THE PERFORMANCE OF HOSPITAL AND TRANSPORTATION NETWORKS AFTER A SIMULATED SEISMIC EVENT

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To my parents.

For their constant dedication to make me happy.

To whoever still believes in something.

Always choose the tougher path.

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Abstract

Hospital overcrowding is a serious issue that compromises daily service quality in many modern communities worldwide. Reduction of ward beds without an increment of low-intensity structures, bad-users, and obsolete equipment are few examples of the common causes of emergency departments overloading. Traffic jam is another ordinary city-scale issue accentuated during the last decades, when the urban population overcame the rural one but roads capacity remained the same. These phenomenon are even more emphasized during emergencies due to natural disasters, because thousands of people need aid. In such situations, roads could be blocked by collapsed buildings, causing an increase of casualties' travel time towards hospitals and the latter reach quickly their maximum capacity therefore patients might need to be relocated in other facilities. This process has to be carefully managed otherwise it can lead to tremendous human losses. The goal of this research is to analyze the response of transportation and hospital networks of a city after a severe seismic event. The case study focuses on modelling the patient flow into a large-scale virtual environment called Ideal City that is based on the city of Turin in Italy. The number of injured people was estimated in four levels of severity. Two simulated scenario, both of them during the night but the second with some closed roads, were applied to the virtual urban environment including eight modelled hospitals. Each of them has its emergency room, but the number of resources and beds vary according to the collected data. Patient flow is described through an agent-based model that simulates the routing towards the closest hospital. Once casualties arrive to a structure, according to the triage code based on the severity level, they have to wait a certain time, in line with the available resources and spaces, before receiving all medications. Different categories of medical treatment time are defined by Emergo Train System guidelines. The waiting time for each patient is then monitored by a discrete-event model, so that when the hospital reaches its maximum capacity, patients can be transferred to another facility. Critical weaknesses are identify and different approaches are discussed to decrease the waiting time and to improve the overall hospital network performance.

Keywords: *Maxi-Emergency, Performance, Hospital Network, Transportation Network, Rescue, Emergency Department, Discrete-Event Simulation Model, Agent-Based Model, Turin.*

Introduction

This thesis is part of a bigger project called “IDEal reSCUE” also known as Integrated Design and control of Sustainable CommUnities during Emergencies. It has been sponsored for five years (2015-2020) by the European Research Council and it is run by a multidisciplinary team directed by Professor Cimellaro (Politecnico di Torino), aims to model the complexity of emergencies. The means used to reach the purpose are strategic infrastructure and their interdependencies, plus human factor. This because the most serious emergencies after a natural hazard, are usually caused by a combination of physical structures issues and human mistakes, but these two different fields are never treated together. The main goal is to develop a user-friendly tool usable by the interested cities, before and after or even during the emergency to simulate the effect their decisions have in term of saved lives. Here, Ideal City is born as large-scale virtual environment based on the city of Turin in Italy, where first simulations could be run. It could be seen, as cities in general, like an overlap of layers representing the critical infrastructure system (CIS), because even though a single part is unable to work, cascading failures could be triggered and the number of casualties could strongly increase. Ideal Rescue is trying to define each layer reaction if the model receive as input a certain disaster type.

Getting into the details, two are the layers this research is going to focus on, representing rescue system: road and hospital networks (Fig. 1). Just think of what could happen during an evacuation due to a wildfire if the road network can’t contain all the vehicles, or though, after an earthquake, the hospitals lose their functionalities caused by structural damage or a blackout. The complexity of these modern CI is positive for the city development but being tightly interconnected is difficult to predict their reaction to an abnormal stress. For these reasons there should be a backup plan at territorial level in case of failure, supported by careful studies.

The project begins after assessing structural damage of the building in Ideal City caused by a simulated seismic event and computing casualties number. Injured people represent the flow to be converged towards the closest hospital and to be handle and treat inside the healthcare facility with the purpose of saving as many lives as possible. If the system is not resilient enough a redistribution of patients towards less stressed environment, is set up. In the end, weaknesses in the process and solutions are identified and accurate details on future research are described.

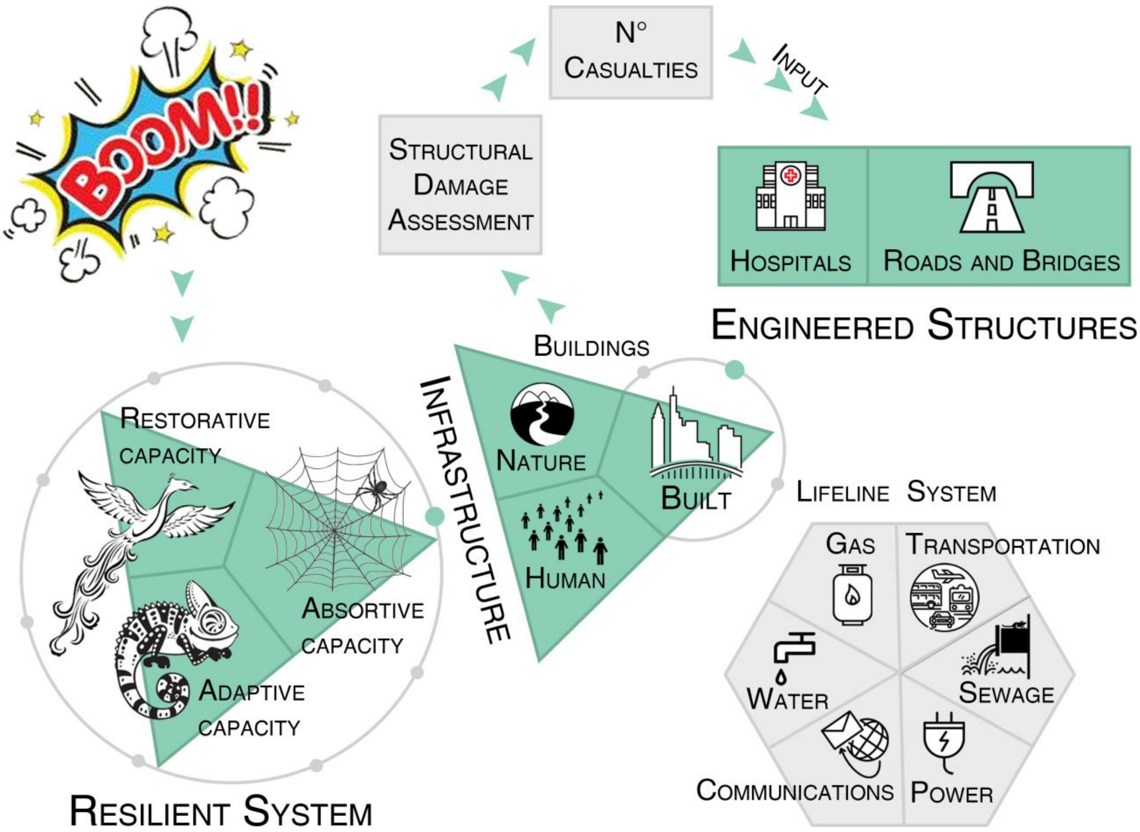


Fig. 1. Initial framework

• Structure

The organization envisage three main sections, in order to take into account all the aspects of the topic.

The first chapter offers a few script to run a particular simulation called Agent-Based model which respond to the question: "How long it takes, for each casualty after an earthquake, to get to the closest hospital?".

Here a coding world is opened with Python as principal language. The lead is the road network and the target is the estimation of his response during adverse conditions. In fact a normal traffic situation after an earthquake could change because of different factors: the agents could modify their usual destinations, the buildings could collapse and the debris could block the streets and the third point is the addition of injured agents who try to go to the hospitals. The result is the travel time of each agent going towards the hospitals, taking into account the previous factors.

The second section present a methodology to create a Discrete Event Simulation (DES) model where agents can move inside a contained environment and take decision according to the changing circumstances. This tool is applied to each hospital of the network and answers at the question: "How many patients can be absorb by each hospital without being overwhelmed and no longer able to save life?". The output is the average waiting time for the total process of medical care, for each level of wounded's severity.

The third part shows the simulations tested on a case study.

Further annex are included to complete the overview, presenting other inherent activities made in parallel to better understand how to develop the research.

• Motivations

Hospital overcrowding is a serious issue that compromises daily service quality in many modern communities worldwide. Reduction of ward beds without an increment of low-intensity structures, bad-users, and obsolete equipment are few examples of the common causes of emergency departments overloading. Bad-user are mostly those people classified at the emergency department as white code, who should go to their medical practitioner even waiting the day after, without any risk. A percentage are people hypochondriac, another part has the assigned doctor who don't take care of them so at least they have some good reasons. The last type of bad-user are terminally patients who are so sick that the ED can do anything, thus they are supposed to go to specific structures but sadly they are often full and not cheap.

Traffic jam is another ordinary city-scale issue accentuated after 2008, when the urban population overcame the rural one for the first time in history, but roads capacity remained the same.

These phenomenon are even more emphasized during emergencies due to natural disasters, because thousands of people need aid. In such situations, roads could be blocked by collapsed buildings, causing an increase of casualties' travel time towards hospitals and the latter reach quickly their maximum capacity therefore patients might need to be relocated in other facilities. This process has to be carefully managed otherwise it can lead to tremendous human losses. A model to simulate an hypothetical emergency, seems to be a good solution to understand, reason and train. Once a doctor told me though, it is difficult to organize a situation that has nothing of ordinary for definition. It is true but simulation modeling is a wonderful tool to test the effects of random variation, statistics and probability distribution. There is need to work on the probability, even more if there are a lot of lives at stake. During my stay in Berkeley, I had the pleasure to listen to the victims of the Campfire in Paradise (California) which got in the city on November the 8th, 2018. They knew the area where they live is dangerous and subject to fires, for this reason a lot of drills has been put in place. Thanks to the prepared authorities and the help of population , 99% of people were saved even if the situation was different from all the others. But still 89 folks died. Next time, the emergency could be again unpredictable but they still want UCB works on simulation model to identify what they could more improve, because a simple human mind can't control all the messy situation and find the solution alone. Maybe the odds next time will be on their side and in any case they will still be more prepared. It's worth a shot working on this.
Maybe in Italy we can start too.

• State of art

State of art helps finding the gaps inside the literature about rescue organization in case of disaster and how it is possible to assess if the performance hypothetically would be acceptable or to improve.
Latest researches, from 2014 to 2018, about hospital resilience, focus on ways to assess it and consequently which solutions could be adopted to increase it. Figure 2 shows which part of an healthcare facility is the central point of each article's idea of evaluation and if external factors are considered or not into the rescue process. The

most part of the proposal talks about the hospital in toto and barely two aim attention at the ED who is the department more afflicted in case of emergency. Then there are papers tries to narrow it down concentrating on structural estimation of damage, lack of staff and/or stuff, or functional issues either internal or external.

According to [21 in figure 2] Virendra PROAG (2014), resilience could be assessed both qualitatively and quantitatively. "Qualitative assessment is useful to understand how bad things are" through risk probability rated from 1 to 9, and relative impact on the project, rated low, medium or high. "Quantitative measures give quantified estimates of performance, time and cost that are more meaningful to stakeholders".

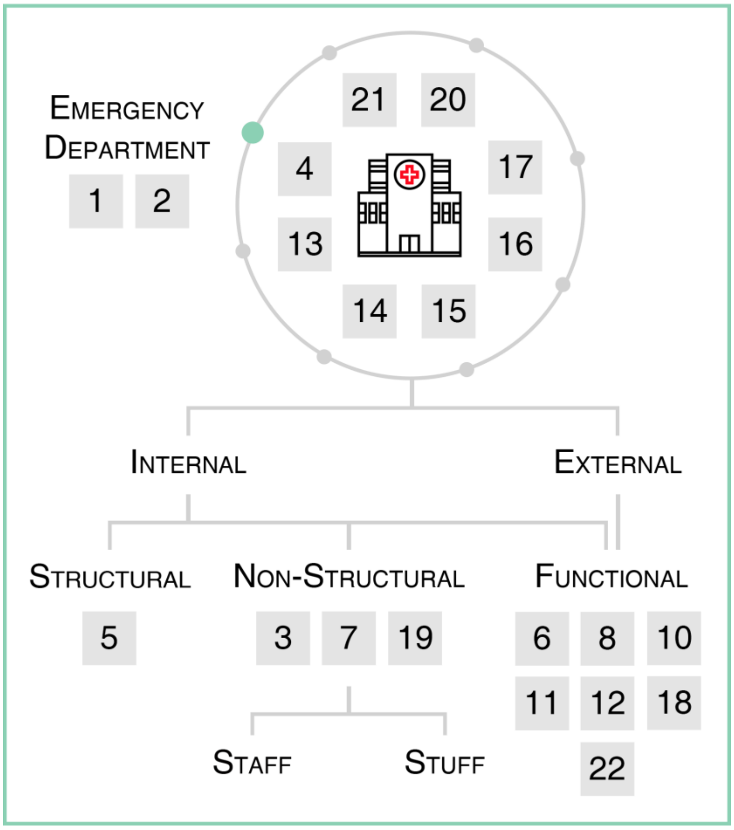


Fig. 2. Articles map

Most of articles take on their thesis about hospital resilience that is extremely important, but few zoom in hospital disaster resilience would be necessary because it is even more crucial. To estimate the latter one, the Emergency Department is the area more meaningful.

In fact [20 in figure 2] Jacques et al. (2014) has invented an equation to compute it, with following input concerning just the ED: functions' number, functions' weigh, number of function redistributed. To have a clear overview of the system's functionality, Jacques has created a fault tree, divided in three principal branches: structure, staff and stuff. It is useful to provide a framework on relation between damage and components.

A job progress has been made through integral of system's functionality of [1 in figure 2] Cimellaro et al. (2016). He has developed a DES (discrete event simulation) model describing hospital "Mauriziano" (Turin) emergency department's ability, with and without Emergency Plan (EP). Principal parameter used to quantify resilience is waiting time (WT). Input to calculate it, are: seismic intensity and number of physicians and available emergency rooms.

In addition [2 in figure 2] Cimellaro et al. (2019) has amplified this speech comparing ED's WT with questionnaire's results about maximum acceptable WT. If hospital can't handle all patients, it is proposed two alternatives: patients' redistribution towards nearest hospitals or to localize an area where to build a new hospital.

Although last two articles have speeded up a deterministic and precis disaster resilience's calculation taking into account only ED, [4 in figure 2] Cimellaro et al. (2018) has tried again to propose a rapid methodology but in this case, for an entire hospital. Hospital's behavior is difficult to assess because it depends on several variables. [15-16 in figure 2] Zhong et al. (2014) has claimed total resilience is the sum of every single variable's resilience. After determining these key factors, it is fixed, with factor analysis, which factors weigh more on calculation. Linear combination of these last, represents hospital disaster resilience.

Nevertheless, first methodologies work better when there is a real emergency and there isn't time. Consequently, the third, is more useful to understand where to intervene in normal situation to face the emergency in the best way, at a later stage.

Many articles didn't concentrate on calculations, but their purpose have been to create a framework matches in every hospital for any catastrophic event to understand where primarily intervene. [14 in figure 2] Zhong et al. (2014) has identified 8 domains (or key factors), 17 sub-domains and 43 indicators. [17 in figure 2] Zhong et al. (2013) has linked these domains with Bruneau's four criteria describing hospital disaster resilience.

Key factors are part of three critical components of hospital disaster resilience, which according to [13 in figure 2] Samsuddin et al. (2015) are: structural, non-structural and functional. Some articles just aim to contribute to improve hospital disaster resilience focusing on one of them.

Assessment of structural damage connected to seismic intensity, present a lot of gaps. In the years take in consideration, only [5 in figure 2] Marasco et al. (2017) has developed a new methodology applied to a Californian hospital, subjected to three cascading hazards. This is an alternative to Monte-Carlo Simulation used by Cimellaro et al. [1-2 in figure 2], reduce time to extract results but, on the other hand, it needs accurate parameters.

Articles about non-structural component concern mainly adaptive capacity during an emergency, of staff and stuff. [19 in figure 2] Vugrin et al. (2014) has defined an entities' hierarchy using an optimization model to substitute each one of them, during a loss of life line services, until it gets to a partial or total evacuation. In addition, [7 in figure 2] Janius et al. (2017) has calculated qualitatively this risk connecting frequency and consequences of the event. Instead [3 in figure 2] Radhakrishnan S. et al. (2014), has tried to explain a resources' rise isn't always the best option. He has proposed to study with Arena software, a better management of those already presents.

Functional component concern all about organization and administration both internal and external. Emergency plan's organization is not easy. It is almost impossible preview all variable.

Human behavior is one of them. Only way to face it is to prevent. [10 in figure 2] *Samsuddin et. al* (2017) has individualized six weakness in hospital's functionality that could influence human behavior and therefore, they should be corrected. While, [8 in figure 2] *Samah et. al* (2017) has proposed a workshop to enhance staff's skills and to generate new idea. Also [11-12 in figure 2] Loosemore et al. (2015) has thought how to teach a method to handle emergency and above all how hierarchy levels of knowledge could significantly reduce resilience: stakeholders, staff, facility managers, have to participate all, to planning process.

Ambulance's system is another important variable. [6 in figure 2] Barbieri et al. (2018) has assessed two of them during double seismic event in Modena's province.

According to [18 in figure 2] Achour et al. (2014) there is also a problem into International Code Resilience regarding impact of utility interruption on healthcare. Only UK and Californian code have appropriate attention, French, Algerian and Italian Code, for instance, don't. Overall author has stated electricity is more significant utilities, followed by pipeline system of gas and water. For these reasons, author invites all States often prone to disasters, to review their Code, especially for electricity network.

Another help, to facilitate emergency plan's coordination is given by [22 in figure 2] Sparf et al. (2017). He has explained like Sweden established a Collaboration Cluster. It provides one person for each organization useful in case of emergency, and it rounds up them in one room. Preliminary results confirm utility to rapid exchange of informations. Negative point is these person can't intervene, but their job is only to pass details to the mother company.

Concluding, there are several gaps in calculation of hospital performance during an emergency. For simplicity, structural damage and human behavior are never taken in consideration. In addition [9 in figure 2] Mieler et al. (2017) has argued several opinion. Two of them still valid today: there isn't a link between loss of functionality and recovery time, and there is need to redefine analytical model including external impact and interaction between single building and system.

The last gap is the main purpose of this thesis.

1

Transportation Network

In the last years natural disasters are holding up the development and the well-being of the communities around the world. An important factor decisive in dealing with an emergency is the number of people and the size of the escape routes. First alarm is heading for the cities because according to the United Nations, the World's population living in urban areas is increasing and from 2008 has passed for the first time that one of the rural areas. By 2050 this is expected to increase to 68%[1].

The consequence is road networks more and more congested requiring a careful assessment of the possible failures. The state of art shows the lack of proper tools adopted by urban planners, especially in Italy, where natural hazards are more frequents, and the massive amount of deaths due to catastrophes, brought our team to study a successful tool receives widespread popularity especially in USA: Agent-Based Model (ABM). It can be used in several fields and depending on which one is consider, the definitions can drastically change. In terms of transportation, the ABM is a powerful method for simulating complex traffic dynamics: traffic is created by hundreds of thousands (or even more) of agents traversing a road network. As shown in figure 3, they can find the quickest route between origins and destinations and possess "personalities" in time-cost preference.

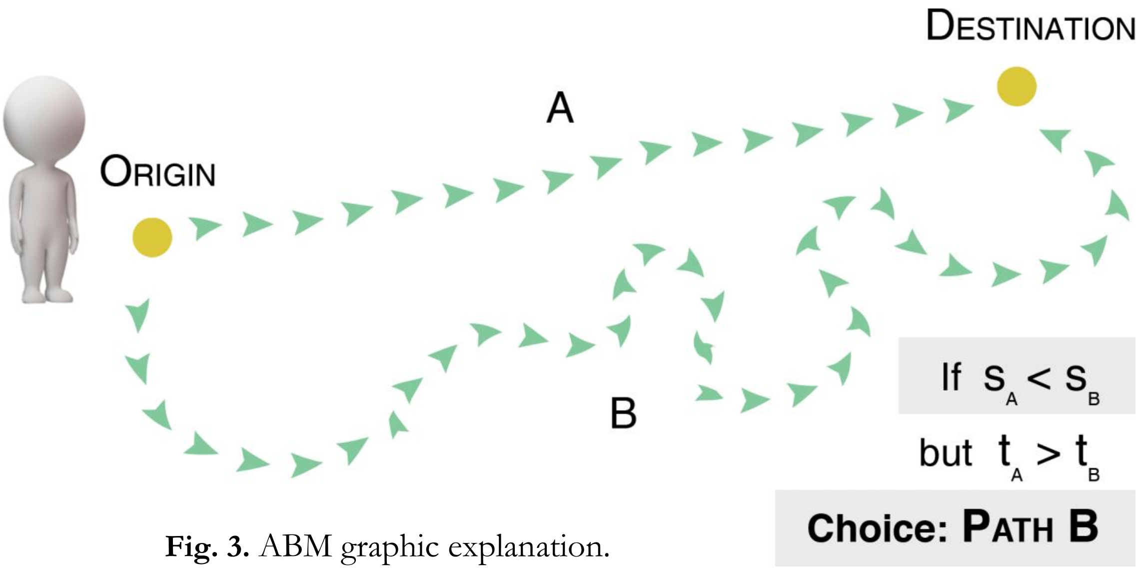


Fig. 3. ABM graphic explanation.

