Università degli Studi di Milano – Dipartimento di Informatica

Health care system

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Course “Simulation” – Exam Project, A.Y. 2023-2024

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Introduction

Introduction

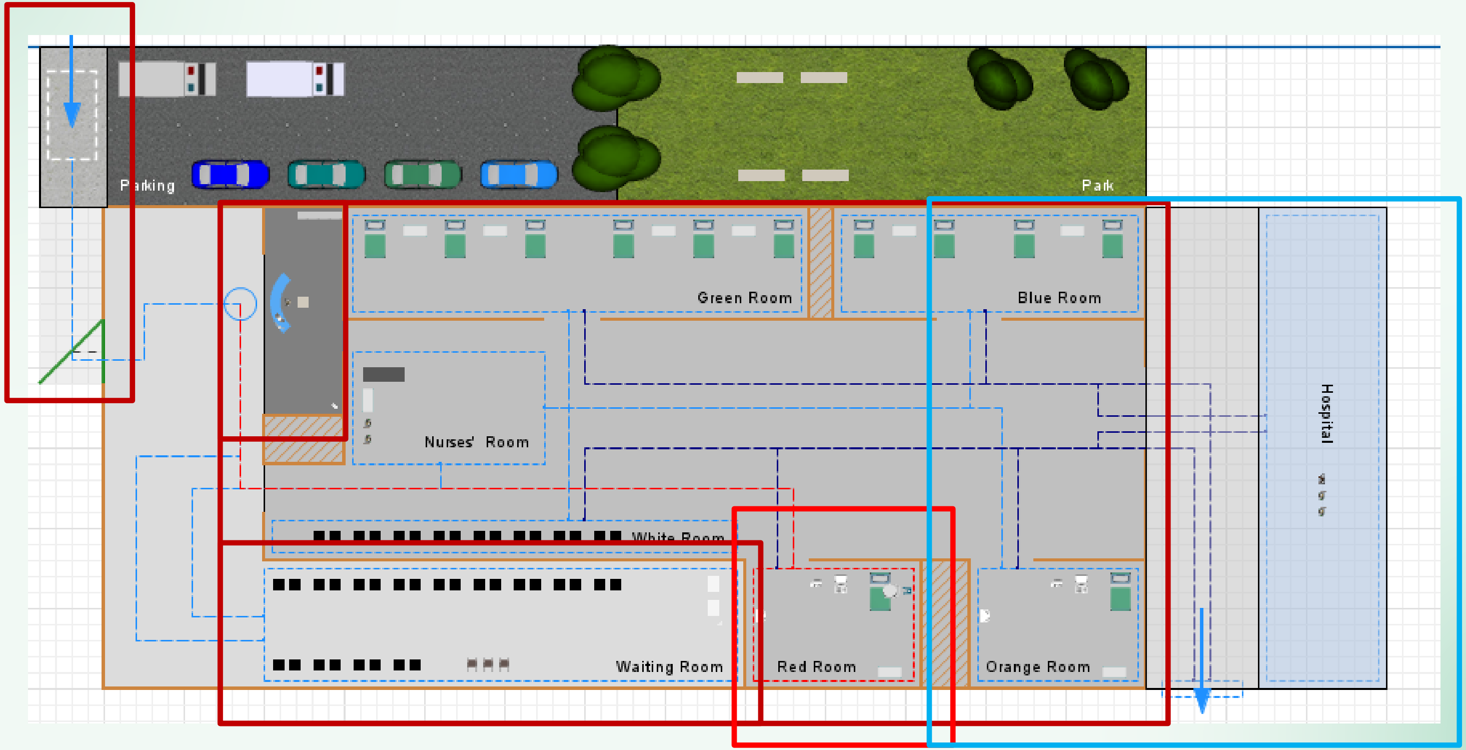
This project focuses on analysing the **flow and management of patients in a hospital emergency room,** addressing key aspects such as

- patient influx,
- queue management,
- resource allocation (nurses and operating rooms),
- waiting times.

