is bigger than to a public hospital.
- The cost of transferring a surgery between hospitals depends on the Euclidean distance between these.

9. CONSTRAINTS AND LIMITS

- The allocation of medical staff other than the head surgeon is not considered.

10. COST/UTILITY FUNCTIONS

The **Average Waiting Time**, expressed in days, has the following formula:

$$\boldsymbol{Average\ Waiting\ Time} = \sum_{p=1}^{n} \frac{\boldsymbol{Waiting\ Time_p}}{\boldsymbol{n}}$$

Where:

- ***n*** is the total number of patients in the system.
- ***Waiting Time*** is the number of days, between the patient p's surgery scheduling and the actual surgery.

The **Occupation Rate** of an operating room, in percentage, is obtained according to the following formula:

$$\boldsymbol{Occupation\ Rate} = \frac{\boldsymbol{Time\ Allocated}}{\boldsymbol{Total\ Time}}$$

Where:

- ***Time Allocated*** is the total of time, in seconds, that an operating room has been occupied with a surgery since the beginning until the last surgery scheduled.
- ***Total Time*** is the total of time, in second since the beginning until the last surgery scheduled.

The **Transference Cost**, expressed as a float number, has the following formula:

$$\boldsymbol{Transference\ Cost} = \boldsymbol{Distance} + \boldsymbol{Private} * \boldsymbol{10}$$

Where:

- **Private** is 1 if the hospital to which the surgery is being transferred is private and 0 if it's public.
- **Distance** refers to the Euclidean distance, calculated based on the coordinates of each hospital, with the following formula:

$$\boldsymbol{Distance} = \sqrt{(\boldsymbol{x1} - \boldsymbol{x2})^2 + (\boldsymbol{y1} - \boldsymbol{y2})^2}$$

Part 3 - Methodological Approach

11. SYSTEM MODEL

11.1. *Modelling metaphor*

NetLogo is a multi-agent programmable modelling environment (ABMS).

11.2. *Input variables*

- Surgeries to be scheduled.
- Existing operating blocks.
- Existing hospitals.
- Existing surgeons.
- Operating policies to be applied.

11.3. *Output variables*

- Schedule of each operating room (surgeries taking place and respective starting time).
- Occupation Rate.
- Average Waiting Time.
- Number of days between the first day in the system and the day of the last surgery schedule (Maximum waiting time).
- Total Transference Cost.
- Total Adaptation Cost.

11.4. *Metrics and Performance measures*

- Average Waiting Time.
- Occupation Rate.
- Maximum Waiting Time.
- Total Transference Cost
- Total Adaptation Cost

11.5. *Indicators*

SNS (Sistema Nacional de Saúde) defines the maximum number of days that a surgery can wait, according to its priority level and medical specialty. For instance, for vascular surgeries, the maximum waiting time is [1]:

- **Level 1 -** 90 days.
- **Level 2 -** 45 days.
- **Level 3 -** 15 days.

11.6. *Decision variables*

- Average Waiting Time.
- Occupation Rate.
- Maximum Waiting Time.

11.7. *Operating policies*

First, all the surgeries are ordered by urgency. Urgent surgeries are the first ones to be allocated. The scheduling occurs according to the following operating policies:

- **Allocation according to specialty:** Each surgery is allocated to an operating room of the same medical specialty as the surgery.
- **Allocation across specialties:** The surgeries will be allocated to the earliest time blocks available, in operating rooms independently of their medical specialty. Surgeries allocated to operating rooms of different specialty will have an associated adaptation cost.
- **Allocation with cooperation between hospitals:** The most urgent surgeries will be allocated to the earliest time blocks in operating rooms of the same medical specialty as the surgery. If there are hospitals with available operating rooms and surgeons where the surgery can happen earlier, the surgery can be transferred with an associated transference cost.
- **Allocation with cooperation between hospitals and across specialties:** The most urgent surgeries will be allocated to the earliest time blocks in operating rooms of any medical specialty as the surgery. If there are hospitals with available operating rooms and surgeons where the surgery can happen earlier, the surgery can be transferred with an associated transference cost.

All the surgeries are known a priori. The system will analyse every existing surgery and apply the operating policies to calculate the respective schedule.

11.8. *States of the system*

- **Stopped -** Waiting for input variables.
- **Running -** Calculating surgeries' schedules.
- **End -** After the last surgery is scheduled.

11.9. *Entities of the system*

Hospitals:

- **Role:** Hospitals own operating rooms where the surgeries are allocated.
- **Attributes:**
  - Identifier (string).
  - Coordinates (pair of integers).