[1] United Nations, and Department of Economic and Social Affairs. (2014). World urbanization prospects, the 2014 revision: highlights.

This is intended to be the beginning and the inspiration for further development, and still not the solution to this problem. The traffic problem is widely applicable to different situations: just recreating the traffic itself during a normal working day, or it could be the simulation of the behavior of the cars after an earthquake like in this research, or even the flow of the people during an evacuation. Many applications can derive from this work and many other can be thought by the reader.

This work was developed collaborating with the city-scale modelling research group of University of California, Berkeley, headed by Professor Kenichi Soga. Thanks to him I spent six months there as Visiting Student Researcher. The results of this chapter were achieved with Bingyu Zhao (PhD student, University of Cambridge and since July,2019 researcher at UCB), and Alessandro Cardoni (PhD student, Politecnico of Torino).

• Methodology

The key elements for understanding the methodology behind the development of a Macroscale Agent-Based Model for traffic simulation, are described in this paragraph. This straight forward structure is designed for a greater clarity because it gives a simpler overview of the framework. For a more complete and wider understanding, the following section 3 (Case study) is suggested to read. That part includes concepts explanation that will help the reader to better understand the transportation network's simulation and reproduce the proposed solution.

The procedure can be summarized in four different steps:

1. Target area and map data collection
2. Generate random OD pairs for the background traffic
3. Create OD pairs with fixed origins and destinations
4. Run Agent-based Model

Software

A few software needed to be installed on a Window operative system for the traffic simulation. To run the script on Mac OS or Linux, the code needs some modifications. The first step can be performed in three different ways as it can be read in the next paragraph. Neverthless, Excel and Notepad++ are always useful to clean the file up in order to be readable by following script. The second and third phases need Anaconda as the perfect tool to simplify the package management in Python because it is an environment which analyze every installed thing, check any version limitations and figures out automatically how to solve incompatible dependencies. Jupyter is an applications already available in Anaconda, allows to not use a command-line commands as interface but a web-based interactive computational environment. The initial release are respectively 2012 and 2015. For the fourth stage, Ubuntu is needed and the App version (available since 2004) is useful for using a Linux operative system even if windows is the main one on the pc. In this research results visualization won't be discussed but here, some hints: Qgis deals with information resulting from geo-referenced databased, is the simplest mean to visualize a static condition of the traffic flow, so it shows the streets more congested. In this case for instance, around the hospitals would be the areas more interested. Whereas, Deck.gl is one of the best visualizer for dynamic traffic flow, but it needs to face a coding part.

First step – Target area and map data collection

Choose the area and collect map data in form of graph is the first requirement. Links are the streets and joints are the intersections. Each element has to be location-based and just the roads, associated to a list of attributes, different according to the objective. Three ways to solve this part are existent. Open Street Map (OSM) is the principal, although similar to Google Maps, it offer simple rendering map but also free digital map with editable elements having attributes stored in a database belonging to the community. By script 1, Turin data can be downloaded but to arrive at a simple visualization there are further several steps: a more script is to adapt the results to a correct syntax, the following to add speed limits and the third to obtain the graph in .graphml format. This method works with any operative system but the process is the longest and the graph has a bounding box, contrary to the second technique. It is called OSMnx and it is a Python package for downloading, cleaning, analyzing and visualizing OSM data with

just a few line of code (Script 2). Some more output easily obtainable are: sized area covered by the network, average streets per node, streets total length and
their average or also visualization of joints' elevation and streets' centrality. In any case the minimum result, i.e. a graph file, can be achieved with just line 30-31. Script 3 convert the output .graphml into .mtx format necessary for the following steps. Bounding shape and faster process are the pros but the limitation concerns the preference of Linux OS.

Last route taken in consideration is AutoCad. It is a tool for technical drawings, useful if the environment is made up or not completely equal to the original. No script needed, just knowledge about Excel and exporting data from Cad. Creating the map without downloading it, two different file are needed in order to keep going on with the next steps. A .csv file has to be fill in with these data for each row: ID road, ID start joint, ID end joint, Coordinate X start joint, Coordinate Y start joint, Coordinate X end joint, Coordinate Y end joint, length [m], width [m], lanes number, average speed [m/s] and capacity [vehicles/s]. The second file has .mtx format and it asks for each row: ID start joint, ID end, joint, weight [s]. The weight depends on the goal of the abm. In this case the model looks for the shortest path in term of time, so the weight of the roads is in seconds.

Being Ideal City based on Turin but not perfectly matching, AutoCad is the right choice.

Second step – Generate random OD pairs for the background traffic

Once the graph is ready, traffic could be added. Origins and destinations for various agents have to be listed. Of course, real traffic data from history are more realistic. In USA, California has a database online for free with these data granted by Uber or Lyft. In Italy we don't have this kind of information free of charge thus the only possible alternative is to generate the origin-destination pairs randomly (Script 4). This is a limitation because it is highly possible the areas more congested in the reality, are cars-free in the simulation. The only information available is the operating vehicles number per hour. Figure 4 shows traffic daily trend in Turin[2]. The script used here is the third on the next section.

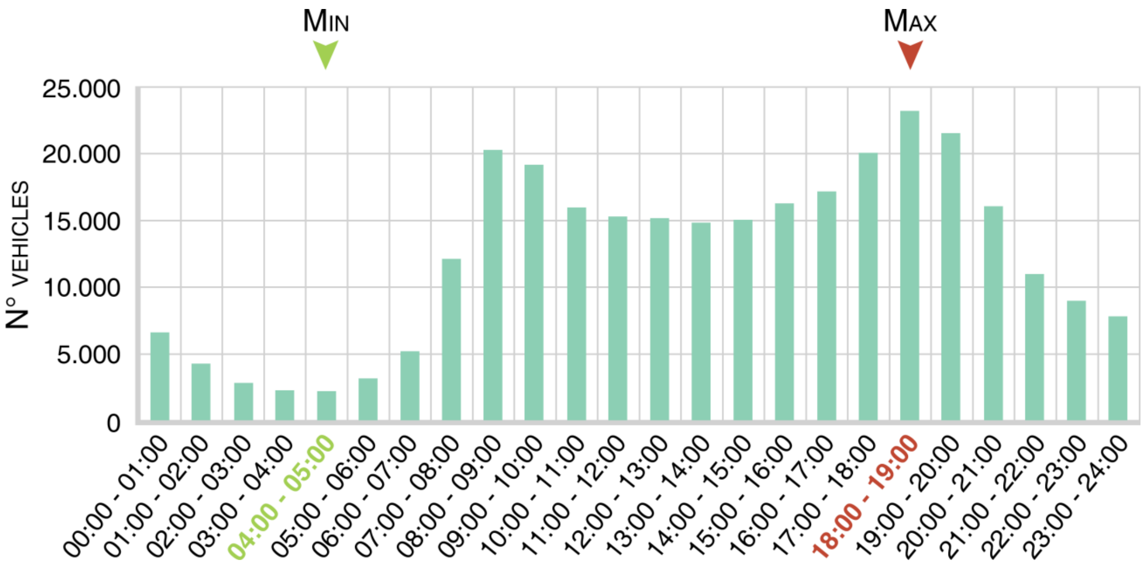


Fig. 4. Traffic daily trend in Turin

Third step – Create OD pairs with fixed origins and destinations

During an emergency case, extra-agents usually not included in daily movements, have to be calculated as injured people routing for the hospitals. The first issue concerns the casualties position compared to the graph. In fact every future patient, placed inside his abode (data collected from Ideal Rescue project), has to be associated to the nearest node of the graph. That's because the model works just with nodes and links, not also with buildings. The same for the hospitals of destination. To accomplish this, three file in .csv format are required, respectively for buildings, nodes and hospitals, with three columns: ID, latitude and longitude. Script 4 (Fig. 5) links each structure with the closest node by coordinates. Once the

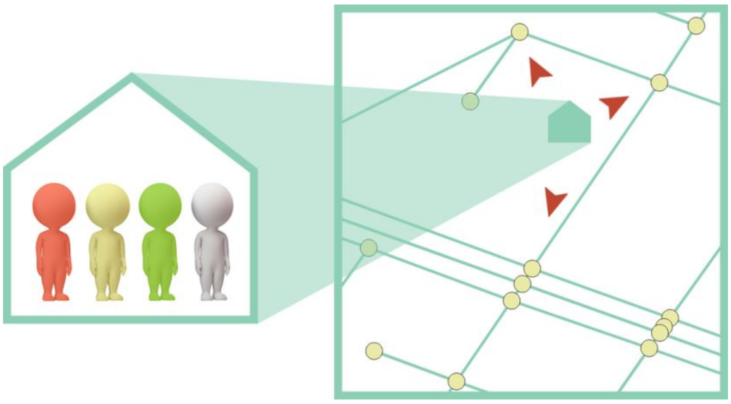


Fig. 5. Script 4 graphic explanation.

[2] Data from https://www.muoversiatorino.it/it/numeri-mobilita/, visited on September 3rd, 2019.

more convenient node is declared, Script 5 (Fig. 6) has to be performed to assign to him the number of casualties, summing them up if more buildings converge to the same intersection and keeping the separation into severity levels. The input are the outcome of the precedent code and another file .csv with the casualties number for each building. The output in this case has node ID, number of people subdivided into patients severity level.

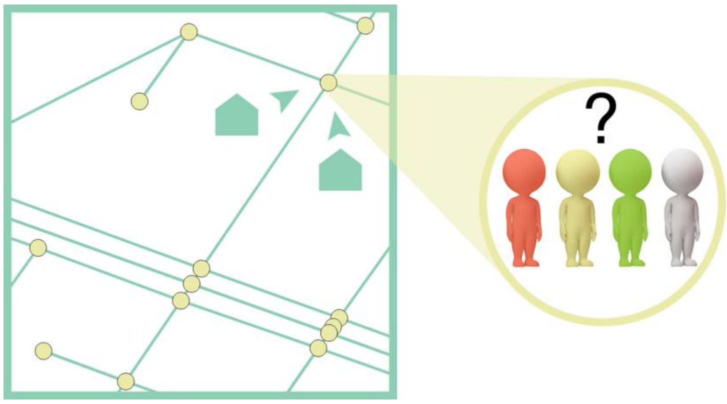


Fig. 6. Script 5 graphic explanation.

After filling in the list of origin nodes with agents number, the OD pairs generations for the future patients of the hospitals, doesn't need a script to be performed. It is necessary to add a column with hospitals' node ID. Every departure point has to be paired with each hospital because the closest one in term of time is calculated in the fourth step.

Fourth step – Run Agents-based Model

This is the heart of the simulation. By Script 6 is possible to compute the shortest path, in terms of time, of all the OD pairs keeping in consideration the possible congestion. Before running the code python has to be interfaced with C++. The instruction are into the Script section.

The shortest paths computations can be analyzed in many ways, all depends on the type of OD:

- Single pair shortest path (SPSP): one origin and one destination;
- Single source shortest path (SSSP): one origin and many destinations;
- Single destination shortest path (SDSP): many origins and one destination;
- Origin-Destination shortest path (ODSP): many origins and many destinations;
- All pairs shortest path (APSP): all nodes are both origins and destinations.

Our traffic analysis is a ODSP type. It is just a special case of SPSP and it is solved using Dijkstra algorithm as many times as many are the sources.

The travel time calculated following the shortest path, takes into account the capacity of the links and the flow on each of them, so the more there is traffic, the more the travel time rises.

There are different type of traffic simulations (Fig. 7). Macroscopic method could be fluid-dynamic or agent-based. The first one doesn't study the individual agents movement but just the general flow and the computation is obviously faster. The distinction between macro and microscopic agent-based is that in the second one, the cars flow is described in details even considering the number of lanes of the roads, how the agents are arranged on those in front of the traffic lights, and so on. In addition a macroscopic agent-based could even be defined with one more subcategory based on the type of assignment, namely: static or quasi-static. An assignment is static when the path is computed just once at the beginning before leaving from the origin. It is quasi-static when, assumed vehicles might not finish the assigned route, they keep stopping after some minutes (prefixed) to recalculate the path. The code used in this research foresees a static assignment.

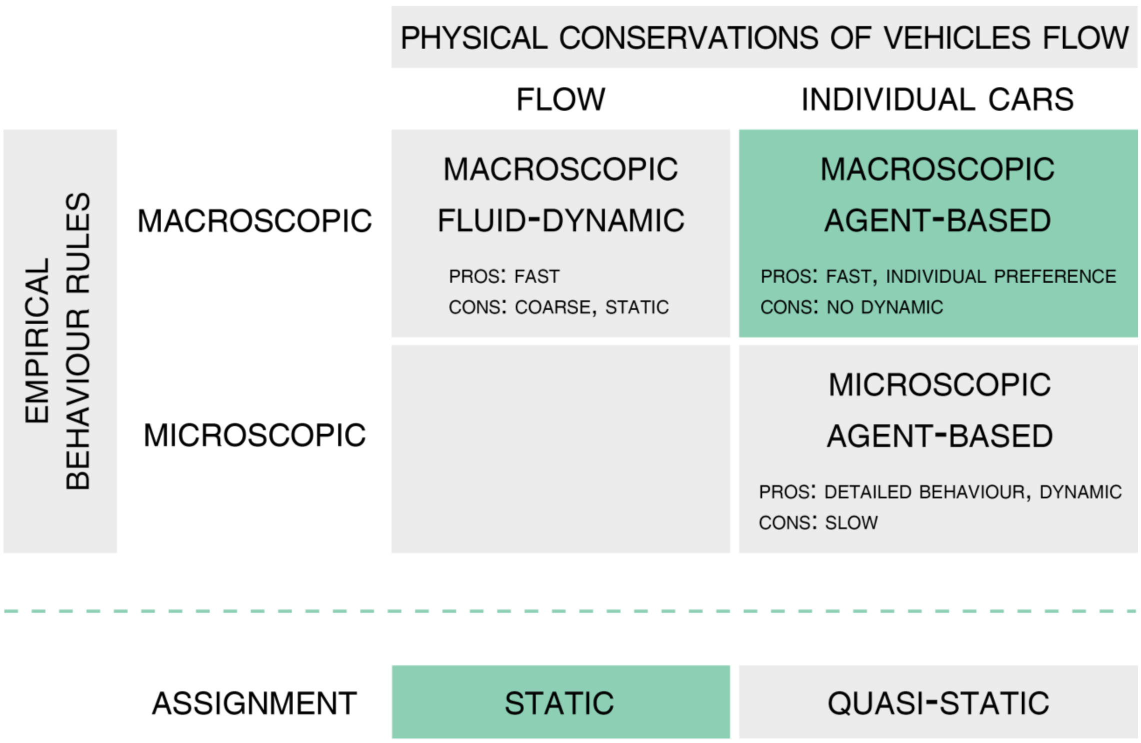


Fig. 7. Type of traffic simulations

• Script

Script 1 – Map download from OSM

```
echo "data=[out:json][bbox:45.1421,7.7509,45.0051,7.6005];way[highway];(._;>;);out;" > query.osm
```

OUTPUT FORMAT: JSON | BOUNDING BOX: TURIN | ROAD TYPE: HIGHWAY | OUTPUT NAME: QUERY.OSM

Script 2 – Map download from OSM with OSMnx

```
import networkx as nx
import osmnx as ox
import requests
import matplotlib.cm as cm
import matplotlib.colors as colors
ox.config(use_cache=True, log_console=True)
ox.__version__

# get a graph for some city
G = ox.graph_from_place('Turin, Italy', network_type='drive')
fig, ax = ox.plot_graph(G)

# what sized area does our network cover in square meters?
G_proj = ox.project_graph(G)
nodes_proj = ox.graph_to_gdfs(G_proj, edges=False)
graph_area_m = nodes_proj.unary_union.convex_hull.area
graph_area_m

# show some basic stats about the network
ox.basic_stats(G_proj, area=graph_area_m, clean_intersects=True,
circuity_dist='euclidean')

# see more stats (mostly topological stuff) with extended_stats
more_stats = ox.extended_stats(G, ecc=True, bc=True, cc=True)
```

```
#use  arguments to turn other toplogical analyses on/off
for key in sorted(more_stats.keys()):
    print(key)

# save graph to disk as shapefile (for GIS) or graphml file (for gephi etc)
ox.save_graph_shapefile(G, filename='turinnetwork_shapefile')
ox.save_graphml(G, filename='turinnetwork.graphml')

# edge closeness centrality: convert graph to line graph so edges become nodes
and vice versa
edge_centrality = nx.closeness_centrality(nx.line_graph(G))

# list of edge values for the orginal graph
ev = [edge_centrality[edge + (0,)] for edge in G.edges()]

# color scale converted to list of colors for graph edges
norm = colors.Normalize(vmin=min(ev)*0.8, vmax=max(ev))
cmap = cm.ScalarMappable(norm=norm, cmap=cm.inferno)
ec = [cmap.to_rgba(cl) for cl in ev]

# color the edges in the original graph with closeness centralities in the line
graph
fig, ax = ox.plot_graph(G, bgcolor='k', axis_off=True, node_size=0,
                        edge_color=ec, edge_linewidth=1.5, edge_alpha=1)

# get the nearest network node to each point
orig_node = ox.get_nearest_node(G, (37.828903, -122.245846))
dest_node = ox.get_nearest_node(G, (37.812303, -122.215006))

# find the route between these nodes then plot it
route = nx.shortest_path(G, orig_node, dest_node, weight='length')
```

```
fig, ax = ox.plot_graph_route(G, route, node_size=0)

# how long is our route in meters?
nx.shortest_path_length(G, orig_node, dest_node, weight='length')

# how far is it between these two nodes as the crow flies?
ox.great_circle_vec(G.node[orig_node]['y'], G.node[orig_node]['x'],
                    G.node[dest_node]['y'], G.node[dest_node]['x'])

# make query an unambiguous dict to help the geocoder find specifically what
you're looking for
place = {'city' : 'San Francisco',
       'state' : 'California',
       'country' : 'USA'}
G = ox.graph_from_place(place, network_type='drive')
fig, ax = ox.plot_graph(G, fig_height=12, node_size=0, edge_linewidth=0.5)

# add elevation to nodes automatically, calculate edge grades, plot network
from keys import google_elevation_api_key
G = ox.add_node_elevations(G, api_key=google_elevation_api_key)
G = ox.add_edge_grades(G)
nc = ox.get_node_colors_by_attr(G, 'elevation', cmap='plasma', num_bins=20)
fig, ax = ox.plot_graph(G, fig_height=6, node_color=nc, node_size=12,
node_zorder=2, edge_color='#dddddd')

# you can get networks anywhere in the world
G = ox.graph_from_place('Modena, Italy', network_type='drive_service')
fig, ax = ox.plot_graph(G, fig_height=8, node_size=0, edge_linewidth=0.5)

# or get network by coordinates, bounding box, or any custom polygon shape
# useful when OSM just doesn't have a polygon for the place you want
wurster_hall = (37.870605, -122.254830)
```

```
one_mile = 1609 #meters
G = ox.graph_from_point(wurster_hall, distance=one_mile,
 network_type='drive')
fig, ax = ox.plot_graph(G, fig_height=8, node_size=0)

# get rail network
# note this is rail *infrastructure* and thus includes crossovers, sidings, spurs,
yards, etc
# for station-based rail network, you should prob download a station adjacency
matrix elsewhere
G = ox.graph_from_place('New York City, New York',
                    retain_all=False, truncate_by_edge=True, simplify=True,
                    network_type='none', infrastructure='way["railway"~"subway"]')
 fig, ax = ox.plot_graph(G, fig_height=10, node_size=0)
```

Script 3. Osm output to .mtx and .csv format

```
import igraph
import sys
import scipy.sparse as sp
import scipy.io as sio
import numpy as np
import json
import time
import os
import pandas as pd
import ast
import re

absolute_path = os.path.dirname(os.path.abspath(__file__))
folder = 'turin_osmnx'
scenario = 'undamaged'