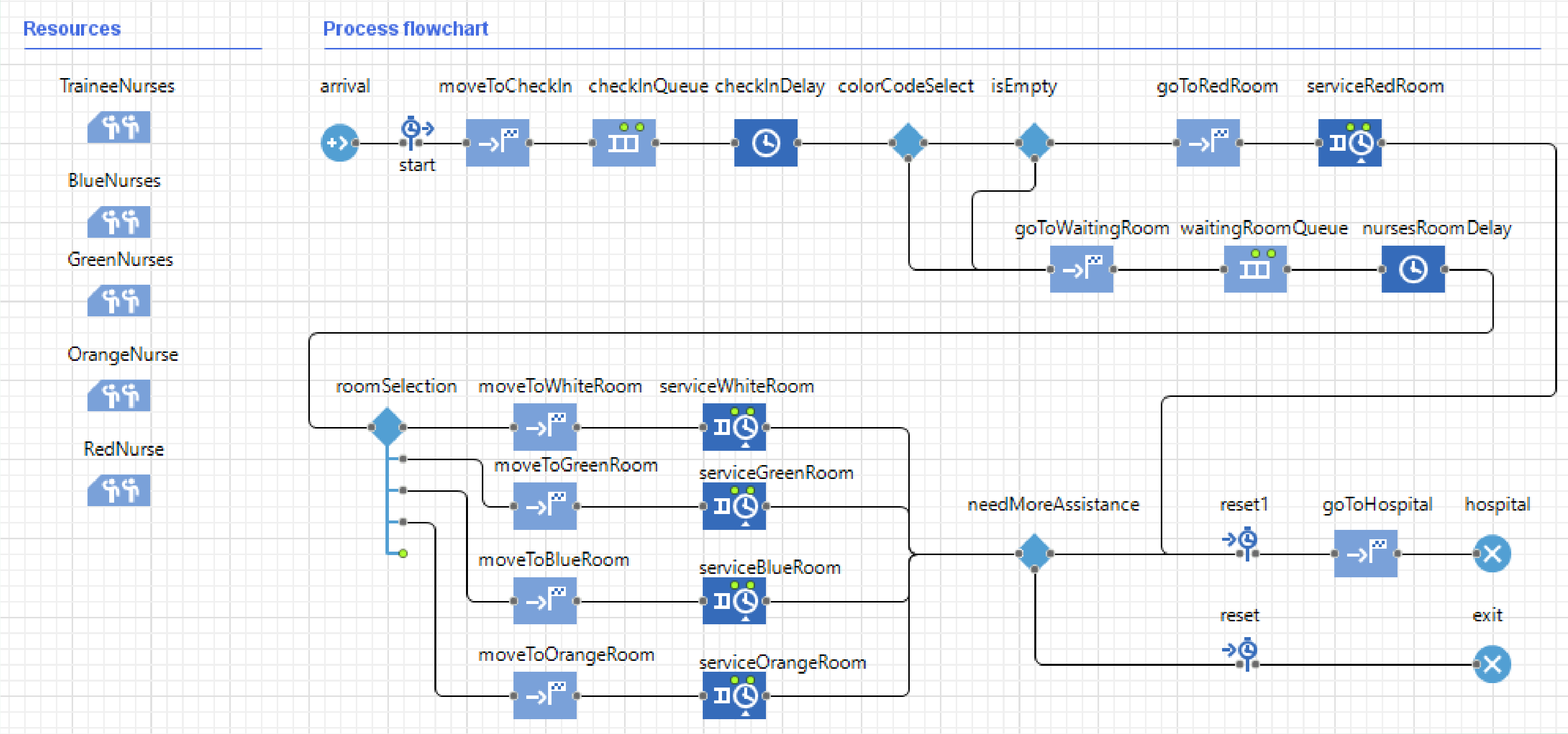
Using **AnyLogic** simulation software, it replicates **the daily operations** of the San Donato Milanese hospital's emergency room over a 24-hour period. The goal is to gain insights into the emergency room's functioning and explore improvements to reduce waiting times and optimize resource allocation, enhancing overall healthcare efficiency.

For this scenario, it was chosen to use a **discrete event-based** and **agent-based simulation** model, which has time basis in minutes.