Operating rooms:

- **Role:** Operating rooms are allocated to surgeries.
- **Attributes:**
  - Identifier (string).
  - Number of hours per day, during which the operating rooms are available to have surgeries (integer).
  - Medical specialty (string).
  - Schedule (bidimensional array, where each row is a day that contains the surgeries that will occur).
  - Hospital to which it belongs to (string).

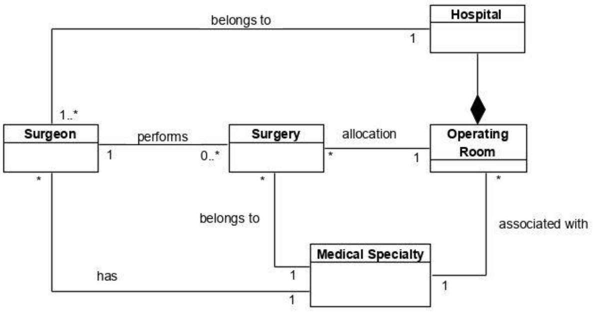
Surgeons:

- **Role:** Surgeons perform surgeries.
- **Attributes:**
  - Name (string).
  - Medical Specialty (string).
  - Schedule (bidimensional array, where each row is a day that contains the surgeries that will occur).
  - Hospital to which it belongs to (string).

Surgeries:

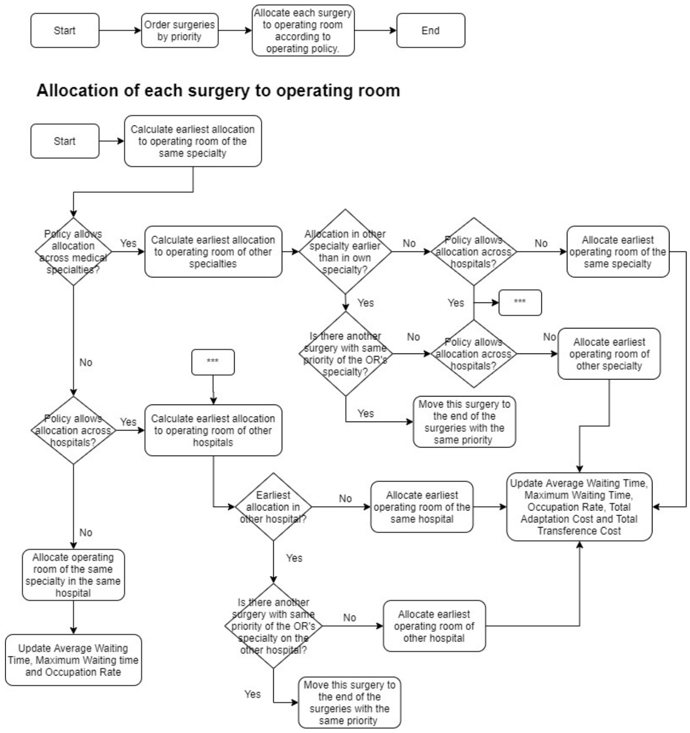
- **Role:** Surgeries are scheduled in a certain time block and operating room.
- **Attributes:**
  - Duration (in minutes).
  - Urgency Degree (integer from 1 to 4).
  - Medical Specialty (string).
  - Head surgeon (string).
  - Operating Room to which it's allocated (string, to be calculated during the execution of the system).
  - Day in which the surgery is scheduled (integer, to be calculated during the execution of the system).
  - Starting time of the surgery (integer, to be calculated during the execution of the system).

12. Conceptual Model



For more detailed version, please consult the **section 20.1** in the annex.

13. Logical Model



For more detailed version, please consult the **section 20.2** in the annex.

14. Coding

The programming language we will use is **Netlogo**.

15. Data requirements (input)

15.1. Data sources

- Records from **ERS** (Entidade Reguladora da Saúde) [1].
- People personal experience obtained from a questionnaire.

15.2. Data collection methods

- We sent a questionnaire to FEUP's community to check what would be an acceptable waiting time for surgery and how long people have had to wait for surgeries.
- Records from **ERS** (Entidade Reguladora da Saúde) [1].

16. Data requirements (output)

16.1. Data analytics

We will analyse the following variables:

- Average Waiting Time.
- Occupation Rate of Operating Rooms.
- Maximum Waiting Time.
- Total Transference Cost

- Total Adaptation Cost

We collected data by sending a questionnaire to FEUP's community, to understand what an acceptable waiting time for a surgery is. On top of this, we will also compare our results with data collected from ERS (Entidade Reguladora da Saúde), that indicates what are the established maximum waiting times and as well as the real waiting times in a normal situation. This data will be used to see if there is a solution that allows to comply with the established maximum waiting times even in a situation of rupture.