```

```
### Read the igraph object in
sf_graph_file =
absolute_path+'/../data/{}/turinnetwork.graphml'.format(folder)
g = igraph.Graph.Read_GraphML(sf_graph_file)
print('Summary of the graph: \n', g.summary())

'''
IGRAPH D--- 224223 549008 -- unnamed
+ attr: crs (g), name (g), simplified (g), streets_per_node (g), highway (v), id (v),
osmid (v), ref (v), x (v), y (v), access (e), area (e), bridge (e), est_width (e),
geometry (e), highway (e), id (e), junction (e), lanes (e), length (e), maxspeed (e),
name (e), oneway (e), osmid (e), ref (e), service (e), tunnel (e), uniqueid (e),
width    (e)
'''

 ### Imputing missing data

 def str2num(l, outtype):
    l = [l_i.partition(',')[0] for l_i in l]
    l = [l_i.partition('-')[0] for l_i in l]
    l = [l_i.partition(' ')[0] for l_i in l]
    l = [re.sub(r'\D', '', l_i) for l_i in l]
    l_array = np.array(l)
    l_array[l_array==''] = '0'
  return l_array.astype(outtype)

attribute_df = pd.DataFrame({
#'uniqueid': np.array(g.es['uniqueid']).astype(np.int),
 'osmid': np.array(g.es['osmid']),
'length': np.array(g.es['length']).astype(np.float),
'highway': g.es['highway'],
'lanes': str2num(g.es['lanes'], np.int),
```

```
 'maxspeed': str2num(g.es['maxspeed'], np.float)})

### US: lanes
### motorway/motorway_link/trunk/trunk_link: 2 or more
### others: 1
attribute_df.loc[(attribute_df['highway'].isin(['motorway', 'motorway_link',
'trunk', 'trunk_link'])) & (attribute_df['lanes']==0), 'lanes'] = 2
attribute_df.loc[attribute_df['lanes']==0, 'lanes'] = 1
### US: speed
### motorway/motorway_link: 65 mph
### trunk/trunk_link/primary/primary_link: 55 mph
### others: 25 mph
attribute_df.loc[(attribute_df['highway'].isin(['motorway', 'motorway_link'])) &
(attribute_df['maxspeed']==0), 'maxspeed'] = 65
attribute_df.loc[(attribute_df['highway'].isin(['trunk', 'truck_link', 'primary',
'primary_link'])) & (attribute_df['maxspeed']==0), 'maxspeed'] = 55
attribute_df.loc[attribute_df['maxspeed']==0, 'maxspeed'] = 25

# add capacity
### Capacity formula from the supplement notes in Colak, Lima and
Gonzalez (2016)
def add_capacity(maxspeed_array, lanes_array):
capacity_array = np.where(maxspeed_array<40, 950*lanes_array,
(1500+30*maxspeed_array)*lanes_array)
capacity_array = np.where(maxspeed_array>=60,
(1700+10*maxspeed_array)*lanes_array, capacity_array)
return capacity_array

attribute_df['capacity'] = add_capacity(attribute_df['maxspeed'],
attribute_df['lanes'])

### Create initial weight
```

```
attribute_df['fft'] = attribute_df['length']/attribute_df['maxspeed']*2.23694
### 2.23694 is to convert mph to m/s;
### the free flow time should still be calibrated rather than equal to the time
at speed limit, check coefficient 1.2 in defining ['weight']
attribute_df['weight'] = attribute_df['fft'] * 1.2 ### According to (Colak,
2015), for SF, even vol=0, t=1.2*fft, maybe traffic light? 1.2 is f_p - k_bay

### Convert to mtx
edgelist = g.get_edgelist()
print(edgelist[0:10])
row, row_x, row_y = [], [], []
col, col_x, col_y = [], [], []
for e in edgelist:
  row.append(e[0])
  row_x.append(g.vs[e[0]]['x'])
  row_y.append(g.vs[e[0]]['y'])
  col.append(e[1])
  col_x.append(g.vs[e[1]]['x'])
  col_y.append(g.vs[e[1]]['y'])
wgh = attribute_df['weight'].tolist()
print(len(row), len(col), len(wgh)) ### 549008 549008 549008
print(min(row), max(row), min(col), max(col), min(wgh), max(wgh)) # 0
224222 0 224222 0.01428062496 3346.709430817758

### Find the information for the longest link
print(np.argmax(wgh)) ### 321231
print(np.argmin(wgh)) ### 152598
#print(attribute_df.iloc[321231])

g_coo = sp.coo_matrix((wgh, (row, col)), shape=(g.vcount(), g.vcount()))
print(g_coo.shape, len(g_coo.data))
#g_csr = sp.csr_matrix(g_coo)
```

```
#sp.save_npz('../data/network_sparse.npz', g_csr)
sio.mmwrite(absolute_path+'/../data/{}/{}/network_sparse.mtx'.format
(folder, scenario), g_coo)
# g_coo =
sio.mmread(absolute_path+'/../data/{}/network_sparse.mtx'.format(folder))

### Additional Attributes from the graph
attribute_df['start'] = row
attribute_df['end'] = col
attribute_df['start_mtx'] = attribute_df['start'] + 1
attribute_df['end_mtx'] = attribute_df['end'] + 1
attribute_df['start_x'] = row_x
attribute_df['start_y'] = row_y
attribute_df['end_x'] = col_x
attribute_df['end_y'] = col_y
attribute_df.to_csv(absolute_path+'/../data/{}/{}/network_attributes.csv'.
format (folder, scenario))
```

Script 4 – Random OD background traffic

```
import sys
import random
import time
import os
import scipy.io as sio
import pandas as pd
import numpy as np
sys.path.insert(0, '/Users/Chiara')
#from sp import interface

 node_list = pd.read_csv('data/Joints.csv')

```

```
absolute_path = os.path.dirname(os.path.abspath(__file__))

folder = 'turin_osmnx'
scenario = 'undamaged'

def generate_random_OD(node_list, pair_count):
    used_pairs = set()
    used_pairs.add((node_list[0], node_list[-1]))
    while len(used_pairs) < pair_count:
    pair = tuple(random.sample(node_list, 2))
    if pair not in used_pairs:
    used_pairs.add(pair)
 return used_pairs

def test_connectivity(g, generated_pairs):
    unreached = 0
    for (origin, destin) in generated_pairs:
        od_sp = g.dijkstra(origin, destin)
        od_dist = od_sp.distance(destin)
        if od_dist > 10e7:
            unreached += 1
    return unreached

def main():
    ### read the mtx format graph into sp
    graph_file = absolute_path+'/../0_network/data/{}/{}/
    network_sparse.mtx'.format(folder, scenario)
    #g = interface.readgraph(bytes(graph_file, encoding='utf-8'))

g_coo = sio.mmread(graph_file)
node_count = g_coo.shape[0]
print("node count ", node_count)
```

```
### generate set of OD tuples
node_list = list(range(1, node_count+1))
target_OD_count = 25000
generated_pairs = generate_random_OD(node_list, target_OD_count)
print('{} OD pairs generated'.format(len(generated_pairs)))

### read the mtx format into scipy.sparse just to get vertex counts
g_coo = sio.mmread(graph_file)
node_count = g_coo.shape[0]
print("node count ", node_count)

### test the connectivity of the graph
#t0 = time.time()
#unreached = test_connectivity(g, generated_pairs)
#t1 = time.time()
#print('{} OD pairs not connected'.format(unreached))
#print('run time {}'.format(t1-t0))

### save
generated_od_list = list(generated_pairs)
generated_od_df = pd.DataFrame(generated_od_list, columns=['O', 'D'])

generated_od_df.to_csv(absolute_path+'/random_OD.csv'.format
(folder, target_OD_count), index=False)

if __name__ == '__main__':
main()
```

Script 5 – Closest node

```
import pandas as pd
import numpy as np
```

```
df_h=pd.read_csv(r'C:/Users/Chiara/Desktop/Tesi/bay_area_abm/1_OD/
data/Hospitals.csv')
df_n=pd.read_csv(r'C:/Users/Chiara/Desktop/Tesi/bay_area_abm/1_OD/
data/Nodes.csv')
df_b=pd.read_csv(r'C:/Users/Chiara/Desktop/Tesi/bay_area_abm/1_OD/
data/Buildings.csv')
df_h.head()
df_n.head()
df_b.head()
df_b = df_b[np.isfinite(df_b['ID'])]

def distance(coord1,coord2):
    return np.sqrt((coord1[0]-coord2[0])**2 +(coord1[1]-coord2[1])**2 )
import doctest
doctest.testmod()

def get_nearest_node_list(df_search, df_node):
   nearest_nodes = []
for index,row in df_search.iterrows():
   hospital_id = row["ID"]
   print (hospital_id)
   lat_h,long_h = row["Lat"],row["Long"]
   min_dist = np.inf
   nearest_node = None
for _, node_row in df_node.iterrows():
    node_id = node_row["NodeID"]
    lat_n,long_n = node_row["Lat"],node_row["Long"]
    dist = distance((lat_h,long_h),(lat_n,long_n))
    if  dist < min_dist:
       min_dist = dist
       nearest_node = node_id
nearest_nodes.append(nearest_node)
```

```
 #break
return nearest_nodes

hospital_node = get_nearest_node_list(df_h,df_n)
hospital_node
df_h["NodeID"] = hospital_node
building_lat = df_b['Lat'].values[:-2]
building_long = df_b['Long'].values[:-2]
node_lat = df_n['Lat'].values
node_long = df_n['Long'].values

node_ids = []
for _, b_row in df_b.iterrows():
   building_id = b_row["ID"]
   lat_b,long_b = b_row["Lat"],b_row["Long"]
  dist_map = np.sqrt(np.square(lat_b-node_lat)+np.square(long_b-node_long))
  node_idx = dist_map.argmin()
  node_id = df_n.iloc[node_idx]['NodeID']
  node_ids.append(node_id)

lennode_ids)
df_b["NodeID"] = node_ids
df_b_nodes = df_b[['ID','NodeID','Lat','Long']]
building_node = get_nearest_node_list(df_b,df_n)

df_b_nodes.to_csv(r'C:/Users/Chiara/Desktop/Tesi/bay_area_abm/1_OD/
data/Closest_joint_buildings.csv')
df_h.to_csv(r'C:/Users/Chiara/Desktop/Tesi/bay_area_abm/1_OD/
data/Closest_joint_hospitals.csv')
```

Script 6 – Casualties number for building

```
import numpy as np
import pandas as pd
df_injuries_num=pd.read_csv('data/Casualties_per_building.csv')
 df_buildings=pd.read_csv('data/ Closest_joint_buildings.csv ').drop(columns=
'Unnamed: 0').rename({'ID': 'BuildingID'}, axis=1)

df_injuries_num.head()
df_buildings.head()
df_merged = pd.merge(df_buildings, df_injuries_num, on='BuildingID')
df_injuries_num.shape
df_merged.shape
df_merged.head()
grouped = df_merged.groupby(['NodeID'])

node_id_list = []
severity1_list = []
severity2_list = []
severity3_list = []
severity4_list = []
building_num = []

for node_id,group in grouped:
    node_id_list.append(node_id)
    severity1_list.append(group['Severity 1'].sum())
    severity2_list.append(group['Severity 2'].sum())
    severity3_list.append(group['Severity 3'].sum())
    severity4_list.append(group['Severity 4'].sum())
    building_num.append(group.shape[0])

severity_dict = {'NodeID': node_id_list,'Severity1Sum': severity1_list,
```

```
'Severity2Sum': severity2_list,'Severity3Sum': severity3_list,
'Severity4Sum': severity4_list,'BuildingNum': building_num}
merged_table = pd.DataFrame(severity_dict)
merged_table.to_csv('data/Casualties_per_joint.csv')
```

Instruction to run Script 7 – Shortest path

- Download zip from https://github.com/cb-cities/sp and past the folder inside Users/Chiara
- Python got to be interfaced with C++ so, download from Microsoft store, Ubuntu 16.04 app and run it.
- Insert username and password as you want and using Ubuntu go ahead:

  $ sudo apt update

  $ sudo apt upgrade

  $ cd ../../mnt/c/Users/Chiara/

  $ sudo apt install cmake

  $ sudo apt-get install build-essential

  $ mkdir build (inside sp folder)
- Go into build with cd command

  $ cmake –DCMAKE_BUILD_TYPE=Release ../

  $ make clean && make –j4

  $ ./sp ../sf.mtx
- Download Sublime Text on www.sublimetext.com

  $ sudo apt install python3

  $ sudo apt autoremove

  $ python3
- Back to sp folder

  $ python3 interface.py
- To run shortest path script:

  $ sudo apt install python3-pip

  $ pip3 install numpy pandas

  $ pip3 install –upgrade pip

```
$ pip3 install pandas
```

Script 7 – Shortest path

```
import json
import sys
#import igraph
import numpy as np
from multiprocessing import Pool
import time
import os
import logging
import datetime
import warnings
import pandas as pd
from ctypes import *
absolute_path = os.path.dirname(os.path.abspath(__file__))
sys.path.insert(0, '/mnt/c/Users/Chiara')
from sp import interface
folder = 'turin_osmnx'
scenario = 'undamaged'
day = 1
hour = 1
def map_edge_flow(row):
### Find shortest path for each unique origin --> one destination
### In the future change to multiple destinations
origin_ID = int(OD_ss['graph_O'].iloc[row]) #+ 1 ### origin's ID to
graph.mtx node ID
```

```
destin_ID = int(OD_ss['graph_D'].iloc[row]) #+ 1 ### destination's ID to
graph.mtx node ID
agent_type = int(OD_ss['graph_Agent_Type'].iloc[row])
traffic_flow = int(OD_ss['flow'].iloc[row]) ### number of travelers with this
OD

results = []
sp = g.dijkstra(origin_ID, destin_ID)
sp_dist = sp.distance(destin_ID)
if sp_dist > 10e7:
    return [], 0, (origin_ID, destin_ID, agent_type, 10e7), 0 ### empty path;
 not reach destination; travel time set to 10e7
    else:
    sp_route = sp.route(destin_ID)
    results = [(edge[0], edge[1], traffic_flow) for edge in sp_route]
    # if ((8635, 1618, traffic_flow) in results) & OD_ss['ss_id'].iloc[row]>0:
   #     print(results, sp_dist)
 return results, 1, (origin_ID, destin_ID, agent_type, sp_dist), sp_dist
 ### non-empty path; 1 reaches destination; travel time

 def edge_tot_pop(edge_flow_tuples, day, hour, ss_id):
     flat_list = [(p[0], p[1], p[2]) for sublist in edge_flow_tuples for p in sublist]
     flat_list_df = pd.DataFrame(flat_list, columns=['id_start_joint',
     'id_end_joint', 'ss_vol'])
     edge_volume = flat_list_df.groupby(['id_start_joint',
    'id_end_joint']).agg({'ss_vol': np.sum}).reset_index()
 return edge_volume

 def map_reduce_edge_flow(day, hour, ss_id):
 ### One time step of ABM simulation
     if OD_ss.shape[0] == 0:
```

```
    edge_volume = pd.DataFrame([], columns=['id_start_joint', 'id_end_joint',
    'ss_vol'])
 return edge_volume

### Build a pool
process_count = 4
pool = Pool(processes=process_count)

### Find shortest pathes
unique_origin = OD_ss.shape[0]
res = pool.imap_unordered(map_edge_flow, range(unique_origin))

### Close the pool
pool.close()
pool.join()

### Collapse into edge total population dictionary
edge_flow_tuples, destination_counts, travel_time_list_incre,
ss_travel_time_list = zip(*res)
edge_volume = edge_tot_pop(edge_flow_tuples, day, hour, ss_id)
travel_time_list_incre_df = pd.DataFrame(list(travel_time_list_incre),
columns=['O', 'D', 'agent_type', 'travel_time'])
if ss_id == 20:
    travel_time_list_incre_df.to_csv(absolute_path+'/
    casualties_travel_time.csv', index=False)
    print(ss_id, np.mean([t for t in ss_travel_time_list if t>0]),
    np.max(ss_travel_time_list))
return edge_volume

def update_graph(network_attr_df, edge_volume, day, hour, ss_id,
total_demand, assigned_demand):
    if assigned_demand == 0:
```

```
return network_attr_df

### first update the cumulative link volume in the current time step
network_attr_df = pd.merge(network_attr_df, edge_volume, how='left',
on=['id_start_joint', 'id_end_joint'])
network_attr_df = network_attr_df.fillna(value={'ss_vol': 0}) ### fill volume
for unused edges as 0
network_attr_df['true_vol'] += network_attr_df['ss_vol'] ### update the total
volume (newly assigned + carry over)
nework_attr_df['true_flow'] =
network_attr_df['true_vol']*total_demand/assigned_demand

if ss_id < 20:
    network_attr_df['t_avg'] = network_attr_df['fft']*(1 +
    0.6*(network_attr_df['true_flow']/network_attr_df['capacity'])**4)*1.2
    update_df = network_attr_df.loc[network_attr_df['t_avg'] !=
    network_attr_df['previous_t']].copy().reset_index()
    for row in update_df.itertuples():
    g.update_edge(getattr(row,'id_start_joint'), getattr(row,'id_end_joint'),
    c_double(getattr(row,'t_avg')))
    #g.writegraph(bytes(absolute_path+'/graph/{}_graph.mtx'.format(ss_id),
    encoding='utf-8'))
    network_attr_df['previous_t'] = network_attr_df['t_avg']
    #g =  interface.readgraph(bytes(absolute_path+'/graph/{}_graph.mtx'.
    format(ss_id), encoding='utf-8'))
    network_attr_df = network_attr_df.drop(['ss_vol'], axis=1)
return network_attr_df

def read_OD1():
   ### Read the OD table
   OD1 = pd.read_csv(absolute_path+'/../2_ABM/OD1.csv')
   OD1['graph_O'] = OD1['O']
```

```
    OD1['graph_D'] = OD1['D']
    OD1['graph_Agent_Type'] = 0
    OD1['flow'] = 1
    OD1 = OD1[['graph_O', 'graph_D', 'graph_Agent_Type', 'flow']]
    OD1 = OD1.sample(frac=1).reset_index(drop=True) ### randomly
    shuffle rows
    print('OD1 length {}'.format(OD1.shape[0]))
return OD1

def read_OD2():
    ### Read the OD table
    OD2 = pd.read_csv(absolute_path+'/../2_ABM/OD2.csv')
    OD2['graph_O'] = OD2['O']
    OD2['graph_D'] = OD2['D']
    OD2['graph_Agent_Type'] = OD2['Agent_Type']
    OD2['flow'] = 1
    OD2 = OD2[['graph_O', 'graph_D', 'graph_Agent_Type', 'flow']]
    OD2 = OD2.sample(frac=1).reset_index(drop=True) ### randomly
    shuffle rows
    print('OD2 length {}'.format(OD2.shape[0]))
 return OD2

def output_network_attr_df(network_attr_df, day, hour):
### Aggregate and calculate link-level variables after all increments
### Output
network_attr_df[['id_road', 'true_vol', 'true_vol1', 'true_vol2', 't_avg',
'fft']].to_csv(absolute_path+'/output/edges_df_test_injured.csv', index=False)

def main():
### Read in the initial network and make it a global variable
global g ### weighted graph
g = interface.readgraph(bytes(absolute_path+'/../0_network/graph.mtx',
```

```
encoding='utf-8'))
global OD_ss ### substep demand

### Read in the edge attribute for volume delay calculation later
network_attr_df = pd.read_csv(absolute_path+'/../0_network/
graph_attributes.csv')
network_attr_df = network_attr_df[['id_road', 'id_start_joint', 'id_end_joint',
'length', 'capacity', 'fft']]
network_attr_df['previous_t'] = network_attr_df['fft']*1.2
network_attr_df['true_vol'] = 0
network_attr_df['t_avg'] = network_attr_df['fft']*1.2

### Define substep parameters
substep_counts1 = 20
substep_ps1 = [1/substep_counts1 for i in range(substep_counts1)]
### probability of being in each substep
substep_ids1 = [i for i in range(substep_counts1)]

### Read the OD pairs
OD1 = read_OD1()
OD1 = pd.DataFrame([], columns=['graph_O', 'graph_D', 'flow'])
OD2 = read_OD2()
#print(OD.head())
#sys.exit(0)

total_demand = OD1.shape[0] + OD2.shape[0]
assigned_demand = 0

### Divide into substeps
OD1_msk = np.random.choice(substep_ids1, size=OD1.shape[0],
p=substep_ps1)
OD1['ss_id'] = OD1_msk
```

```
OD2['ss_id'] = 20

for ss_id in substep_ids1:
    OD_ss = OD1[OD1['ss_id'] == ss_id]
    #assigned_demand += OD_ss.shape[0]
    assigned_demand = total_demand
    ### Routing for this substep (map reduce)
    edge_volume = map_reduce_edge_flow(day, hour, ss_id)
    ### Updating
    network_attr_df = update_graph(network_attr_df, edge_volume, day,
    hour, ss_id, total_demand, assigned_demand)
    network_attr_df['true_vol1'] = network_attr_df['true_vol']
    # output_network_attr_df1(network_attr_df1, day, hour)

ss_id = 20
OD_ss = OD2[OD2['ss_id'] == ss_id]
#assigned_demand += OD_ss.shape[0]
assigned_demand = total_demand
### Routing for this substep (map reduce)
edge_volume = map_reduce_edge_flow(day, hour, ss_id)
### Updating
network_attr_df = update_graph(network_attr_df, edge_volume, day, hour,
ss_id, total_demand, assigned_demand)
network_attr_df['true_vol2'] = network_attr_df['true_vol'] –
network_attr_df['true_vol1']
# output_network_attr_df2(network_attr_df2, day, hour)
output_network_attr_df(network_attr_df, day, hour)

sta_stats1 = []
sta_stats2 = []
### Update carry over flow
sta_stats1.append([
```

```
    day, hour,
    np.sum(network_attr_df['fft']*network_attr_df['true_vol1']/OD1.shape[0]),
    np.sum(network_attr_df['t_avg']*network_attr_df['true_vol1']/OD1.shape[0]),
    np.sum(network_attr_df['length']*network_attr_df['true_vol1']/OD1.shape[0]),
    np.mean(network_attr_df.nlargest(10, 'true_vol1')['true_vol1'])
            ])
    print(sta_stats1)

sta_stats2.append([
    day, hour,
    np.sum(network_attr_df['fft']*network_attr_df['true_vol2']/OD2.shape[0]),
    np.sum(network_attr_df['t_avg']*network_attr_df['true_vol2']/OD2.shape[0]),
    np.sum(network_attr_df['length']*network_attr_df['true_vol2']/OD2.shape[0]),
    np.mean(network_attr_df.nlargest(10, 'true_vol2')['true_vol2'])
            ])
    print(sta_stats2)

def test():
    travel_time = pd.read_csv('travel_time_injured.csv')
    travel_time = travel_time[(travel_time['travel_time']<1e7) &
    (travel_time['travel_time']>0)]
    print(travel_time.describe())
    print(np.sum(travel_time['travel_time']))

if __name__ == '__main__':
np.random.seed(0)
main()
test()
```

2

Hospital Network

The performance assessment of a system under pressure, as it can be a city during extreme weather events, is not easy to define in advance because there is a huge amount of details have to be considered. Simplifying the situation to build a model, infrastructures are identified as more influent elements on disaster resilience. As a matter of fact, during an emergency like flood, earthquake or fire, or also non-natural event like terrorist attack, cities or regional systems are obviously shocked and the infrastructures are certainly one of their components hardcore for the casualties report. Lifeline system can cause consistent, even cascading, damage and further slowdown at the rescuer but without roads and hospitals, people can't be saved, especially without the second one. This is the reason why healthcare facilities have to remain in use in every situation and it's clear it is very important to analyze and to assess their functionality in order to find a solution in case of weakness and to prevent them.