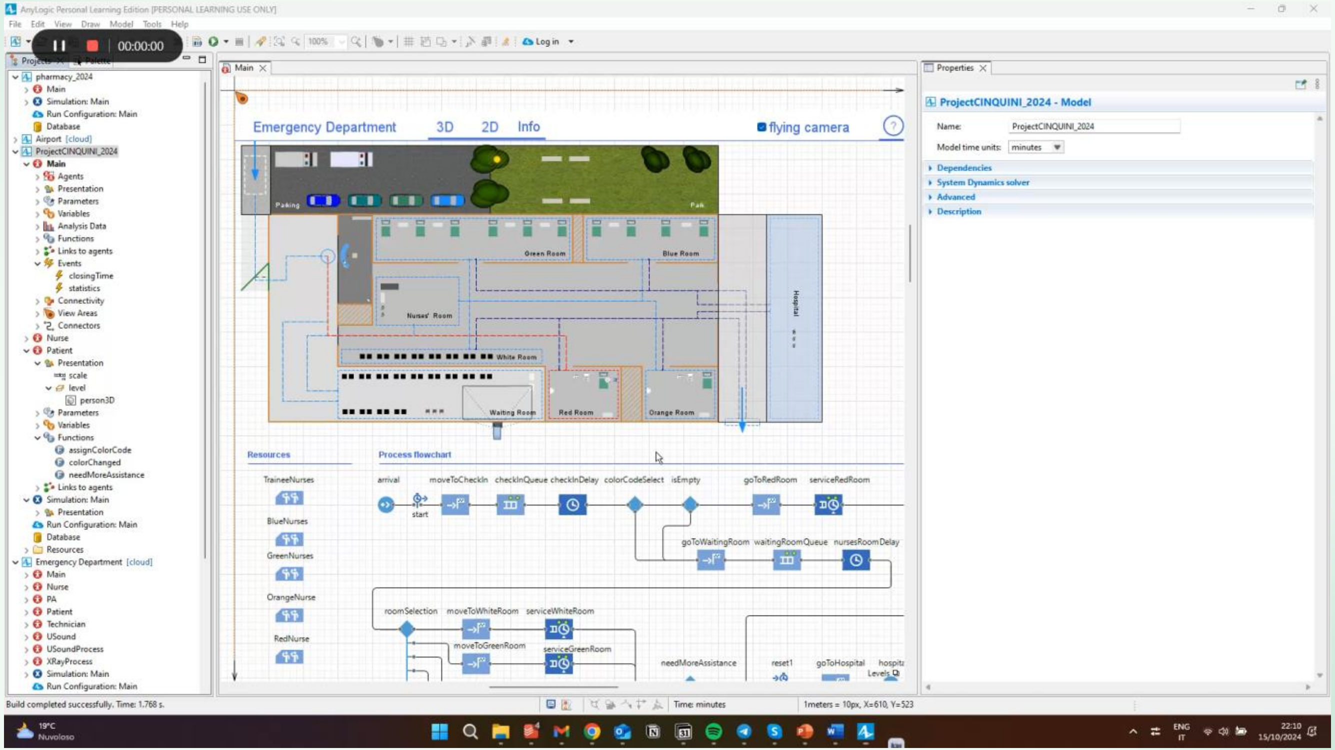
WORKING FLOW



WORKING FLOW



working flow



2

AGENTS

Types of Agents

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Agents
This agent-based approach allows for a flexible, realistic simulation of the emergency department, where individual behaviours, and stochastic events combine to influence the system's performance.

- Patient
- Nurse

Types of Agents - Patient

The emergency room of the San Donato Polyclinic in San Donato Milanese manages an average of between **65 and 80 patients per day**, so it was chosen to use the value **70** as the starting value for the population.

Each patient has this properties:

Arrival Time	In minutes
Base Priority	According to the color code
Dynamic Priority	To determine the waiting queue
Color Code	Represents the patient's level of urgency
Rate of Increment	To calculate the patient's priority

3 Implementation

Working Flow

Color Codes Assignment

Code that uses probability to assign colour codes to patients.

The uniform(0, 1) function generates a random number with uniform distribution over [0,1], meaning that each value in that bin has an equal chance of being generated.

The code uses a simple form of cumulative distribution, where the sum of the probability bins covers the entire interval [0,1].

```
double random = uniform(0, 1);
if (random <= 0.1) {
    person3D.setColor("Material__5__Surf", red);
    color_code = 0;
    // Red (probabiloty: 10%)
} else if (random <= 0.3) {
    person3D.setColor("Material__5__Surf", orange);
    color_code = 1;
    // Orange (probabiloty: 30%)
} else if (random <= 0.6) {
    person3D.setColor("Material__5__Surf", blue);
    color_code = 2;
    // Blue (probabiloty: 60%)
} else if (random <= 0.9) {
    person3D.setColor("Material__5__Surf", green);
    color_code = 3;
    // Green (probabiloty: 90%)
} else {
    person3D.setColor("Material__5__Surf", white);
    color_code = 4;
    // Red (probabiloty: 10%)
}
trace("\nColor Code:");
trace(color_code);
```

Working Flow

Dynamic Algorithm for Priority

A **priority algorithm** is used to manage the queue, such that depending on the colour code and the waiting time, the patient will be assigned a priority value.

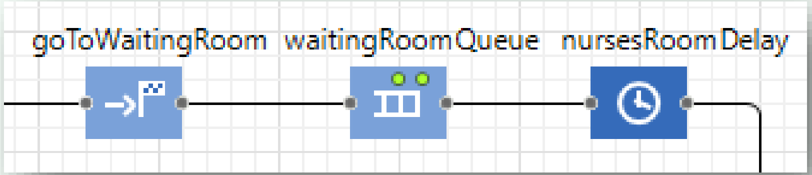
The idea is to assign each patient a priority score that changes over time, increasing as the waiting time increases. In this way, <u>even less severe patients will be treated sooner or later, as their score will increase enough to surpass them on the list</u>.

```
double waitingTime = (now - p.arrival_time) / 60.0;

double basePriority = p.base_priority;
double timeIncrement = p.rate_increment * waitingTime;

return basePriority + timeIncrement;
```

WORKING FLOW - ROOMS

When the patient is called, he will move **from the waiting room to the desk where the nurses are present**, who will indicate the correct room in which he will be placed.
In the emergency room there are 5 different rooms, one for each colour code. The capacity depends on the availability of resources in the Emergency Room, in our case:

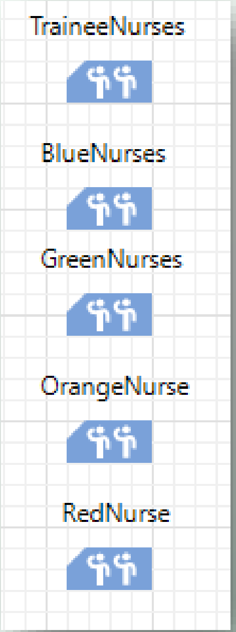
- The red room has a maximum capacity of 1 patient.
- The orange room has a maximum capacity of 1 patient.
- The blue room has a maximum capacity of 4 patients.
- The green room has a maximum capacity of 6 patients.
- The white room has a maximum capacity of 15 patients.