Most of our conclusions will come from the comparison of the results between the simulation with different scenarios, because this situation hasn't been very studied and there isn't a lot of data regarding mass surgeries in a post-pandemic context.

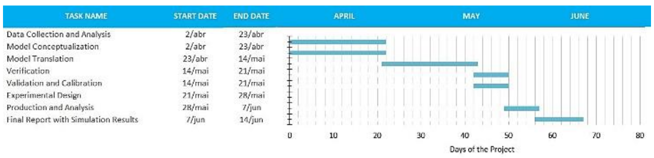
16.2. *Data visualisation techniques*

- Charts to display how each of the variables above behave with different inputs.

17. SIMULATION SCENARIOS

17.1. *Reference scenarios*

The scenarios tested will differ according to the operating policies chosen to run the system. These are specified in the operating policies' topic.



17.2. *What-if scenarios*

- What happens to the average waiting time if the number of surgeons / operating rooms increase/decrease?

17.3. *Simulation plan*

We will calibrate the system with various hospitals with an initial amount of operating rooms per specialties representative of real hospitals. We will also create a data set of surgeries to be used in the system. With this, we will test the different operating policies used to decide the surgeries' schedules and find out what the most desirable one is.

Then, to see how changes in the initial values of the system affect the final results, the system will be run with different numbers of operating rooms and patients. We will test the system many times:

- Increasing the number of operating rooms and maintaining the remaining variables, to check if an increase in operating rooms makes the system more capable of handling big amounts of patients while minimizing average time.
- Increasing the number of patients and maintaining the remaining variables, to check from which point does the system stop being able to schedule surgeries while respecting the boundaries on maximum waiting time defined in the SNS.

18. WORK PLAN

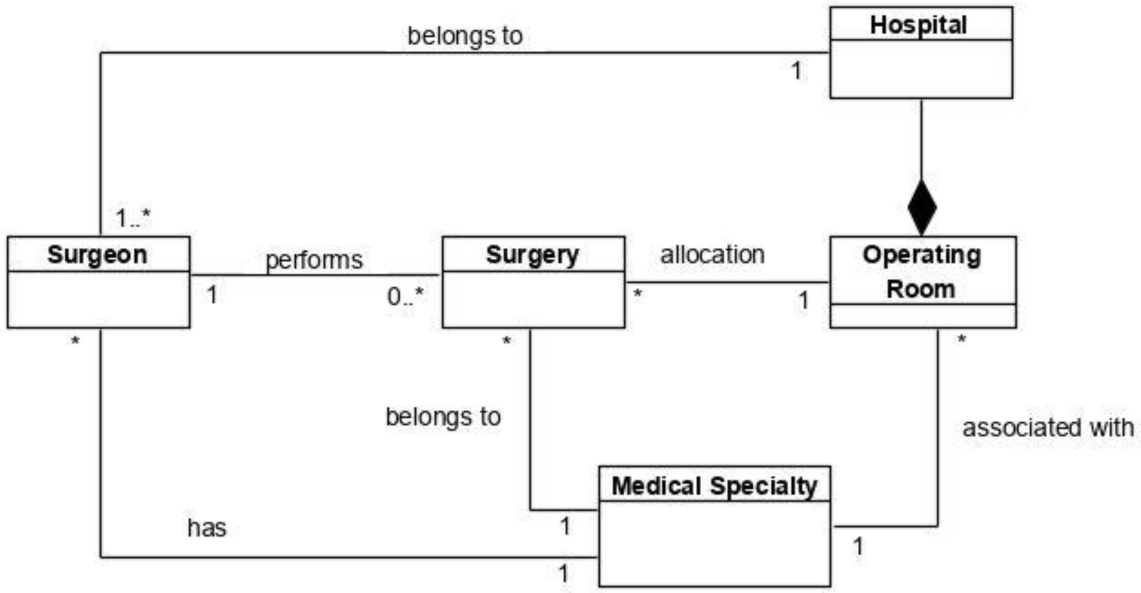
For more detailed version, please consult the **section 20.3** in the annex.