The tool choose for this purpose is a Discrete Event Simulation Model. It is able to deal with situations keep changing, taking better decisions faster than any human being highly qualified. To better understand his functionality an elevator inside a skyscraper can be taken as example (Fig. 8). Considering every two minutes the situation of waiting agents at different floor changes because someone joined the queue and/or others chose the stairs, a DES model is able to compute the stops order that guarantees to each agent to wait for the shortest possible time.

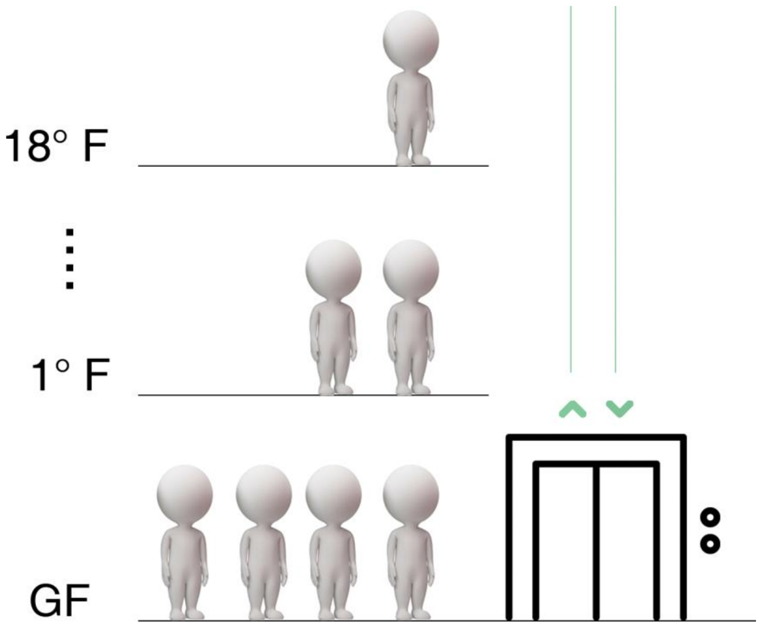


Fig. 8. DES graphic explanation

This work wasn't possible without helpful suggestions by Molinette health management, Operative Center 118 Emilia Est and the Italian branch of Emergo Train system. In particular thanks to Diego Visconti (Molinette PEIMAF Director) and Alfonso Flauto (Operative Center nurse, full scale simulation director at AUSL Bologna and ETS teacher).

• Methodology

The key elements for understanding the methodology behind the development of a Discrete-Event Simulation Model for a hospital, are described in this paragraph. For a more complete and wider understanding, the following section 3 (Case study) is suggested to read. That part includes practical concepts explanation that will help the reader to better understand the hospital network's simulation and reproduce the proposed solution.

The procedure can be summarized in two different steps:

1. Data collection
2. Data entry

Software

In this research, the emergency department simulations, has been developed by MedModel 2018. The student version was downloaded at the cost of 35$, on August 21st, 2018. MedModel is a discrete-event simulation (DES) software. And it' s a specified version of Promodel for healthcare facilities, having a more appropriate library. For using it, there is need of previous knowledge about the functioning of an Emergency Department; it's not enough just to be able to handle a simulation software. In fact a lot of meeting has to be scheduled with someone amongst the medical staff, specialized in management of maxi-emergency. The purpose of this phase is to learn the necessary information and how to simplify the most difficult ones.

First Step – Data Collection

Building a model, there is need to define inputs data both for ordinary and emergency conditions. Furthermore, information can be split into external and internal input. The first concerns incoming patients flow and his daily distribution. The second groups all the features typical of each healthcare facility as plan and locations' position, resources' number (like doctor, nurses, ambulances, medical tools and so on), internal paths, time in operation for each type of injured patient and their rate for each travelled route.

Second Step – Data Entry

Data entry work changes according to the software in use. MedModel classifies those previous information into the following categories:

- Plan of the hospital called background graphic;
- Entities, people to be cured. The model won't stop until the last one is stepped out. In this case there are different type of patients according to their severity level. The speed with which they move can be defined;
- Locations represent fixed area from and to where entities can move. The capacity and the number of units for each time of location, can be set up as other rules like: which entity can get in first (the oldest one by priority, randomly, that one with the highest or lowest attribute value etc.) and when can head out (there is no queue so they are free, the first in is the first out, the last in is the first out, the order is dictated by the attribute value etc.);
- Arrivals are the incoming entities at one specific location. The number of occurrences, when the first lap starts and which is the frequency they occur, have to be delineated. Under logic field it is possible to specify the priority, giving a value to the respective attribute. While establishing the arrival cycle of the patients, a specific table has to be filled out with rates or quantity for each hour. This is the part where data are the output of the previous model;
- Resources are person, piece of equipment or other device used to cure the entities or just to accompany them through all the path. Established the number of each type of resource, on which road network they can move,

which is the node-home of the network and which entity has to looking for first, another element can be explained;

- Path Network, a series of links and nodes where entities can move, connecting different area of the plan. Patients and resources walk just on the drawn path network. Any locations must be connected at one node. Sometimes there are two possible route to go from one point to another. In this section it's possible to specify which one must be traveled. How long it takes to go from one node to another, is automatically computed based on the layout scale and the movement speed defined by the user;
- When there are so many agents running around, the variables are extremely useful. They are counter, visible even during the simulation to have a full understanding of the numbers of agents we are looking at;
- Attributes are subdivision of an entity typology. Inside the hospital there are different path according to the casualties level and type. For instance a green patient can follows different roads inside the healthcare facility. Each path has a corresponding value and to channel the patient into the correct direction, the respectively value of that path is attached to him as attribute;
- Users distribution is a tool delineating the percentage of incoming patients for each attribute value. The entire is the number defined in the arrivals section.
- When the main items are described, the routing and process sector interconnect all of them obtaining interactions that the software must handle in the best possible way.

In addition, Medmodel provide other tools to better interpret the real functionality of the ED, but in our model, we won't consider them. Once it's all set up, for running the model, some simulation options, like the run length, type of scenario, clock precision, number of replications, has to be decided. To conclude, a editable page with all the results will show up.

Emergo Train System

Often, data, especially if interests situations where people can pass away, are very sensible and the structures involved don't allow leak of information. This thesis has been affected by lack of hardcore data about incoming patients characteristics on average. ETS helped to fill the gaps defining patients subdivision based on injuries and not just by triage code, and then, for each group, their percentage, internal path and time spent in each location (Fig. 9).

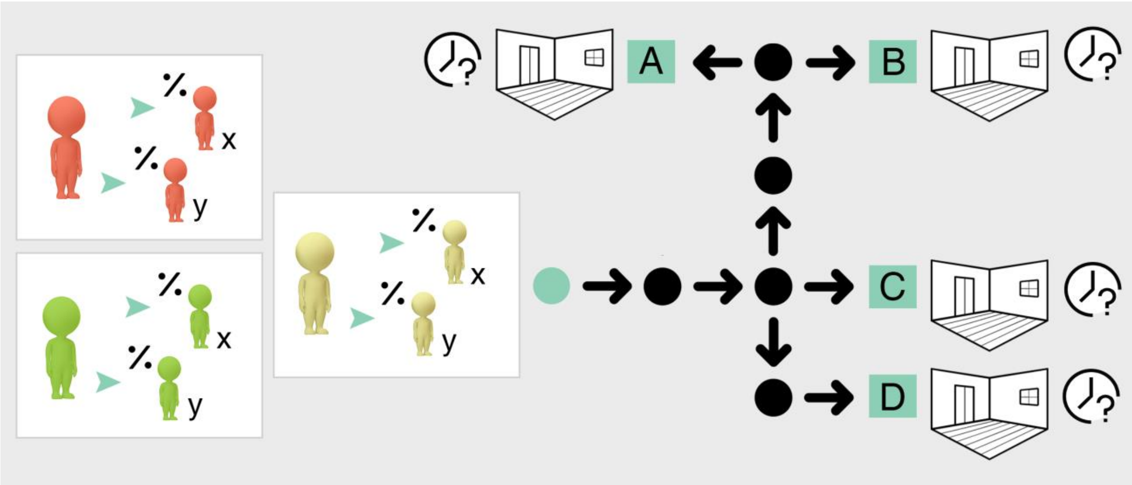


Fig. 9. ETS usage graphic explanation

Emergo Train System is a new method for education and training into emergency and disaster medicine. It was developed by the KMC (Centre for Teaching and Research in Disaster Medicine and Traumatology in Linköping (Sweden) in collaboration with Linköping University. It is used over 35 countries but there are just eighteen centers authorized for teaching: Linköping in Sweden, Helsinki (Finland), Bologna (Italy), Auckland, Seoul (Korea), Al Ain (United Arabic Emirates). Dr. Stefano Badiali took ETS in Italy in 1997 but he received the license to use it around all Italian territory just in 2013. Thanks to Alfonso Flauto, nurse of the 118 Emilia Romagna's operation center and member of ETS Italy, I learnt a lot about this method more and more used into disaster training. On their website Emergo Train System is defined as a tool useful for: education and training in emergency and disaster medicine, education and training in command and control, testing preparedness and management of emergencies, major incidents and disasters, testing organizations, table top and surge capacity exercises, training and evaluation of individual roles and functions throughout the response system, evaluation of patient outcome, data collection and research.

ETS consists in magnetic boards on which the staff could move some puppets, imagining it is a real situation as shown in figure 10. On each puppets there's written on the front what is the condition the rescuer has to deal with (if patients speaks or he doesn't respond, if he can walk or not, how he looks and what is visible, etc.), while on the back there are some medical value easily to obtain in the near minutes or seconds. There are different type of puppets according to the critical situation: car crush, fire, war, bomb, building collapse and so forth. After numerous drills, ETS lists a set of movements with the correspondent execution average time, accomplished during the rescue and even inside the hospital. Hence, the missing real information can be patched with these simulated data but internationally used.

Fig. 10. ETS practical emergency simulation

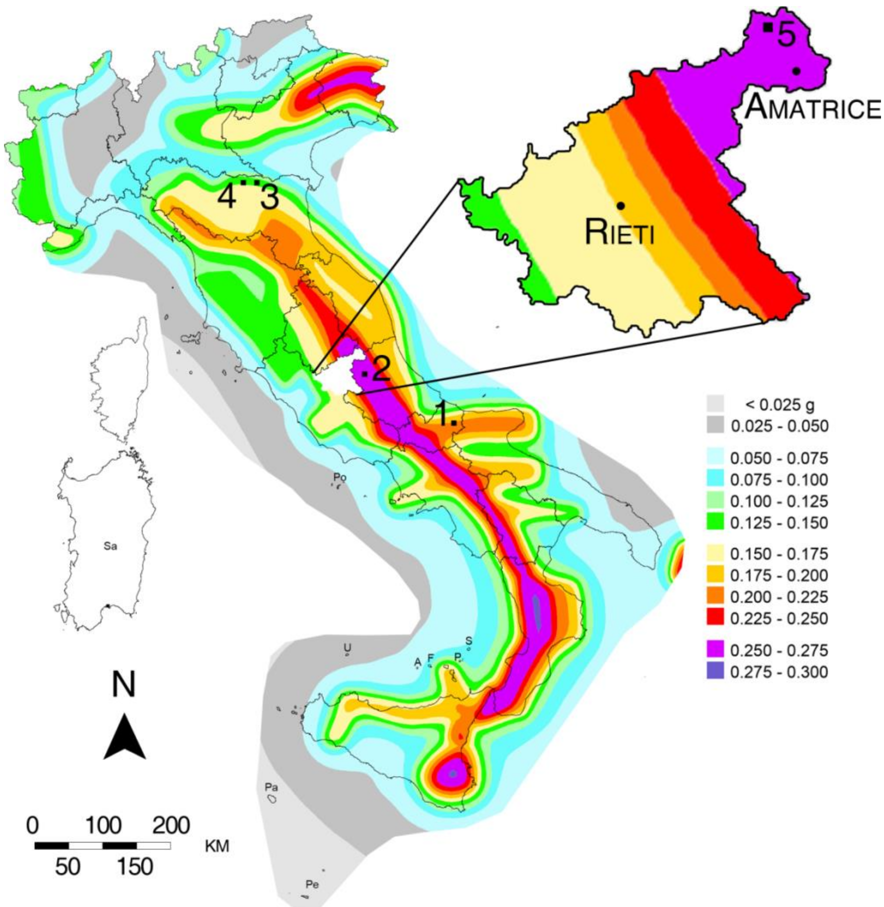
3

Case Study

Italy is almost entirely a seismic zone, especially the center, which saw recently the collapse of entire cities caused by earthquakes, as for instance Amatrice and her surroundings, with the earthquakes of 2016, or L'Aquila in 2009. Figure 11 shows the levels of seismicity of the Italian territory and lists the major Italian earthquakes of the 21st century. These are also areas where mobility needs leads to rapid traffic arteries, and no less, in the first case at least one specialized healthcare facilities because the only hospital was very small (ten bed at the moment of the accident) and it wasn't able to treat people highly injured. Therefore when a maxi-emergency occurs, it takes very long time for the rescue to arrive on the site and after picking-up the evacuating casualties, going back and dropping them off to a prepared hospital (Fig. 12-13).

The issue of researching on previous disasters is that reliable historical data (of traffic or the patients' numbers the hospitals had to deal with) are very difficult to obtain in general, especially if the investigations are still in progress. The same for different emergencies like in Piazza San Carlo (Turin) on June 3rd, 2017, when the scared crowd escaped from a false alarm, killing a few people and lightly injuring the most part of those present.

The first goal was thus to analyze a real emergency to identify some mistakes in the management and functioning of the road and hospital networks and to suggest some improvements post-eventum. But because of the preceding motivations, the final case study will be simulated. It is located in the northwest of Italy, in particular in Turin, a city extends among the Pianura Padana. The choice fell on this area because an inherent European research ("Ideal Rescue" see Introduction) was already set there and this dissertation can provides her a consistent help. The investigation where I'm getting in is headed by two researcher Ali Zamani, Sebastiano Marasco and a PhD Alessandro Cardoni from Politecnico of Turin. They're trying to create a large-scale virtual environment called Ideal City that is based on the city of Turin in Italy. It interconnects different lifeline system (electric, power, water, waste water, transportation, hospital) and if subjected to a stress, it reacts and shows the results specific for each network, offered by the city. A GUI interface allows to choose the hazard's type and the number of networks to analyze. Despite the typical hazard in Turin is flood, the dissertation estimates the answers after an earthquake. In particular, an earthquake with the same features of Norcia's seism hit the center of Italy on August 2016. Nevertheless, the methodology won't be just specific for this case but easily applicable, if useful data are known, on different framework where seismic forces could be more frequent. In this thesis transportation and hospital networks are performed.



N°	Date	Epicenter	Richter Scale	Moment Magnitude scale
1	31 October 2002	San giuliano	5,8 ML	6 M_w
2	6 April 2009	L'Aquila	5,9 ML	6,3 M_w
3	20 May 2012	Finale Emilia	5,9 ML	5,9 M_w
4	29 May 2012	Medolla	5,8 ML	5,7 M_w
5	24 August 2016	Accumuli	6 ML	6 M_w

Fig. 11. **M**ajor italian earthquakes of the 21st century

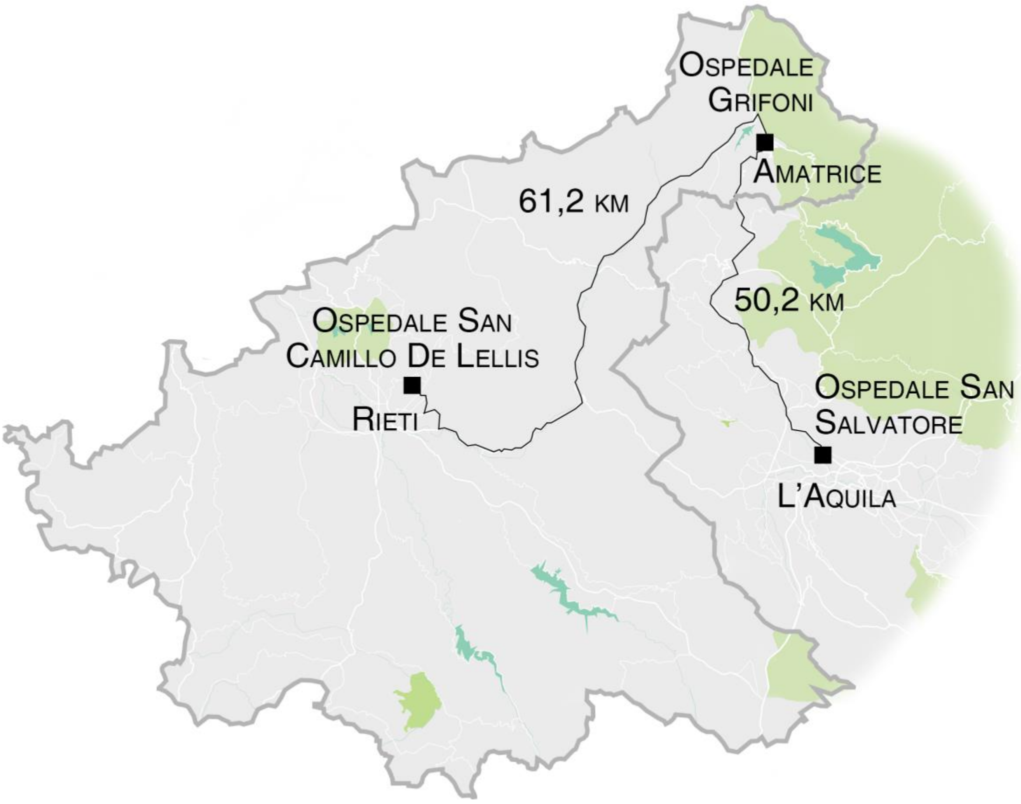


Fig. 12. Ambulances path

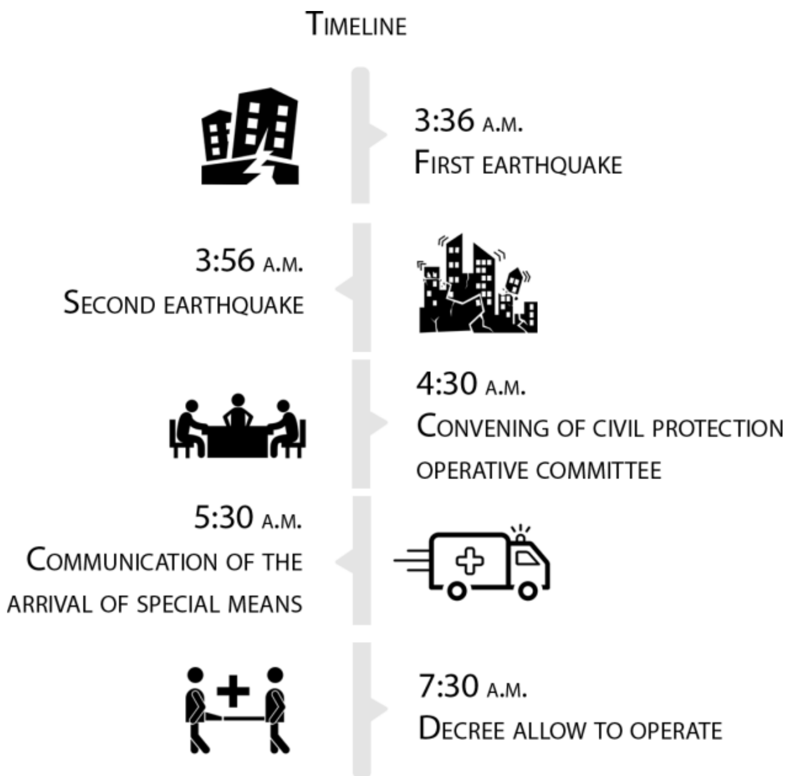


Fig. 13. Timeline before rescuing

The following image (Fig. 14) schematizes the case study flow chart.