Working Flow - Resources

Each room is associated with several nurses who will dedicate themselves to the patients present. Since the codes with higher priority need prompt assistance, it was decided to divide the team as follows:

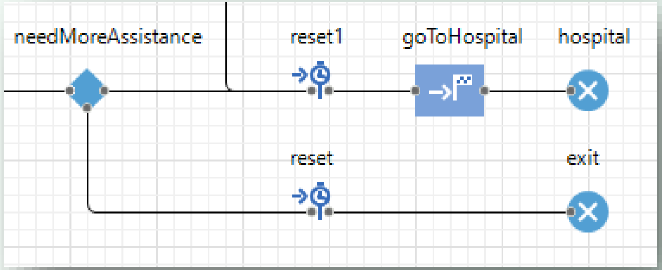
- For orange and red codes, for which the operating room can be occupied by one patient at a time, one nurse is assigned per ward respectively; this allows treatments to be speeded up.
- For blue codes, there can be a variable number of nurses ranging from 1 to 4.
- For green codes, it was decided to assign a maximum of 3 nurses.
- For white codes, the maximum number of residents is 2.



WORKING FLOW - HOSPITAL

NEEDING MORE ASSISTANCE

After, it must be understood whether the problem has been managed or whether it is necessary to keep the patient for longer. Generally, those who hold a code equal to green or white, will end their stay in the emergency room and will be able to go to the exit. If patients have more urgent conditions a further examination will have to be performed to determine whether it is necessary to move them to the appropriate hospital



WORKING FLOW - HOSPITAL

NEEDING MORE ASSISTANCE

The code assigns different probabilities for a patient's condition to worsen based on their colour code. The probabilities set are as follows:

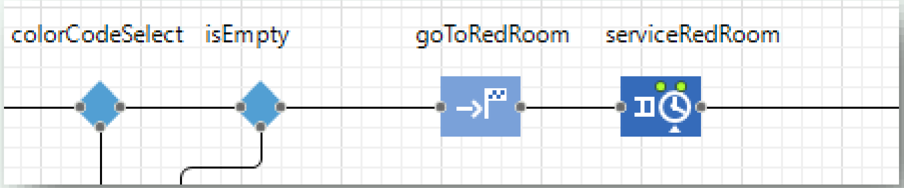
- Orange code (1): 70% chance of worsening.
- Light blue code (2): 30% chance of worsening.
- Green code (3): 5% chance of worsening.
- White code (4): 0% chance (so never worsens).

This approach reflects the idea that more severe patients have a higher chance of worsening, while less severe patients have a much lower chance, or none. A **conditional probabilistic approach** was used.

```
double probability = 0;

if (color_code == 1) {  // orange
    probability = 0.7;  // 70% prob of getting worst
} else if (color_code == 2) {  // blue
    probability = 0.3;  // 30%
} else if (color_code == 3) {  // green
    probability = 0.05;  // 5%
} else if (color_code == 4) {  // white
    probability = 0;
}

boolean result =  randomTrue(probability);
if(result == true){
    moreAssistance = 1;
} else {
    moreAssistance = 0;
}

trace("\nMora assistance? ");
trace(result);

return result;
```

Working flow - Red code

The case in which the patient is a code is treated differently: upon arrival at the reception desk, he will have the highest priority and **will be immediately moved to the correct department.**



If it is occupied, an attempt will be made to move the patient to the operating room used for patients with orange colour code.

For this reason, a function was created that controls the capacity of the room, in case there is a patient present, the procedure is as follows:

1. the patient is moved to the waiting room but always keeping the highest property so as to allow him to be the first in the list;
2. the patient's colour is changed to allow him to go to the orange room.

WORKING CODE

RED CODE

The first code reports the control if the red room is occupied: not having a specific queue for the management of red codes (given their urgency) in case the room was previously occupied, an error was obtained in the system. In this way the error is avoided.