19. REFERENCES

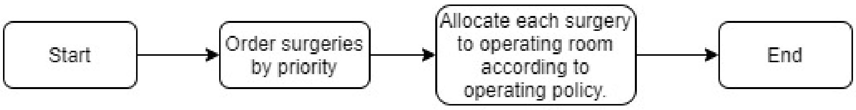
[1]
https://www.ers.pt/uploads/writer_file/document/2518/ERS_-_Tempos_de_espera_Mai.2019__publicar_.pdf

20. ANNEXES

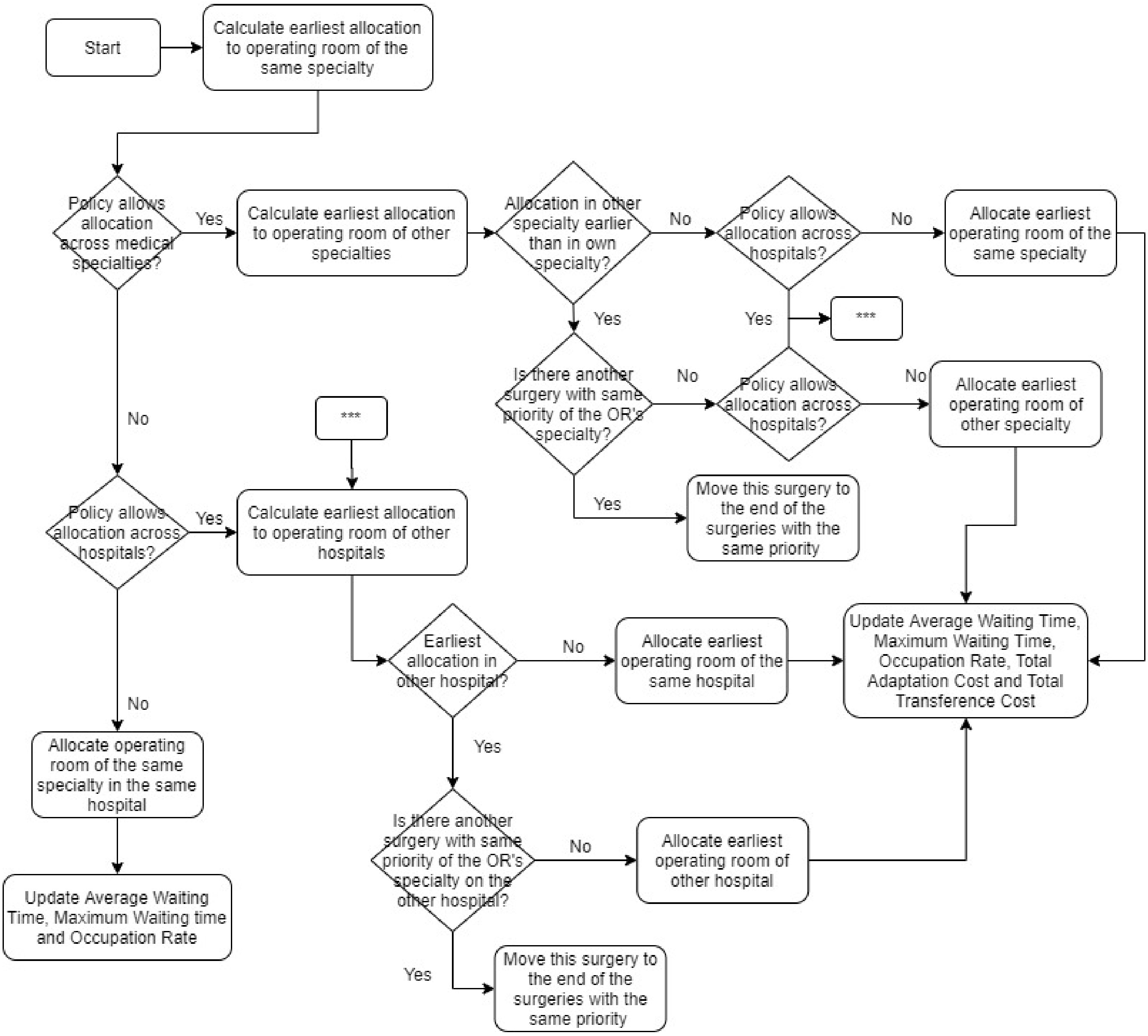
20.1. Conceptual Model



20.2. Logical Model



Allocation of each surgery to operating room



20.3. Work Plan

TASK NAME	START DATE	END DATE
Data Collection and Analysis	2/abr	23/abr
Model Conceptualization	2/abr	23/abr
Model Translation	23/abr	14/mai
Verification	14/mai	21/mai
Validation and Calibration	14/mai	21/mai
Experimental Design	21/mai	28/mai
Production and Analysis	28/mai	7/jun
Final Report with Simulation Results	7/jun	14/jun