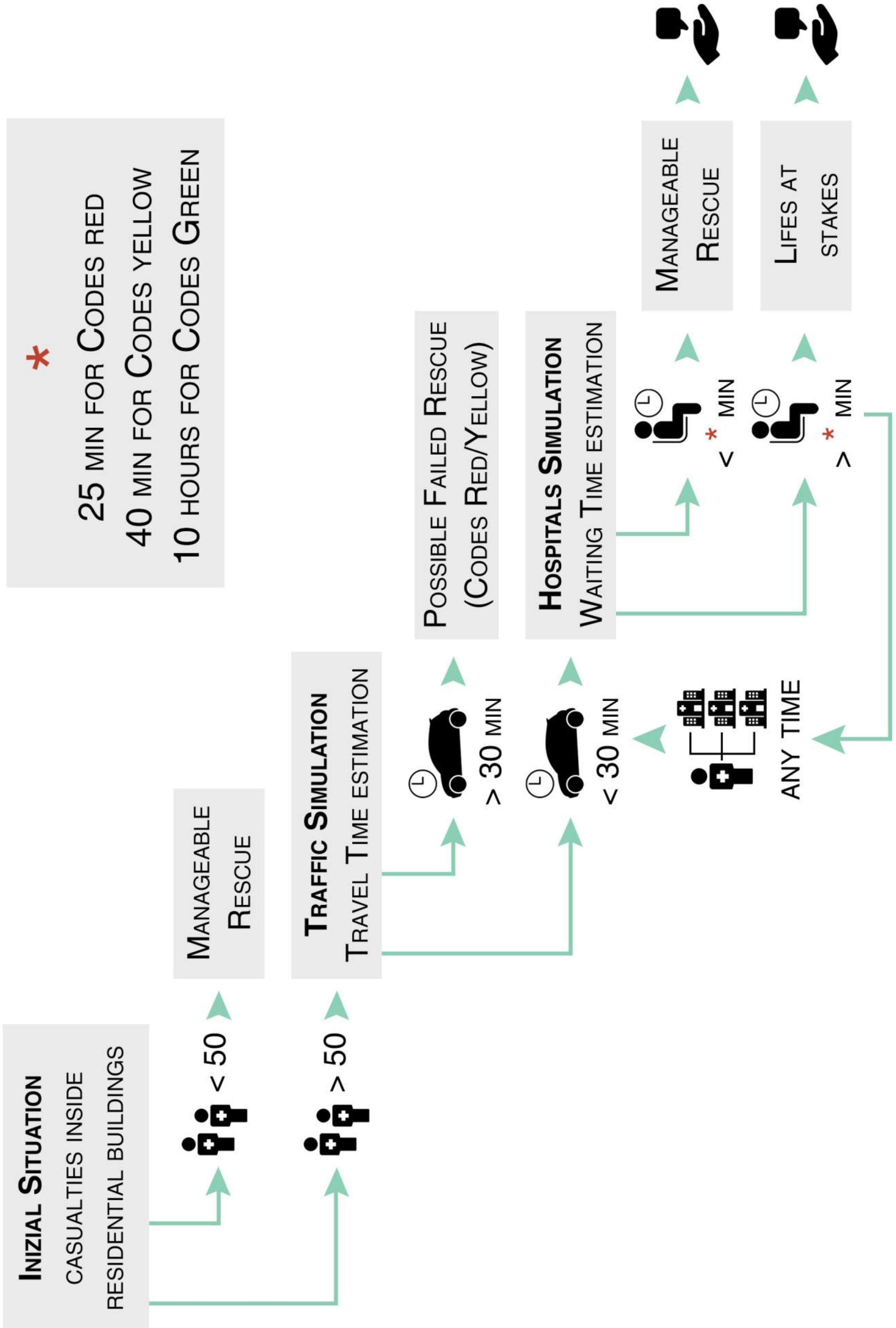


Fig. 14. Case study flow chart.

• Transportation Network

Scenario

The results of a traffic simulation could change according to the day of the week and the hour of the day. Thus, initially two scenario were analyzed: one during the night between 4:00 and 5:00 a.m., when travelling cars are approximately just 2300, the second one, throughout the day peak hour (6:00 – 7:00 pm) with around 25000[3] drivers. The result was a 40% difference of travel time but then it was realized the number of casualties was computed just keeping in consideration residential buildings. So, in light of this, the day scenario was dropped and another at night was added. The difference between the two nocturnal scenario is the second has a certain amount of closed roads by debris belonging to collapsed buildings. This calculation was made by Cimellaro's research team and figure 15 shows a part of Ideal City with the unusable streets.

Fig. 15. Ideal City center with closed roads.

[3] Data from https://www.muoversiatorino.it/it/numeri-mobilita/, consulted on September 3rd, 2019.

Input

The simulated event is an earthquake strikes with the same features of the earth tremor in Norcia on 2016. The magnitude registered was 6 on the Richter Scale, so this is the same intensity hits the Ideal City model with 23.417 buildings. Domaneschi et al. (2018) and Zamani et al. (2019) worked on residential buildings reaction. They aimed, respectively, to improve the prediction of structural damage level caused by a seismic hazard, and to estimate four severity levels of casualties (1 to 4, correspondingly minor and critical injury level). According to them, the number and the severity grade is strictly correlated to the buildings level of damage. So, the casualties number and their locations are found (Fig.16). From this point this dissertation begins. The goals are multiple: to create an external stress for the hospitals and to investigate the interactions between the single health facilities with the transportation and hospital networks. Afterwards identify critical weaknesses and solution to increase the networks' performance. Specifically, the focus is on modelling the casualties flow directed to the closest hospital, calculating the average

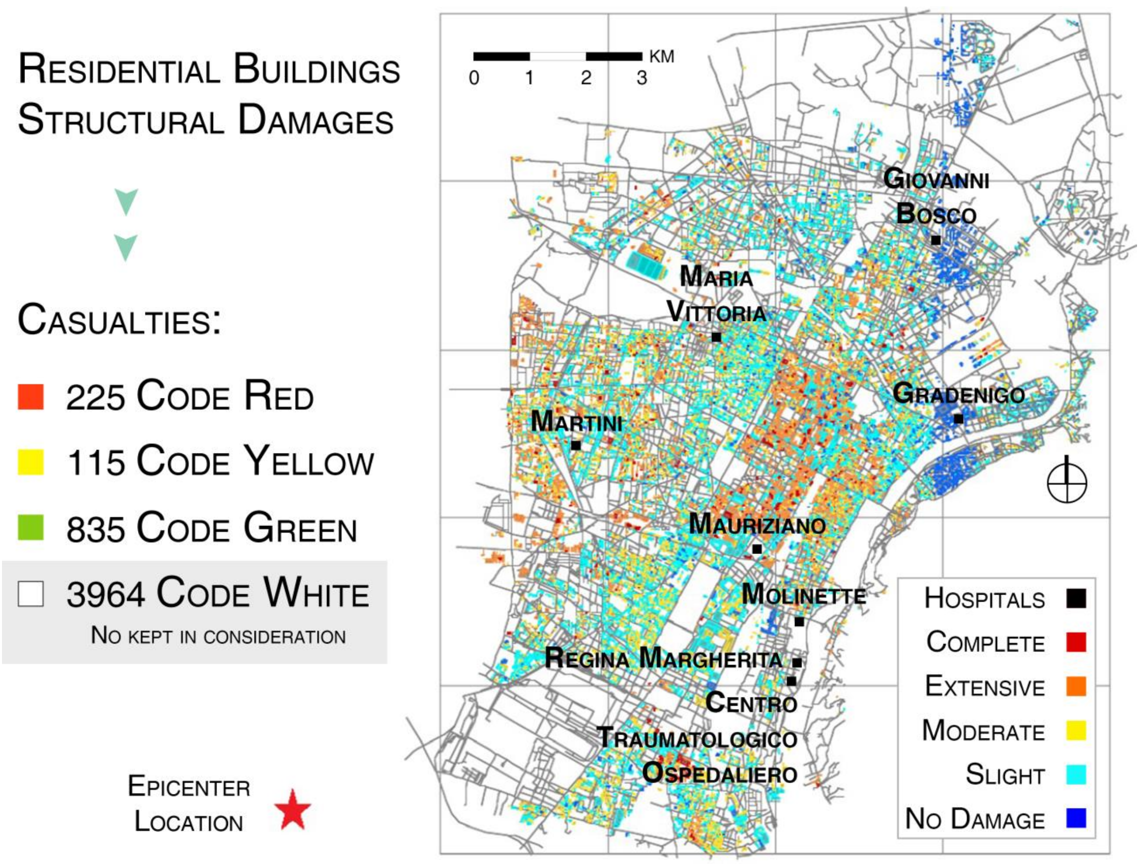


Fig. 16. Residential building structural damage and casualties total amount.

waiting time for the patients at the emergency room and if it isn't satisfying, organizing a redistribution towards other healthcare facilities of the network, less crowded in that moment.

Framework description

This paragraph aims to complete the overview already made inside the methodology section of chapter 1. As said there are four steps. With the first a graph is obtained, the second and third add to the graph respectively the origins and destinations joints of the background traffic and of the wounded people, the last one computes the shortest path for each agent in term of time.

All starts with the environment print, made using AutoCad, representing a graph composed by 23.714 links and 10.780 nodes (Fig. 17). Agents move on it as if links and nodes were roads and intersections. The total amount of casualties as is presented in the previous paragraph is 1175, 225 of which are red, 115 are yellow and 835 are green. White patients aren't treated during emergency thus they aren't considered.

Fig. 17. Ideal City graph.

Limitations

- Being a macroscale agent-based model, instead of microscale, traffic lights and stops aren't contemplated, but a percentage of delay has been included into the script.
- Random OD list for the traffic can't be very realistic because the traffic jam is always located in specific zones.
- Simulation localized people just inside residential buildings.
- Staggering departure aren't set up and all the agents leave together because the ambulance system is not included yet.

Results

This simulation permits to give a schedule for the arrivals time at the hospitals. But, not having staggered starts, for the hospital simulation is used another distribution, at least until the ABM code won't be updated with the ambulance system.

Scenario A

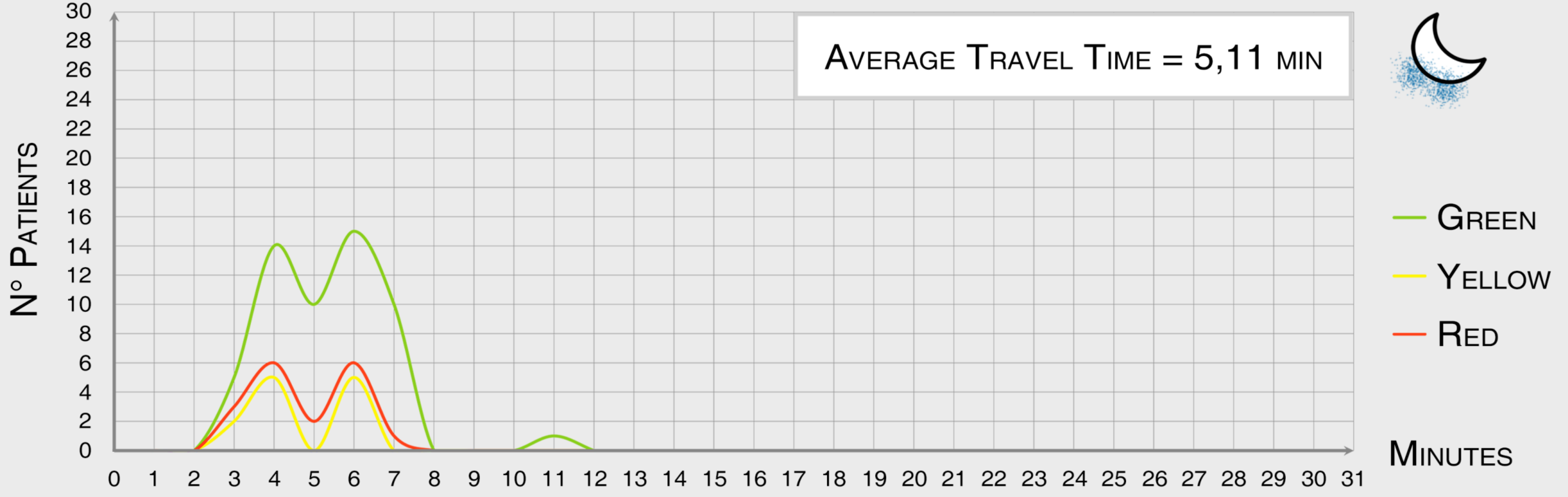
The results show 1175 agents at night, when they are not obligated to take deviations, get to the closest hospital by maximum twelve minutes. Looking at the following graphs, Mauriziano, Martini and Maria Vittoria hospitals receive the largest number of injured people. The explanation can be found in figure 16 where the buildings more damaged are those around these three hospital because are the older area of the city. The average travel time are quite low but it is pretty plausible that without traffic light and traffic, people could arrive at destination by an average time of 5,26 minutes. Regina Margherita is the only facility to rest because nobody get there. The reason is the extreme closeness to CTO entrance.

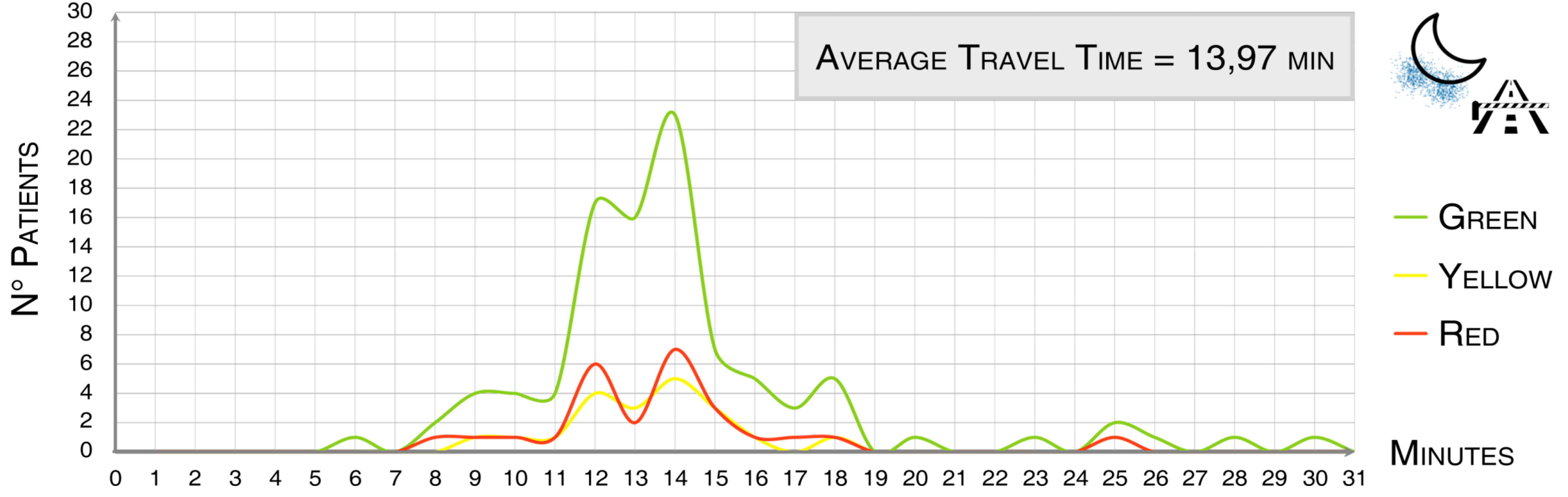
Scenario B

In this case interesting differences must be noticed. First of all 1175 leave but just 1103 finish their path because 72 agents are stuck in their building or can't arrive at destination. In fact Gradenigo has the entrance to the emergency department blocked by debris and the simulation hijack the theoretical arrivals towards the second hospital in order of closeness. Another structure not to get patients is Regina Margherita. In this case, collapsed buildings are not the problem but even here, the CTO entrance is practically in front of it and according to abm computation, CTO is always closer than a few seconds. Having two less hospitals, their patients will be added to someone else. In fact Giovanni Bosco, Molinette and CTO have an average growth of injured people of 53%. In contrast with this increment, Martini and Maria Vittoria have less patients in this scenario. Their casualties probably found too much closed roads on their path compared to the route to get to Giovanni Bosco and Mauriziano, which has an increase too.

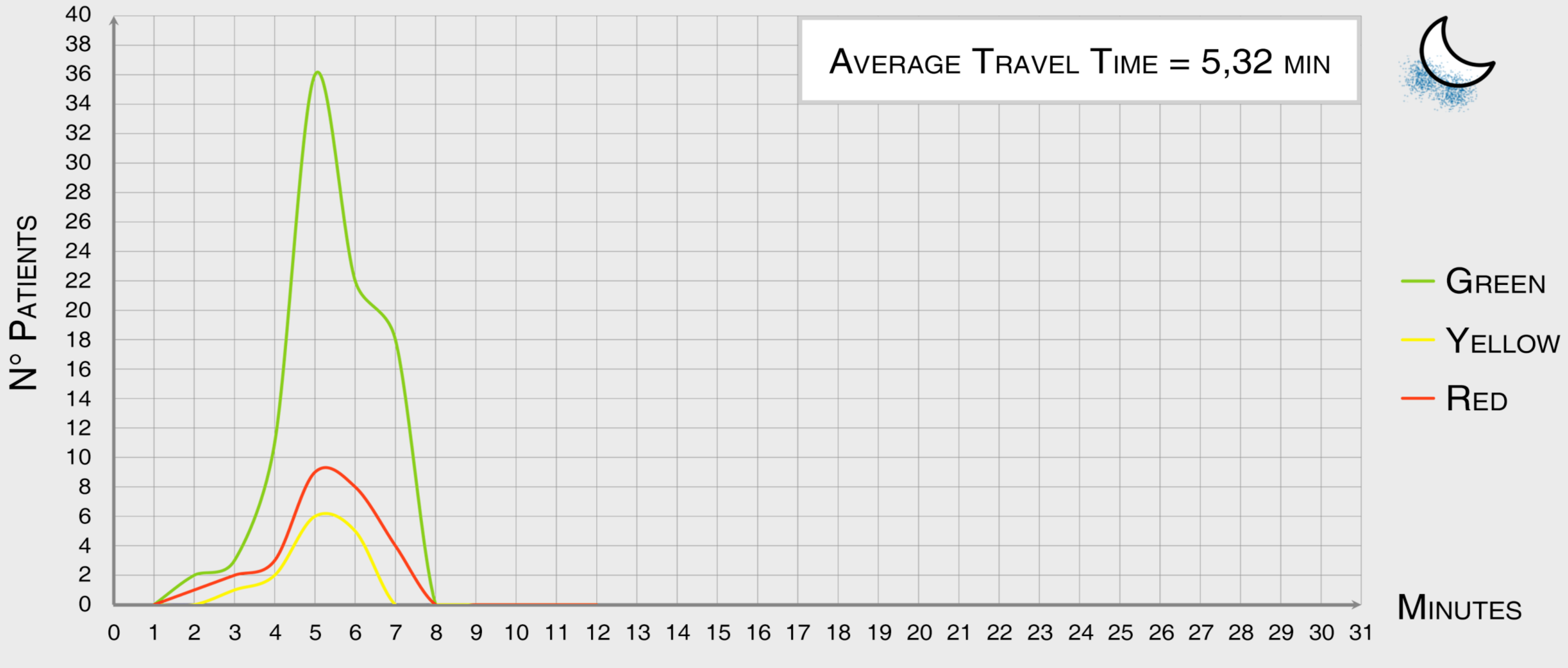
In a glance, in both scenario there is inequality in the distribution of patients. Obviously a redistribution has to be done after knowing the maximum capacity of the hospitals more stressed. The redistribution results are exposed in the second section of this chapter.