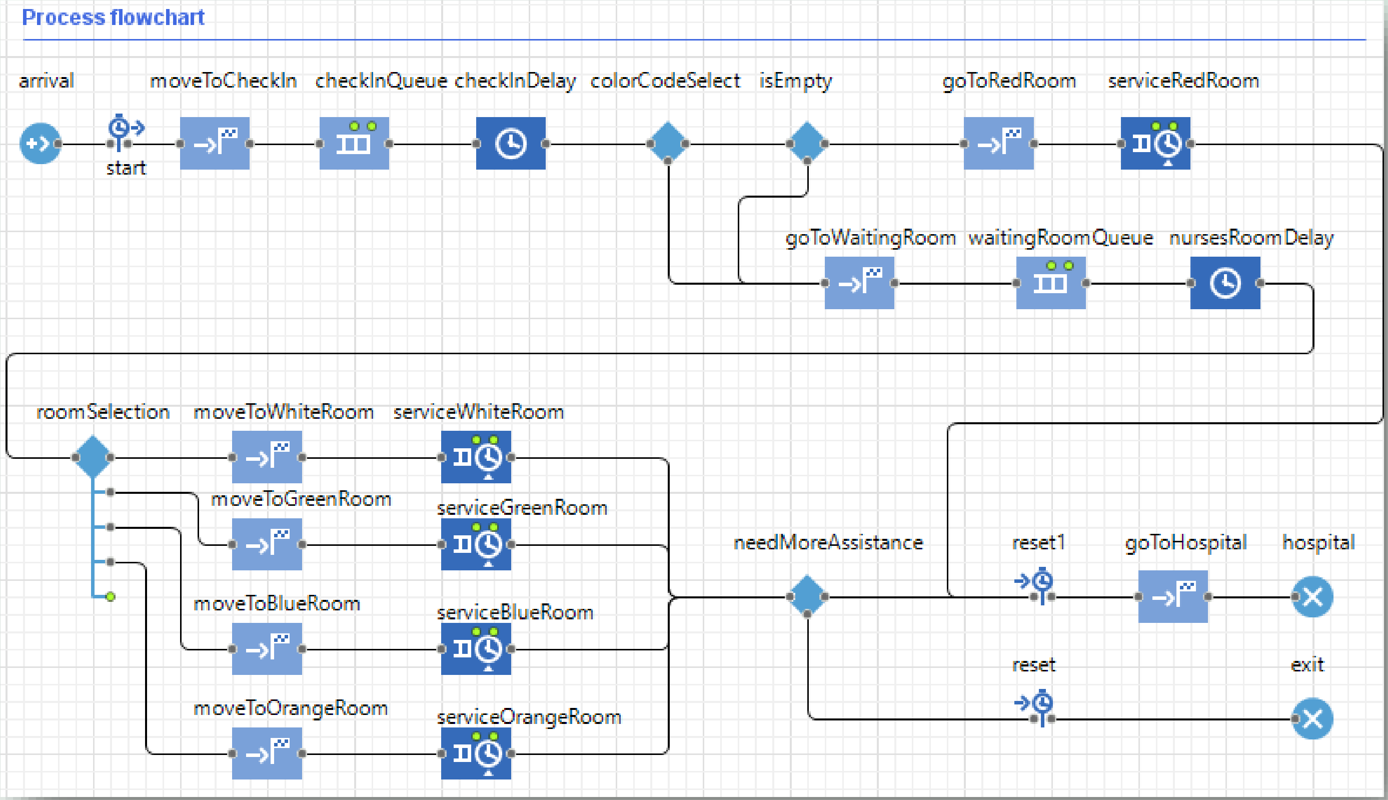
As previously mentioned, however, it is necessary to change the patient's colour code while maintaining the same (high) priority.

```
if(goToRedRoom.size() <= serviceRedRoom.queueCapacity){
    return true;
}
return false;
```

On exit (false):

```
agent.color_code = 1;
```

4 FLOWCHART

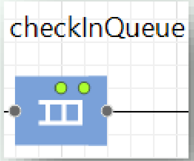


Process flowchart
arrival
start
moveToCheckIn
checkInQueue
checkInDelay
colorCodeSelect
isEmpty
goToRedRoom
serviceRedRoom
goToWaitingRoom
waitingRoomQueue
nursesRoomDelay
roomSelection
moveToWhiteRoom
serviceWhiteRoom
moveToGreenRoom
serviceGreenRoom
moveToBlueRoom
serviceBlueRoom
moveToOrangeRoom
serviceOrangeRoom
needMoreAssistance
reset1
goToHospital
hospital
reset
exit

FLOWCHART

ARRIVAL

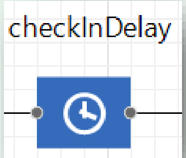
It’s introduced to represent incoming patients in the emergency room. Since patient arrivals are unpredictable, they follow an **exponential distribution.**



QUEUE, CHECK IN

Patients in the queue for admission are placed in a queue following **FIFO** logic. The reason why the logic of colour codes is not followed is that in real hospitals, there must be an initial feedback from the nurse to observe if the urgency is real.

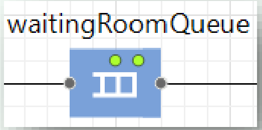
Flowchart



Delay

This delay is intended to simulate admission to the emergency room. As often happens, you have to wait for a certain time, which is why you represent the wait through a **triangular variable time distribution** .

Each patient is randomly assigned a **colour code** based on a probability distribution: red (10%), orange (20%), blue (30%), green (40%), or white (default).



Waiting room

To determine the <u>**maximum capacity**</u>, we considered some factors:

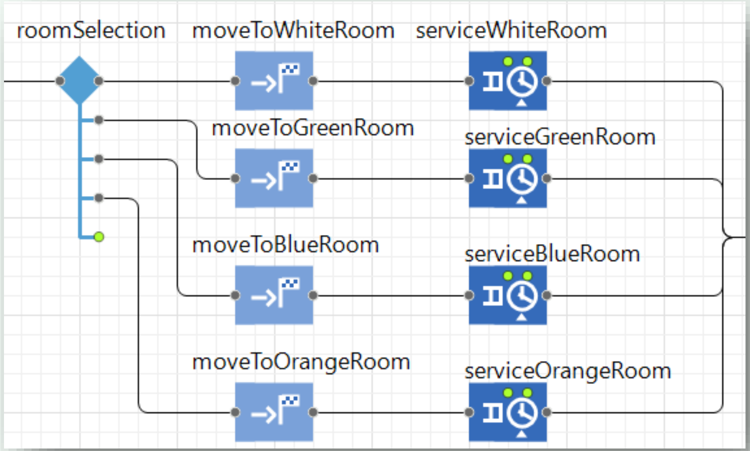
- The number of patients who can be treated in nursing rooms
- The average treatment time
- The Ability of Nurses to Manage Patients

Considering possible subsequent delays, we used a queue with a capacity of **30.**

As we said, we use a <u>**dynamic algorithm**</u> to manage the queue

FLOWCHART

service ROOM



Temporal distributions (triangular) were also used for patient management to simulate treatment time.

Waiting times differ according to the complexity of the operation and treatment, and according to the patient’s colour code. Therefore, longer waiting times for higher colour codes may be observed.

5 EXPERIMENTS

Python Notebook

KPS & KPI

KPS	KPI
Room Capacity	Average Wait Time
Number of Nurses	% of Patients Trated within an acceptable time
Distribution of Arrivals	Resource Utilization
Priority Management Algorithm	Number of Untreated Patients

In this section we report the **Key Parameter of the System** and the **Key Performance Indicator.**

It affects waiting time.

KPS & KPI

KPS	KPI
Room Capacity	Average Wait Time
Number of Nurses	% of Patients Trated within an acceptable time
Distribution of Arrivals	Resource Utilization
Priority Management Algorithm	Number of Untreated Patients

In this section we report the **Key Parameter of the Systemb** and the **Key Performance Indicator.**

It determines how quickly the patients are treated.

KPS & KPI

KPS	KPI
Room Capacity	Average Wait Time
Number of Nurses	% of Patients Trated within an acceptable time
Distribution of Arrivals	Resource Utilization
Priority Management Algorithm	Number of Untreated Patients

In this section we report the **Key Parameter of the Systemb** and the **Key Performance Indicator.**

An exponential distribution can simulate the variability of arrivals throughout the day.

The exponential distribution was chosen for these reasons:

1. **Poisson processes**, allows to have a good approximation of random and independent events, allows to represent the time interval between two consecutive events
2. **Memory less property**, patient arrivals do not depend on previous patients

KPS & KPI

KPS	KPI
Room Capacity	Average Wait Time
Number of Nurses	% of Patients Trated within an acceptable time
Distribution of Arrivals	Resource Utilization
Priority Management Algorithm	Number of Untreated Patients

In this section we report the **Key Parameter of the Systemb** and the **Key Performance Indicator.**

It balances patient severity with wait time.

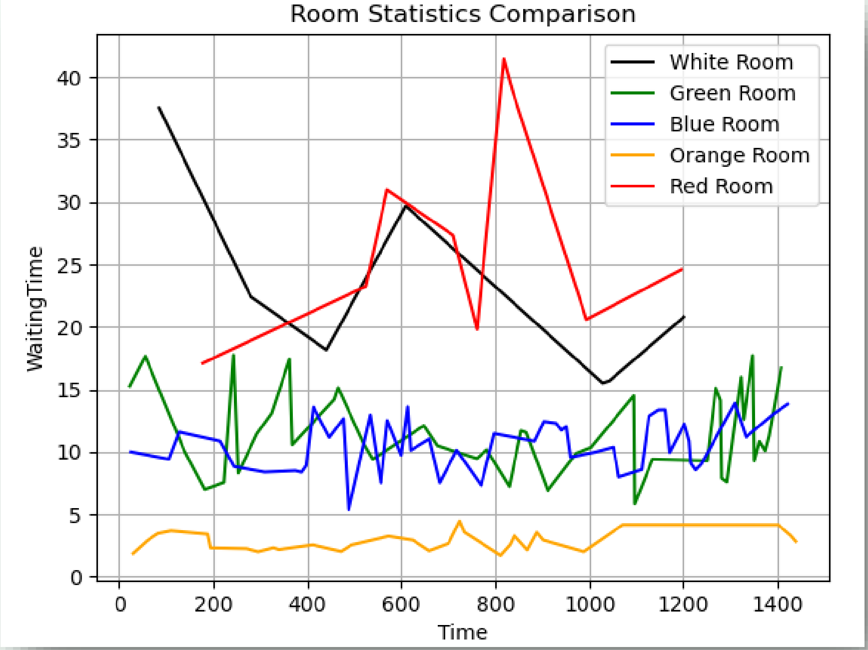
KPS & KPI

KPS	KPI
Room Capacity	Average Wait Time
Number of Nurses	% of Patients Trated within an acceptable time
Distribution of Arrivals	Resource Utilization
Priority Management Algorithm	Number of Untreated Patients

In this section we report the **Key Parameter of the Systemb** and the **Key Performance Indicator.**

This KPI is crucial for evaluating the efficiency of the system.