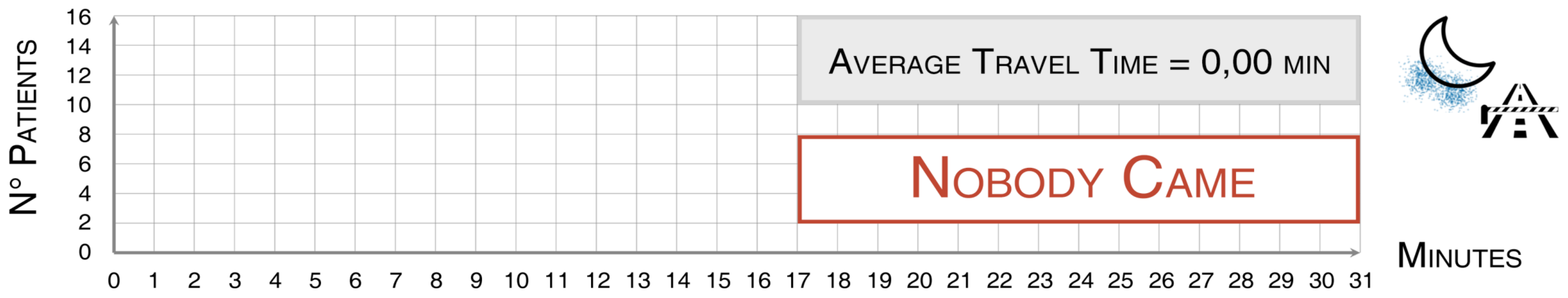
Giovanni Bosco


N° Patients
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Average Travel Time = 5,11 min
Green
Yellow
Red
Minutes

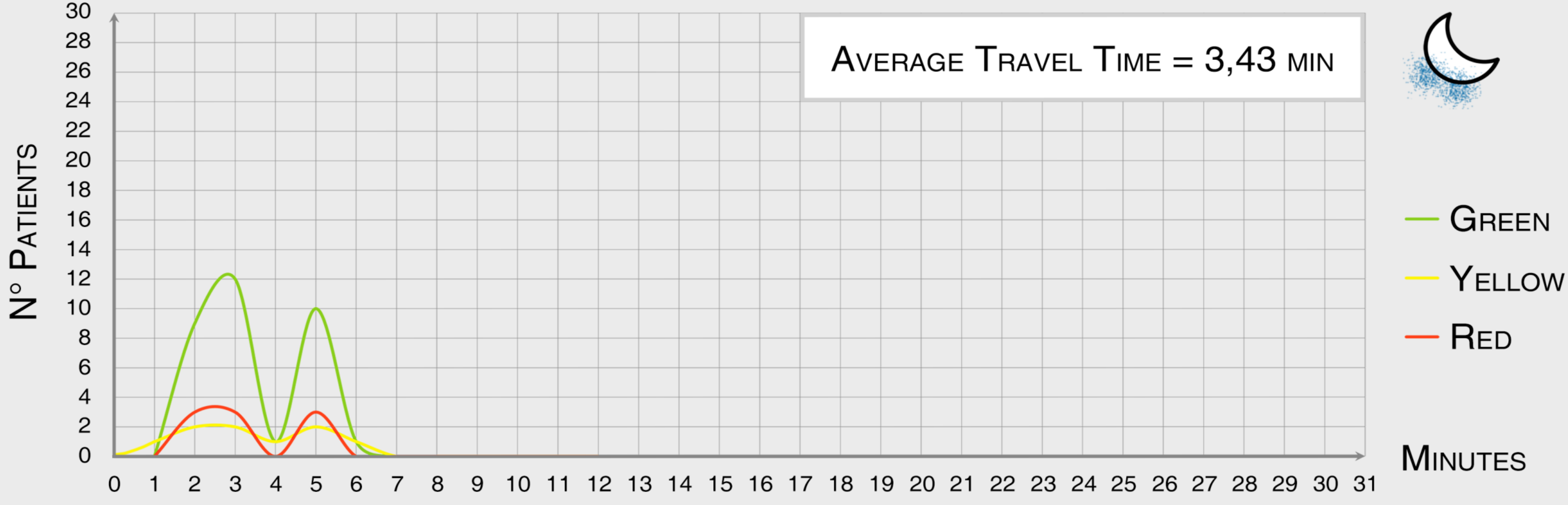

N° Patients
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Average Travel Time = 13,97 min
Green
Yellow
Red
Minutes

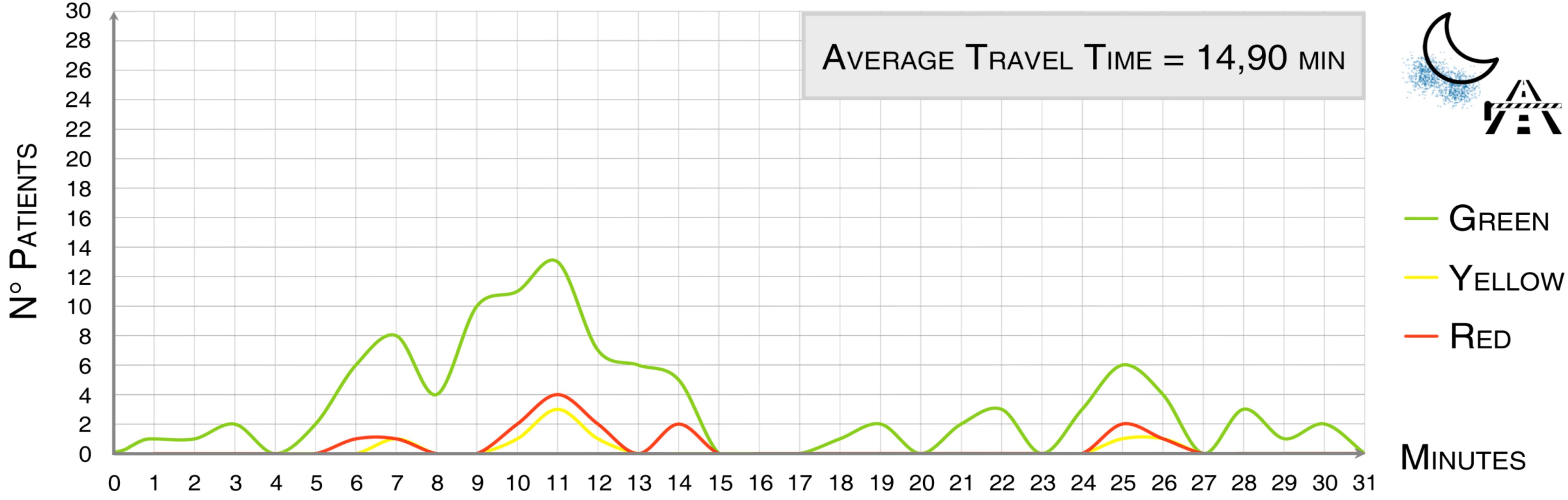
GRADENIGO


Average Travel Time = 5,32 min
Green
Yellow
Red
N° Patients
Minutes
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

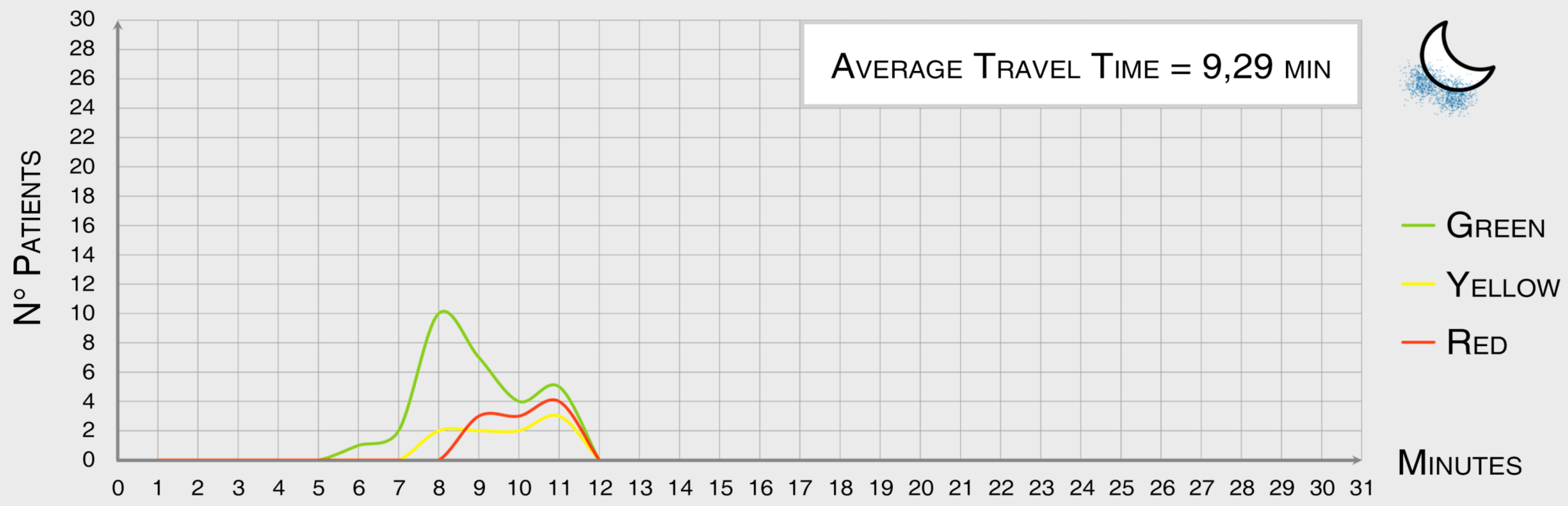

Average Travel Time = 0,00 min
Nobody Came
N° Patients
Minutes
0 2 4 6 8 10 12 14 16
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

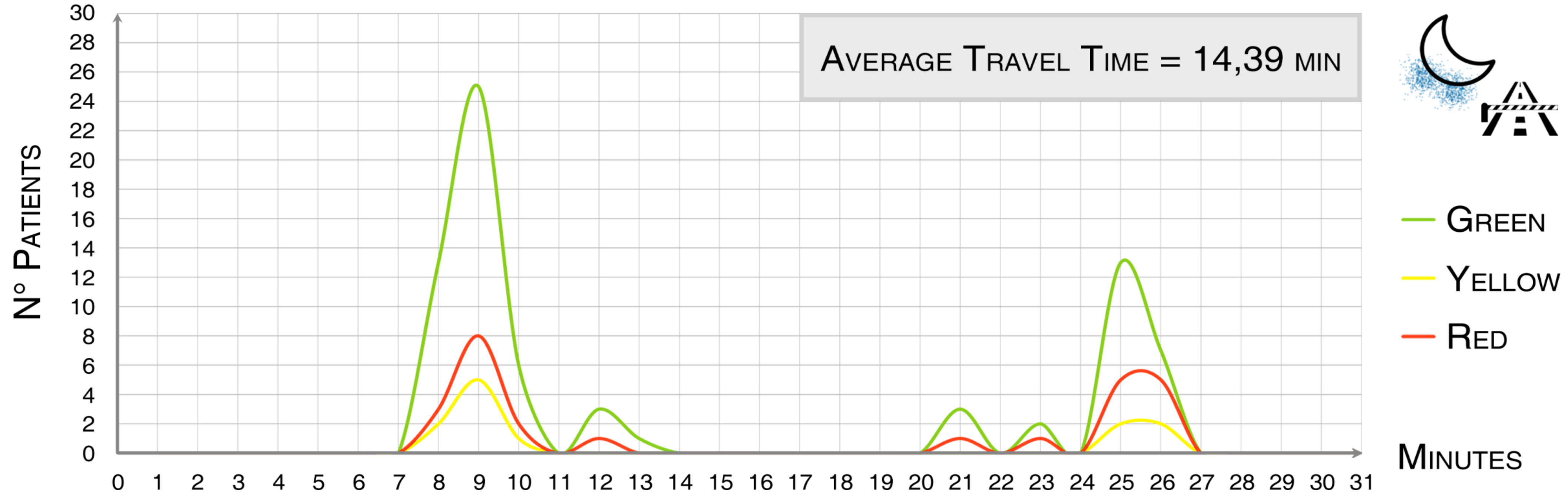
MOLINETTE


Average Travel Time = 3,43 min
N° Patients
Minutes
Green
Yellow
Red
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

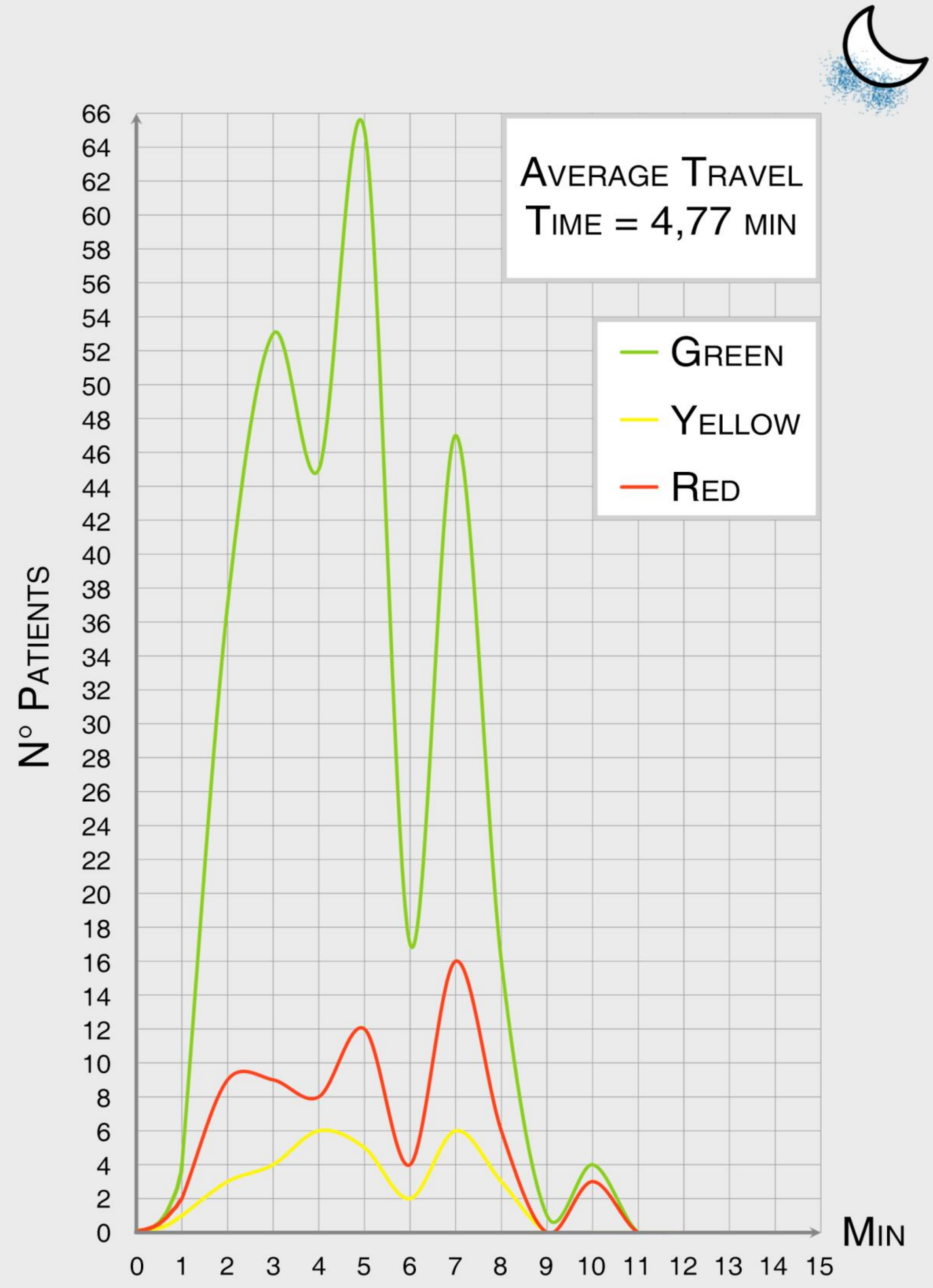

Average Travel Time = 14,90 min
N° Patients
Minutes
Green
Yellow
Red
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

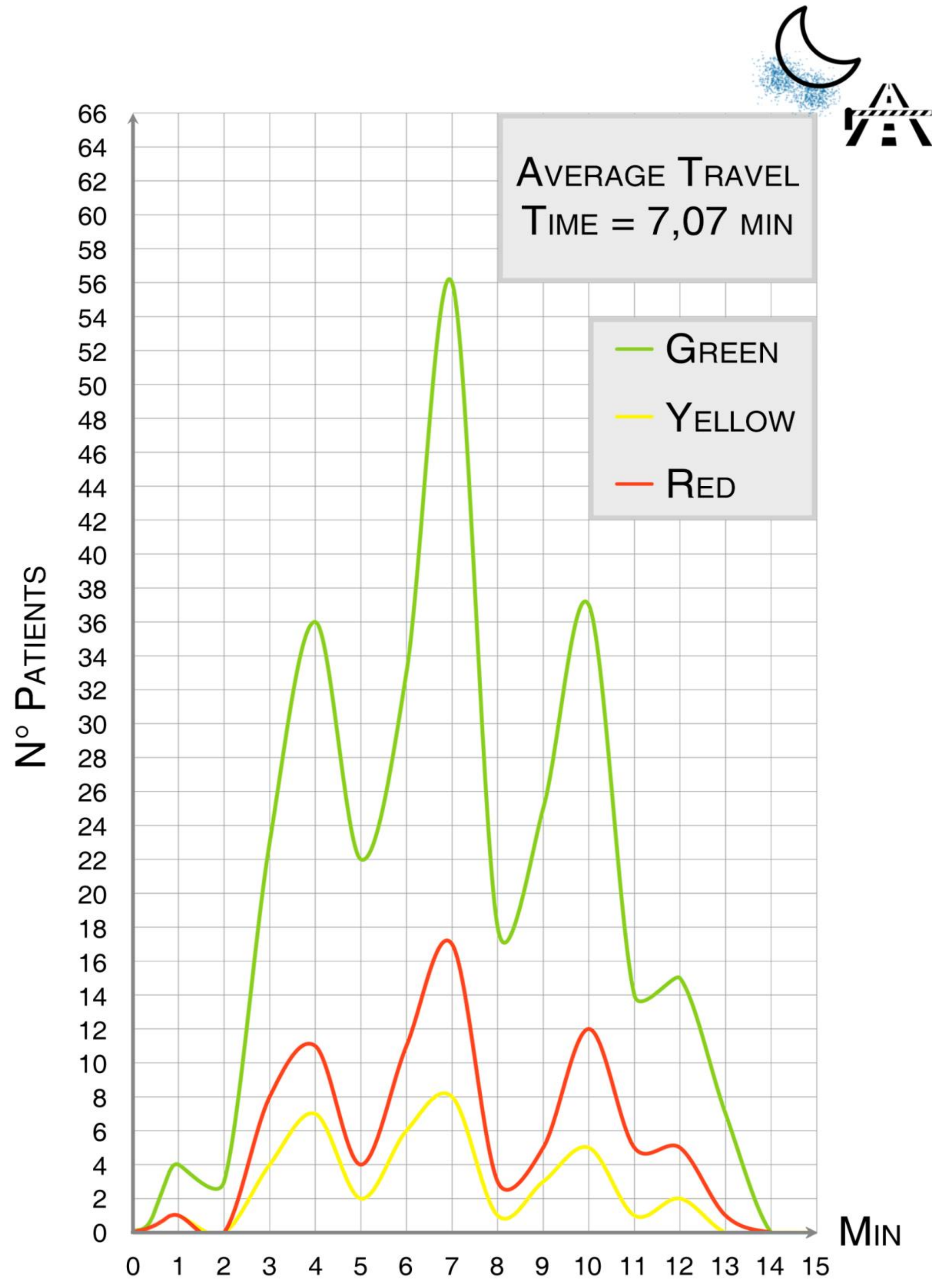
Centro Traumatologico Ospedaliero


Average Travel Time = 9,29 min
N° Patients
Minutes
Green
Yellow
Red
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