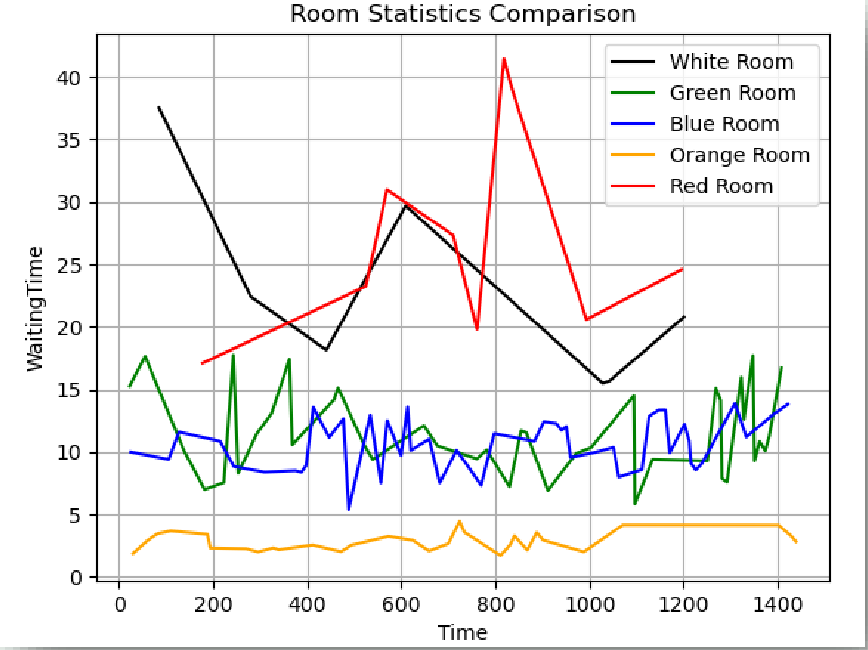
STATISTICS



ROOMS' COMPARISON

The **White room** shows a decreasing trend (in the first section) and then has variable peaks. Therefore, during the simulation of 09/10, an increase in demand was visible in the second half of the simulation period.

STATISTICS

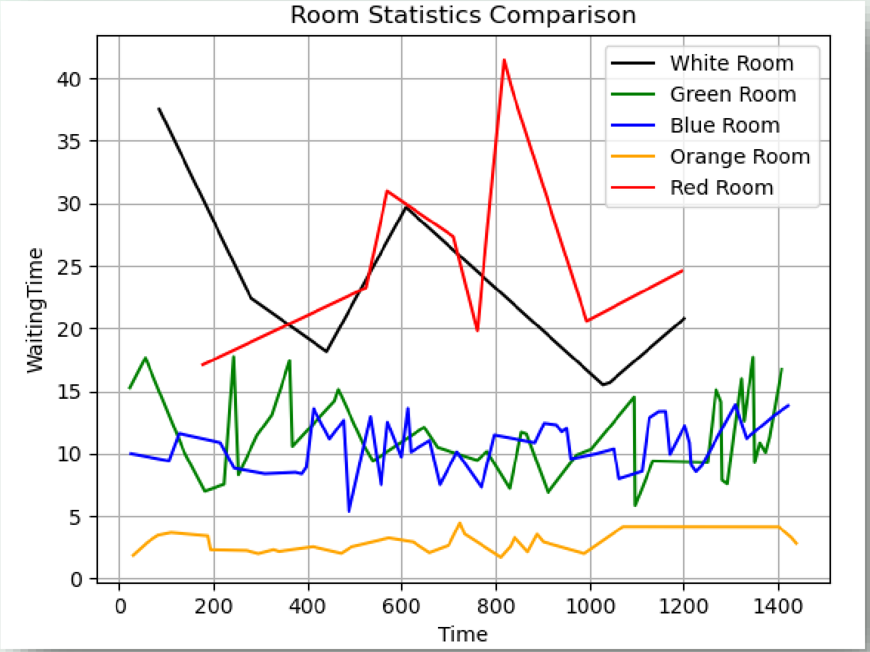


ROOMS' COMPARISON

The **Green room** has a stable waiting time, with some peaks, but which remains constant for medium-low values. Therefore, it is possible to conclude that the workload was managed efficiently.

The **Blue room** has stable waiting times, so it was not possible to observe an overload of resources.

STATISTICS

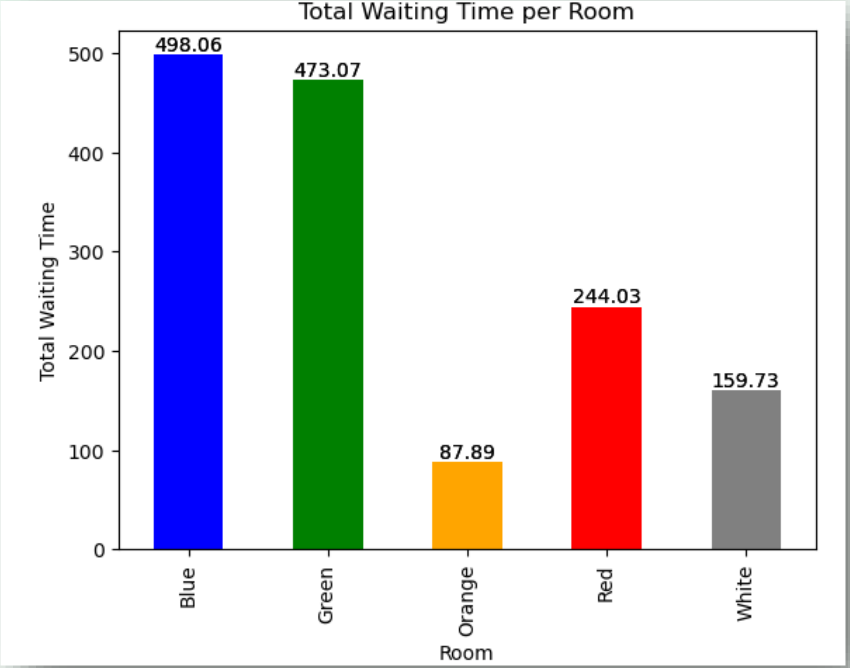


ROOMS' COMPARISON

The **Orange room** has low and stable waiting times. There are no different fluctuations, so this is less used but <u>certainly very efficient.</u>

The **Red room** shows an initial decreasing trend up to a certain point, and then <u>has variable peaks and a rise towards the end of the period.</u> This could indicate an increase in demand in the second half of the simulation period.

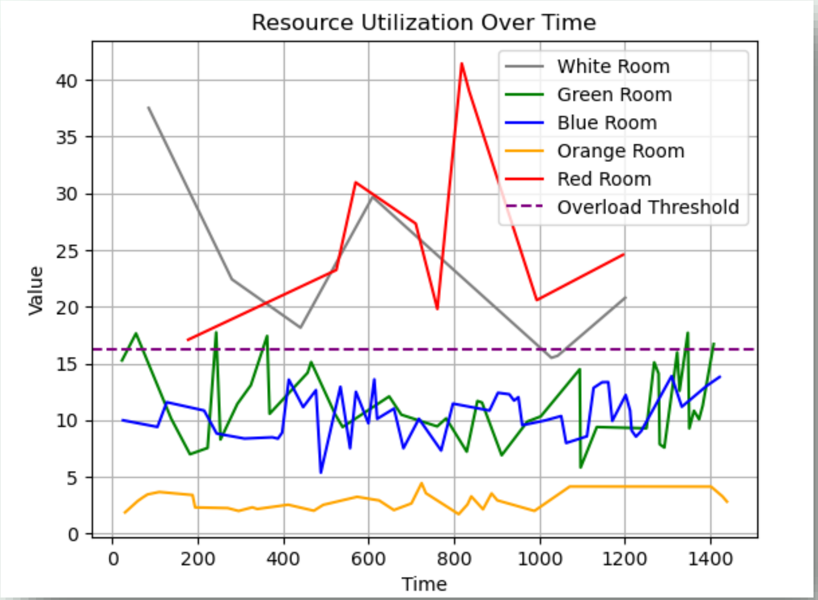
STATISTICS



AVERAGE TREATMENT TIME & TOTAL ROOM USAGE

	mean	sum
	WaitingTime	WaitingTime
Room		
Blue	10.597028	498.060309
Green	11.538203	473.066333
Orange	2.835231	87.892165
Red	27.114881	244.033931
White	22.818608	159.730256

STATISTICS



RESOURCE UTILIZATION OVER TIME

In the graph, we clearly see that:

- Overload in the **White** and **Red Rooms;**
- Good management in **the Green** and **Blue Rooms;**
- Underutilized **Orange Room**

The **overload threshold** was equal to

```
threshold_value =
df['WaitingTime'].mean() * 1.5
```

These results were calculated with a different threshold value, which is the average value for each room.

STATISTICS

% OF UNTREATED PATIENTS

For this calculation, both patients in line for check-in and patients waiting in the waiting room were considered.

```
percentage_not_managed = (non_managed_patients / totPatients) * 100
print(f'Percentuale di pazienti non gestiti: {percentage_not_managed}%')
```

```
Percentuale di pazienti non gestiti: 20.0%
```

% OF PATIENTS TREATED WITHIN ACCEPTABLE TIME

```
Percentage of White Room patients treated within 36 minutes: 85.71428571428571%
Percentage of Green Room patients treated within 16 minutes: 87.8048780487805%
Percentage of Blue Room patients treated within 12 minutes: 87.8048780487805%
Percentage of Orange Room patients treated within 4 minutes: 87.8048780487805%
```

By acceptable time, we mean a period of time that is equal to **80%** of the maximum waiting time, respectively for each room..

6 conclusion

conclusions

To further improve the system, you could consider to:

- **Add more levels of severity** in patients to better differentiate critical cases from less urgent ones.
- **Simulate scenarios with variable patient flows**, such as emergencies or peak arrivals, to assess the resilience of the system under stressful conditions.

The simulation model demonstrated its usefulness in providing a detailed picture of the operation of an emergency department, identifying inefficiencies and suggesting potential improvements. Implementing the recommendations provided could lead to reduced waiting times, better use of resources, and ultimately increased efficiency of the healthcare system.

THANKS

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