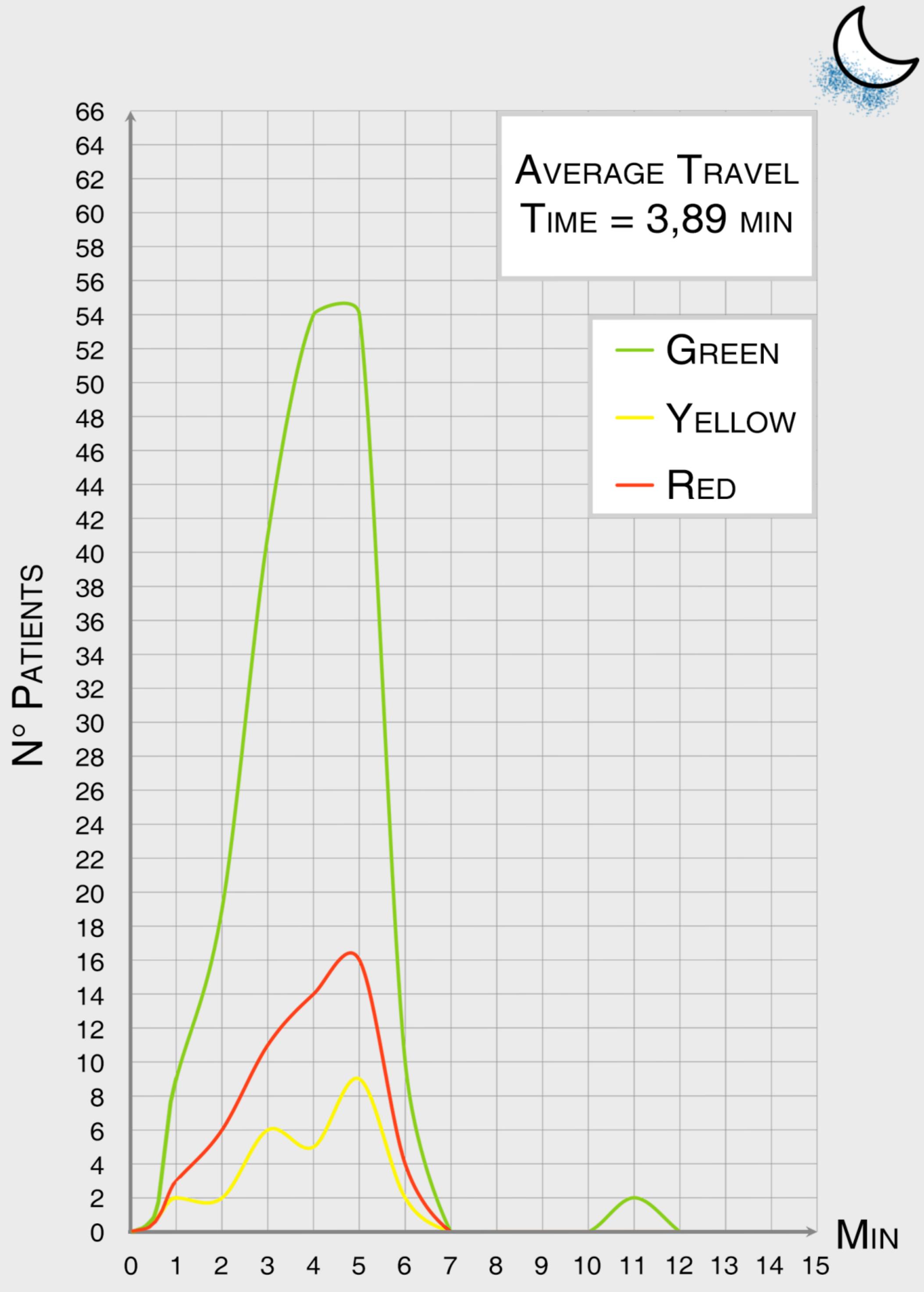

Average Travel Time = 14,39 min
N° Patients
Minutes
Green
Yellow
Red
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

MAURIZIANO

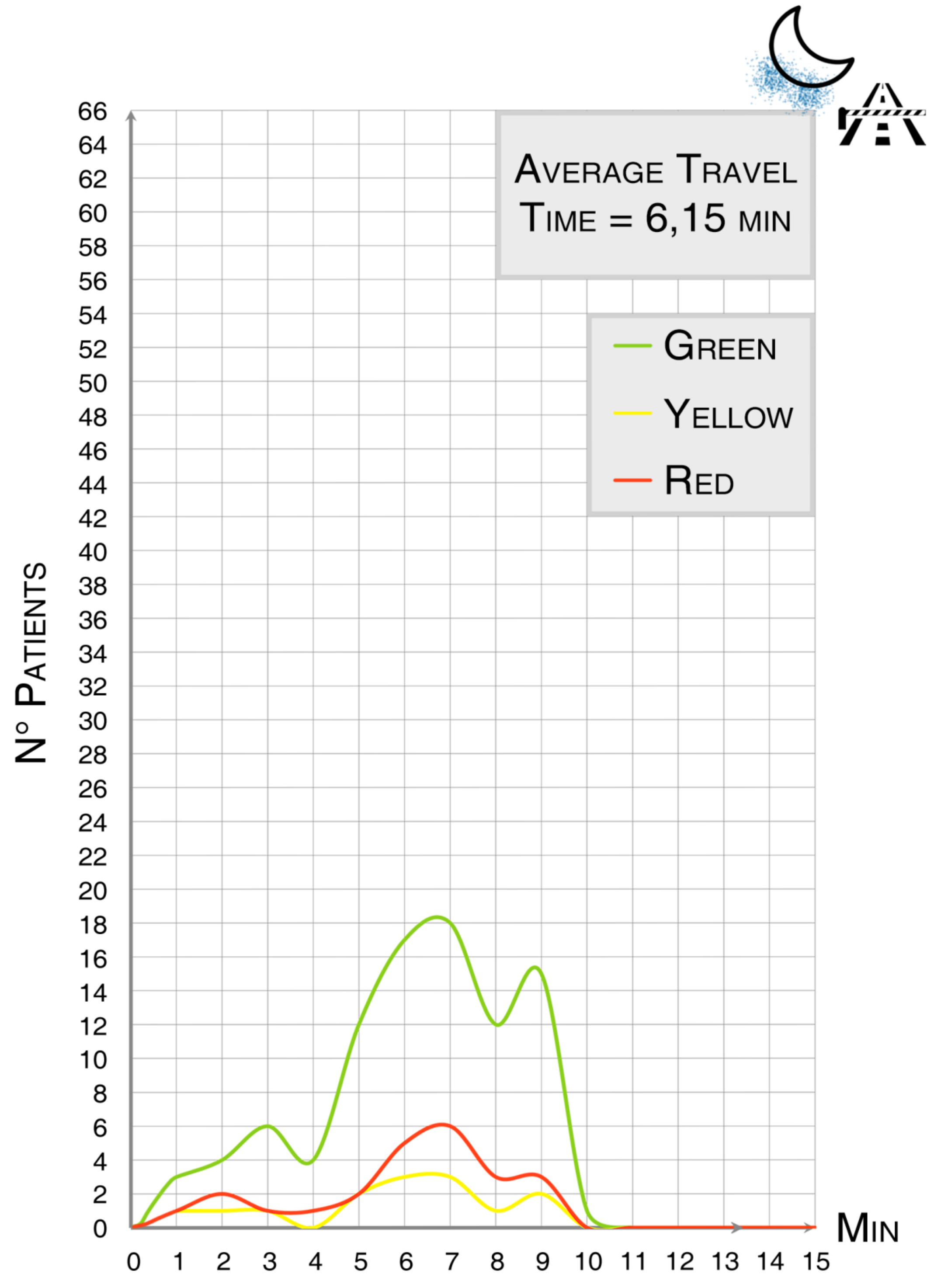

Average Travel Time = 4,77 min
Green
Yellow
Red
N° Patients
Min
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Average Travel Time = 7,07 min
Green
Yellow
Red
N° Patients
Min
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

MARTINI

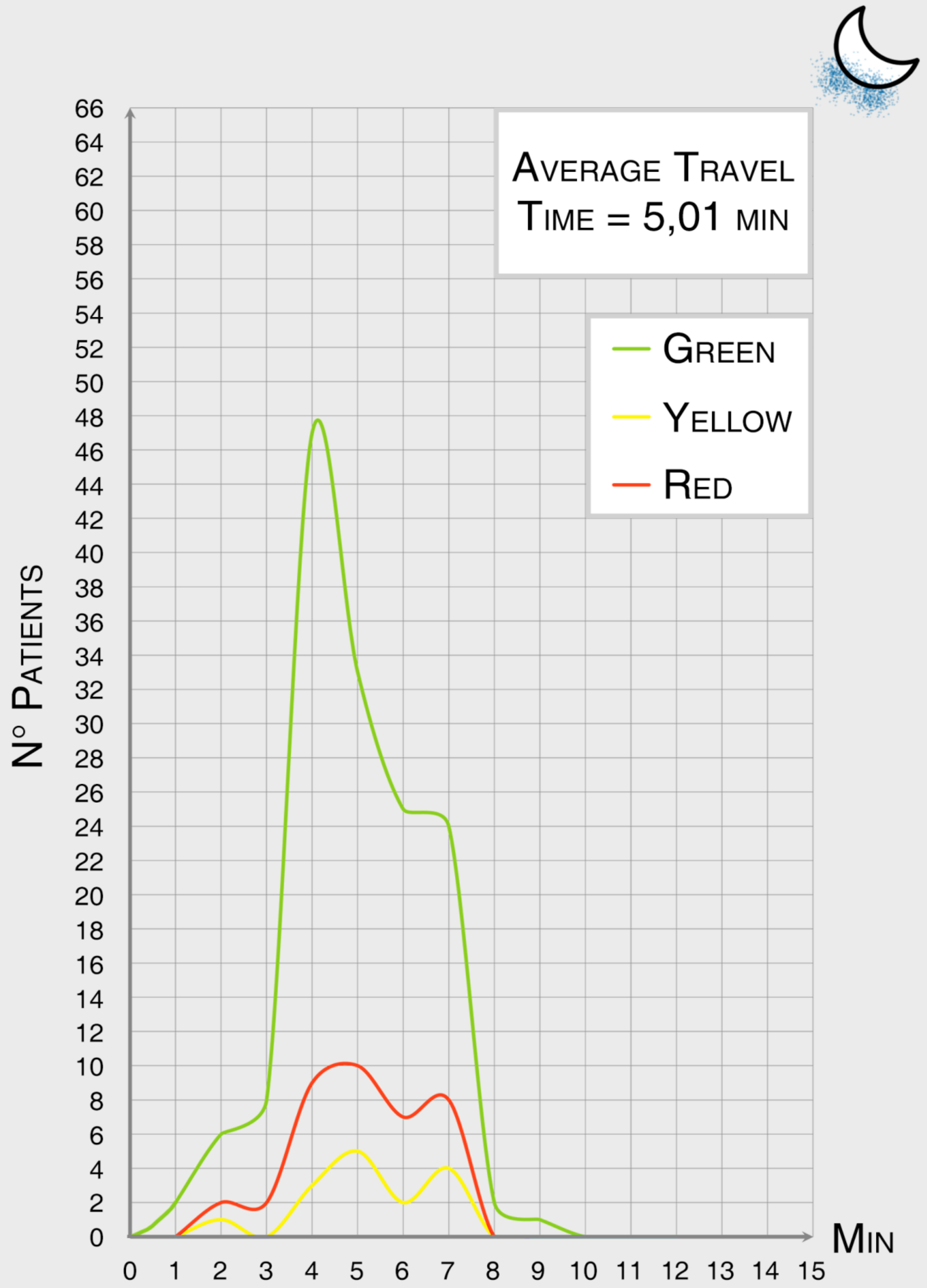


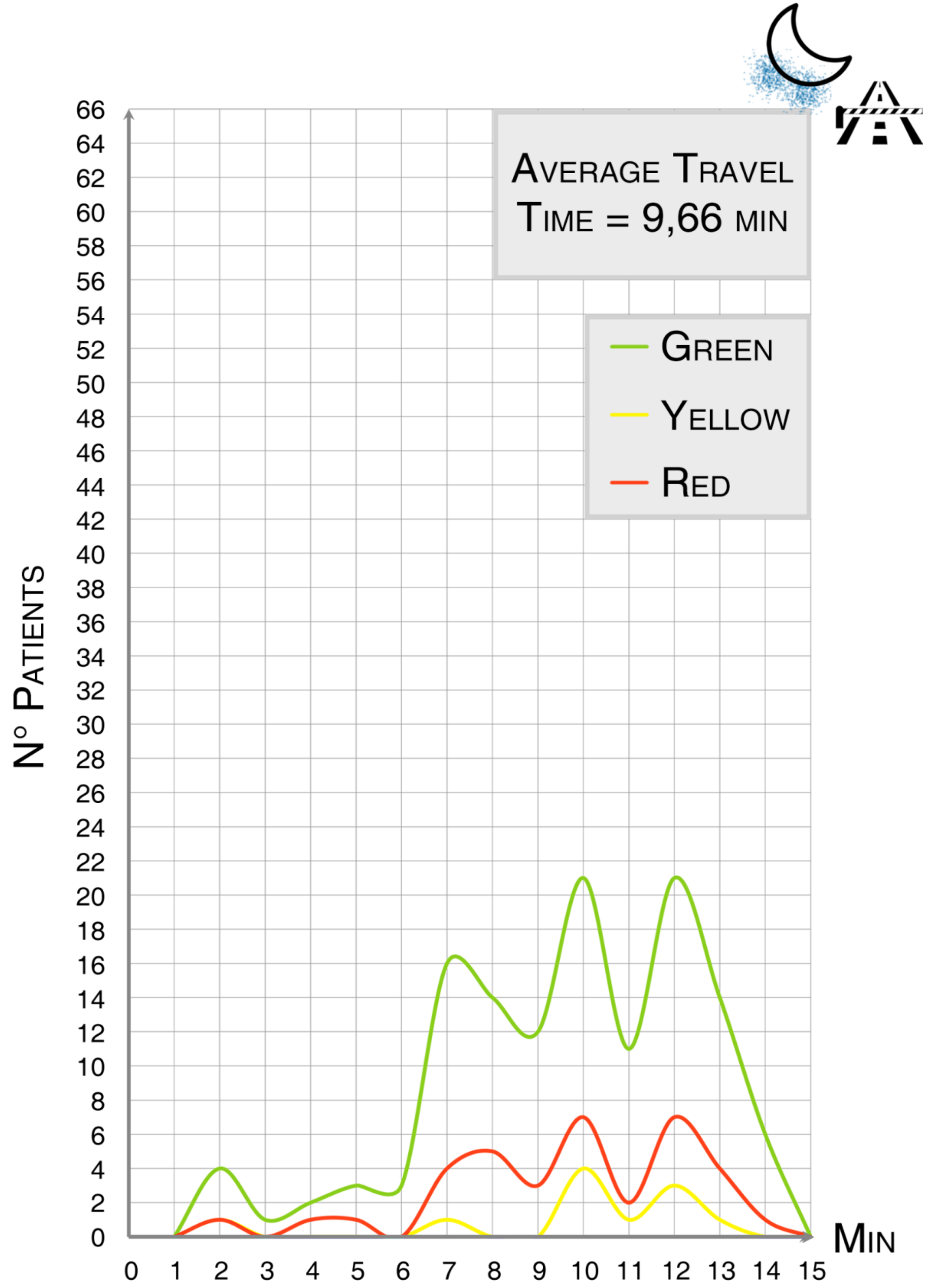
Average Travel Time = 3,89 min
Green
Yellow
Red
N° Patients
Min
66 64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15



Average Travel Time = 6,15 min
Green
Yellow
Red
N° Patients
Min
66 64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

MARIA VITTORIA


Average Travel Time = 5,01 min
Green
Yellow
Red
N° Patients
Min
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Average Travel Time = 9,66 min
Green
Yellow
Red
N° Patients
Min
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

	N° Patients				Average Travel Time	N° Patients				Average Travel Time
GB	18	12	55	85	5,11 MIN	26	21	98	145	13,97 MIN
GR	27	14	92	133	5,32 MIN	0	0	0	0	0,00 MIN
MOL	9	9	33	51	3,43 MIN	15	8	103	126	14,90 MIN
CTO	10	9	29	48	9,29 MIN	26	12	73	111	14,39 MIN
RM	0	0	0	0	0,00 MIN	0	0	0	0	0,00 MIN

	N° Patients			Average Travel Time	N° Patients			Average Travel Time
MAU	69	30	289	4,77 min	83	40	293	7,07 min
	388				416			
MAR	54	26	189	3,89 min	24	14	92	6,15 min
	269				130			
MV	38	15	148	5,01 min	36	11	128	9,66 min
	201				175			

	1.175	72 stucked in their buildings	1.103	
		5,26 min	+111%	11,02 min

ABMs compared

This methodology comes from a similar ABM used for Paradise, a city in California. It is another case study of maxi-emergency due to a wildfire, developed with University of California Berkeley. The result (Annex 1) of the first study was submitted to the Natural Hazards Workshop, University of Colorado, Boulder in fulfillment of the requirements for Quick Response Grant QR 20181221_03 on June 15, 2019. After receiving funds further investigations will be carried out.

	Paradise	Ideal City	Ideal City
Agents	Cars: Traffic	Cars: Traffic + Injured	Pedestrian: Injured
Traffic Data	Real OD pairs	Random OD pairs	-
Human Behaviour	No	No	Yes (basic level)
Visualization	Qgis (Static) Deck.gl (Fluid-dynamic)	Qgis (Static) Deck.gl (Fluid-dynamic)	Unity (3D dynamic environment)
Tools	Terminal	Terminal	Unity
Goal	Real Scenario Traffic issues and solutions	Future scenario Shortest Path	Future Scenario Shortest Path
Map Data	OSM / OSMnx	Cad / OSMnx	Cad
ABM	Macro-scale	Macro-scale	Macro-scale
Assignation	Static (soon quasi-static)	Static	Quasi-Static

Tab. 2 ABMs compared.

In table 2 these technique are compared with an additional ABM, which another team at Politecnico di Torino is developing for Ideal City.

All the methodologies are efficient, the choice depends on the inputs available and the outputs needed.

Future Researches

It is obvious the model has to be implemented and future research could mainly focus on three additions:

- Real OD list instead of random.
- Introduction of ambulances for the coordination of serious injuries pick-up and drop-off.
- Upgrade to micro-scale dynamic agent-based model.
- 3D dynamic visualization.

• Hospital Network

Building hospital models but narrowing it down to one department, makes clear how is difficult to coordinate even just one part of this machine.
Speaking of disaster, the emergency department is the best sector to assess the performance of the structure under stress. But to start, some assumptions have to be made because a simulation can't have all real data and variables under control; especially after natural hazards. To have a good approximation of the real case manifold items have to be investigated and a lot of month of research are requested.

Assumptions

The assumptions in this simulation could also be the limitations of the study:

- hospitals don't present significant structural damage therefore it is assumed, the emergency departments don't lose their functionality;
- the simulation was set for running seven days and the emergency conditions started after two days but for simplicity the emergency plan was applied for the entire period;
- the model handles patients, resources and spaces inside an ED, without considering tools and all material stuff. They are very important because if, for instance, there is a specific accident with all the same injuries, like a fire, all the necessary to take care of them will be over after few hours. Despite material stuff are very hardcore, in this simulation they are not considered;
- Martini and Maria Vittoria didn't take part in the research, therefore Giovanni Bosco model was used also for them.

Hospitals Description

Turin has nine hospitals with emergency room but for different type of patients and with various specialization's levels. Almost all of them are managed and grouped by considerable organizations.

On January 1st, 2017 "Azienda Sanitaria Locale Città di Torino" was created by merging ASL TO1 and TO2. It offers three hospitals: Giovanni Bosco, Martini and Maria Vittoria.

Giovanni Bosco is the third facility in size of the city. The project was approved in 1955 and it is a reference point for districts 6 and 7. It is an hub hospital of second level Emergency and Acceptance Department (DEA) with 347 beds. The ED is developed over one level, all reunited and easy to achieve. There are three access around triage area according to the severity level of the patient. The red zone doesn't have a waiting room because the wounded has to be cured as soon as possible. It has two bed in the shock room, one operating room and four places into the intensive room. The green area matches with the white one if there isn't an emergency, otherwise white patients aren't admit into the building. Two visiting rooms, and one cast room, two for medication and two used as radiology, are located in this area. The yellow sector presents, in addition to the wide waiting room, three visiting rooms, two for medication and nineteen beds under medical supervision, including one isolated.

The following two hospitals didn't want to participate to this research, for this reason there aren't data about the plan.

Maria Vittoria was founded in 1879, that's why the buildings structural damages map shows his level as quite moderate. It is a first level DEA as well as reference point for materno-infantil department of north area. It has 301 beds.

Martini is the newest and also the second smaller. Born in 1970, it has just 209 beds and offers a first level DEA service.

The second corporation is "Città della salute e della scienza di Torino" and this is even a hospital-university center. The network includes more healthcare facilities than we treat, but those having the ED are: Molinette, CTO, Regina Margherita and Sant'Anna.

Molinette, since 1935, is the biggest working hospital in Piemonte and the third in Italy with his 1270 beds. It is a focus of excellence highly qualified and a further goal, but to cure people, is teaching and making research. In fact it is a second level

DEA. In case of emergency the internal division would change and the green patients would be rerouted to the physiatric center one hundred meters forward, while red and yellow casualties have the same access. For simplicity this subdivision is maintained even during the simulation in normal conditions. The first ones go directly to the shock room with two places and then, or to one on three operating rooms or to the intensive room with three beds in the same chamber and another one isolated. What's innovative about Molinette is a second triage for red and yellow codes in order to first identify people most in need. If the code is yellow again, nine visiting room are available. Other ones are close to the observation room, useful to control who was already visited. A big waiting room is accessible. The radiology zones is in this block, so, it is not clear where the moved green patients can take advantage of that service. The green area is not designed for maxi flow of people to be cured. There are a lot of beds useful for long stay, a little waiting room and three rooms re-adapted for visiting.

CTO is the regional trauma center and the seat of the 118 Operative Center of Turin. A very important structure counts 419 beds. Being a destination for very urgent cases, it is a second level DEA. It is spread on three floors, but the more accessible ground level is dedicated to red and yellow injured. The most critical zone has two shock rooms, six visiting rooms and four operating rooms. The yellow one, three visiting rooms, two for medications and eleven bed for staying, of which two isolated. At the second floor there is the green area with two visiting rooms and two for x-ray, more 29 bed for people in recovery. Five of the latter are under continue observation.

Regina Margherita is the principal children's hospital of the city with an ED specialized in second level performances. It is looking for guarantee better and better conditions for children and their families. Besides, a special unit for minors dealing with abuse and violence, is activated. It has 286 beds and inside the ED doesn't have a division by code. There are a waiting room and one shock room, two for visiting and two for medicating, plus ten beds for lying in. The ED doesn't have his own operating room.

The last hospital of Città della Salute is Sant'Anna and it won't be taken into account in our research, as a result details of the internal organization are not considered. It is an obstetric gynecological hospital very qualified but into a tight domain, it follows that it doesn't participate to the rescue and treatment network in case of maxi-emergency. It has 477 beds.

The last two hospital have their own system.
Mauriziano is another Dea II closes to the center which in 1885 was set in motion with 448 beds available. As usual, there are two beds for the shock room, four for the intensive care and just one operating room. Yellow patients have three visiting room, two for medication and thirteen beds in supervision. The green ones two visiting rooms and fifteen beds, amongst those, one is isolated. The radiology block is at the center of the department so, easily reached for all.

Gradenigo starts his history in 1900. It is a private hospital and is part of Humanitas group. Regrettably it is just a Base Hospital not very specialized and with only 184 beds. The emergency department is two storied because the operating block with four rooms is common with all the hospital's sectors. At the ground floor a resuscitation room is in front at the elevator. Then two visiting rooms are located almost at the entrance like the waiting room and following the corridor there are two bedrooms with three places each for observation. The yellow area presents two visiting rooms, one medication room and two rooms overseen, with respectively eighteen and six plus one isolated bed. Is not clear where is the radiology zone.

Scenario

Hospitals simulation may have very different results from normal to emergency conditions. So, scenarios facing off in this chapter are two, both of them that last for 7 days: one in ordinary conditions with just coming the daily flow, the other during emergency. In the latter case figure 25 shows when the 1103 casualties are added to the daily flow. Injured people are not 1175 because just scenario B of the traffic simulation is considered here.

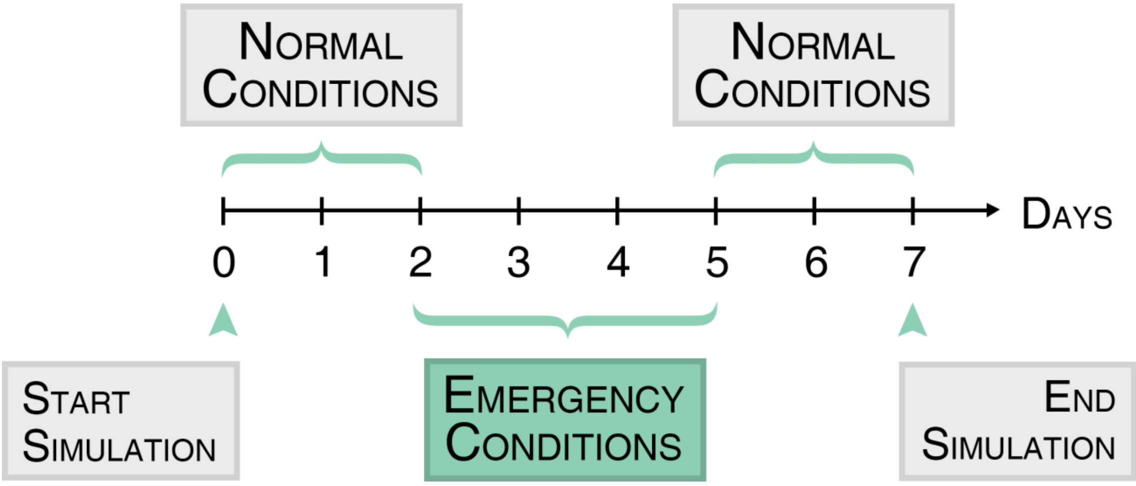


Fig. 25. Simulation duration.

Input

Many input are requested in order to run the second simulation. They can be external if they are about incoming patients, internal if they are all that concerns intramural organization.

External

External input concern the arrivals both daily and extraordinary and while, for the ordinary sick people, data are an average based on the results of the last year, the second depends on the traffic simulation.

Table 3 presents the ordinary incoming patients flow obtained from database of real daily patients. Months with the higher and lower patients flow were picked and the daily average was found. In figure 26 the maximum error are displayed depending on different arrival rate of patient per each month. Gradenigo, Martini and Maria Vittoria should be notice because they didn't want to hand data over. A motivation is there are sensible data, and moreover, if a trial is still on going, as for Piazza San Carlo event, no one wants to take the risk to show them, secondly even though it were possible to divulge them, often health direction's chief doesn't allow leaking information which re-elaboration could be used against the hospitals. It follows the research will include hypothetical data, in this case, Giovanni Bosco data are used even for them. From the real database, instead, still an average of incoming patients daily distribution was extrapolated and figure 27 is the result.

H	Months with higher and lower Patients Number					Monthly Average				Daily Average			
A	May August	46 32	459 387	3060 2545	3554 2227	39	423	2802,5	2890,5	1,3	14,1	93,4	96,4
B	-	-	-	-	-	-	-	-	-	-	-	-	-
C	February April	128 127	1098 1186	3738 4504	390 571	127,5	1142	4121	480,5	4,3	38,1	137,4	16
D	May August	17 21	257 189	1878 1472	2196 1882	19	223	1675	2039	0,6	7,4	55,8	68
E	May August	10 6	542 347	3299 1768	315 298	8	444,5	2533,5	306,5	0,3	14,8	84,5	10,2
F	May August	29 16	802 649	3765 3060	573 564	22,5	725,5	3412,5	568,5	0,8	24,2	113,8	19
G	-	-	-	-	-	-	-	-	-	-	-	-	-
H	-	-	-	-	-	-	-	-	-	-	-	-	-

Tab. 3. Ordinary incoming patients.

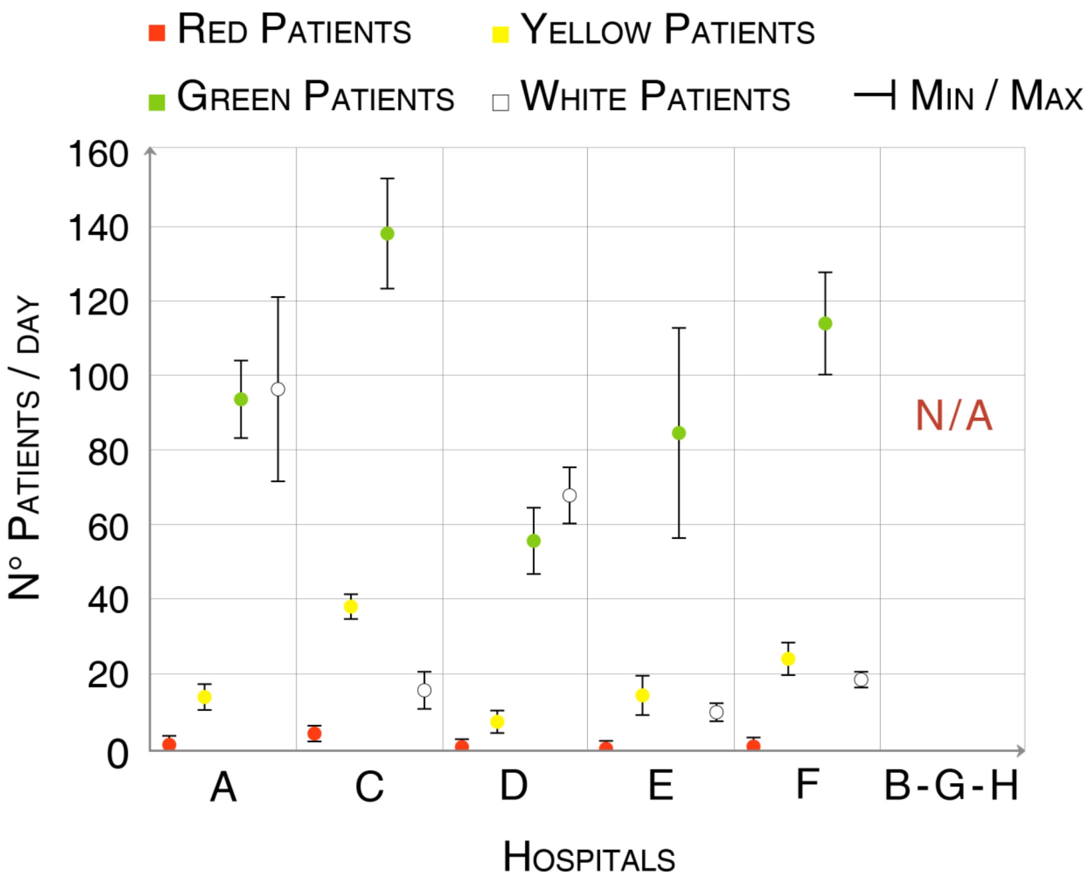


Fig. 26. Ordinary incoming patients.

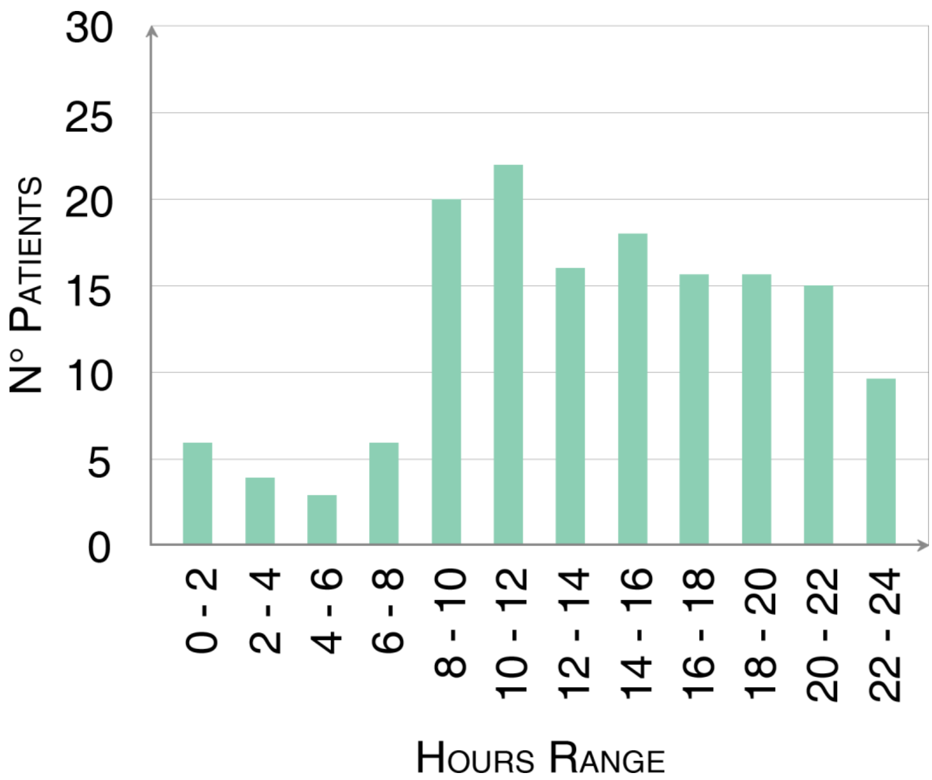


Fig. 27. Ordinary incoming patients daily distribution.

In case of maxi-emergency, instead, table 4 and figure 28 show the injured people flow and figure 29 their distribution over time. About the flow, was already said white casualties aren't accepted anymore in this situation, while for emergency arrivals distribution a few words must be spent. Traffic simulation is still not completed because it missed the ambulance service and thus, the staggered departure. For this reason, a more likely arrivals distribution has to be taken into account. Data collected with this purpose are from Northridge earthquake on 1994 in California. The choice fells on this event because it is the only documented (Stratton et al., 1996; Peek-Asa et al., 1998; McArthur et al., 2000). thanks to a hospital involved. So a possible similar trend of arrivals rate was calculated. Considering it had a pga and MMI respectively equal to 0,568 and 8,6, patients' arrival rate is scaled in order to correspond to the seismic input of Ideal City (Norcia earthquake with pga and MMI equal to 0,48 and 6,5). Eventually, Ideal City arrival rate is the average between the results obtained by pga and MMI values (Fig. 30).

H	Casualties				H	Casualties			
A	26	21	98	-	E	0	0	0	-
B	0	0	0	-	F	83	40	293	-
C	15	8	103	-	G	24	14	92	-
D	26	12	73	-	H	36	11	128	-
TOT	210	106	787	-		1.103			

Tab. 4. Emergency incoming patients.

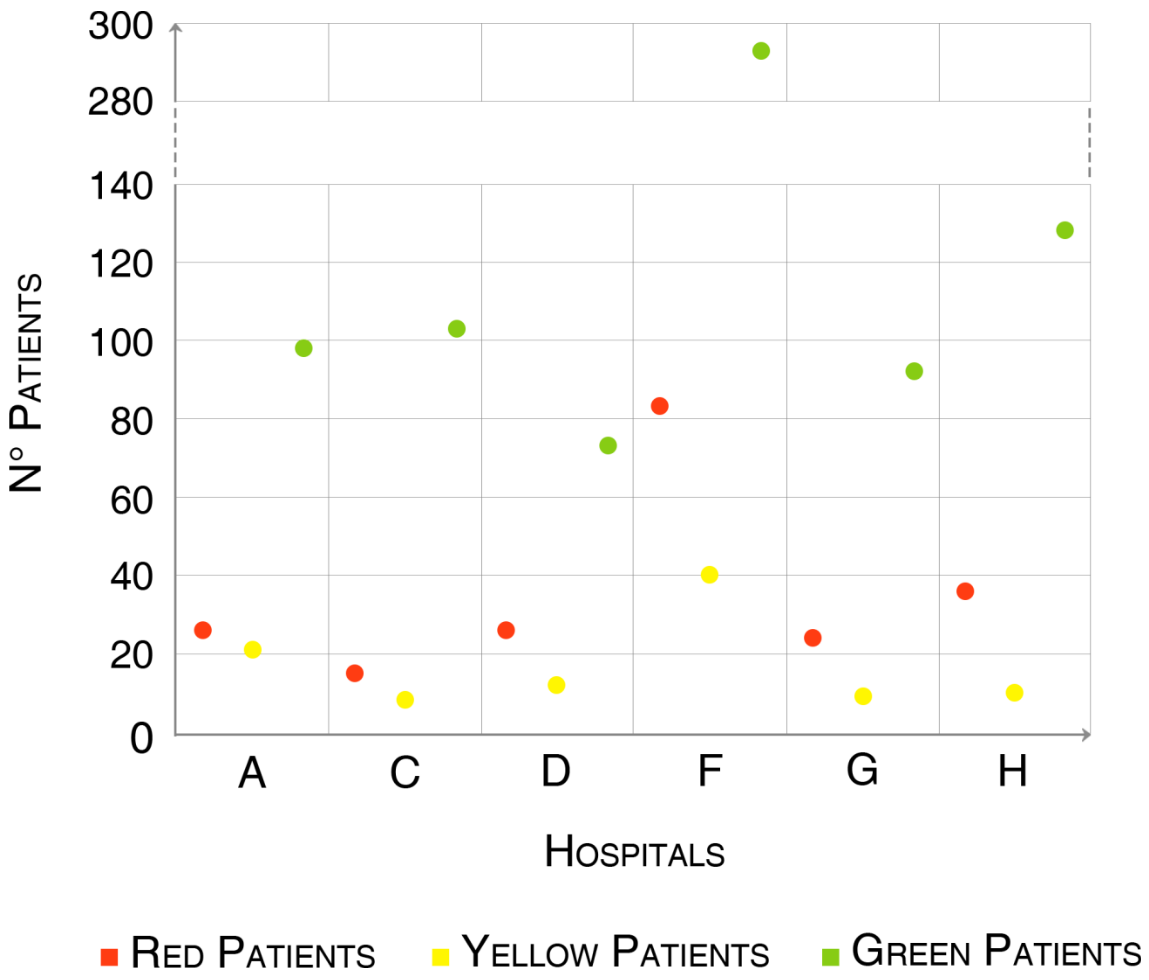


Fig. 28. Emergency incoming patients.

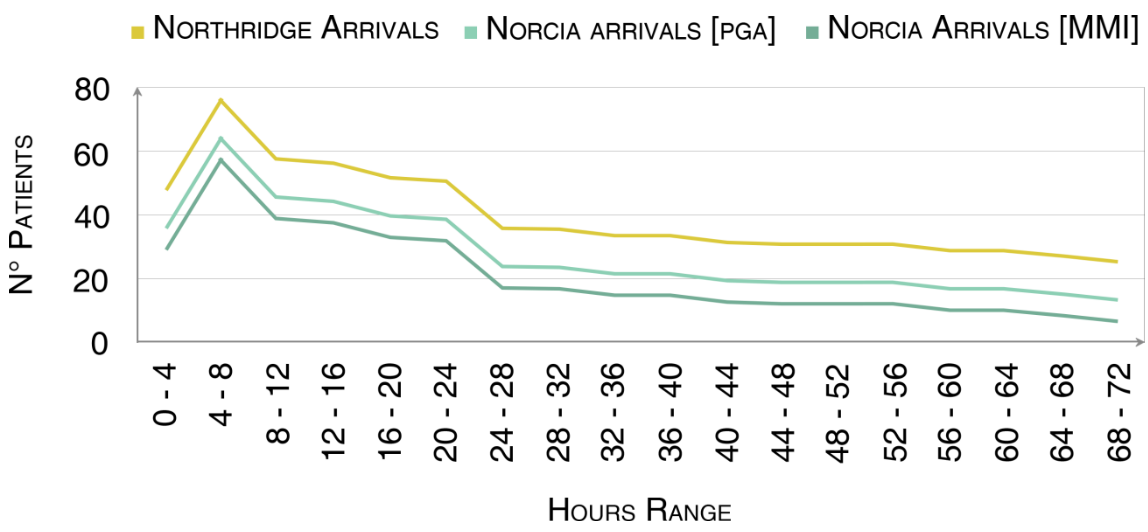


Fig. 29. Arrivals rates scaled by pga and MMI values .

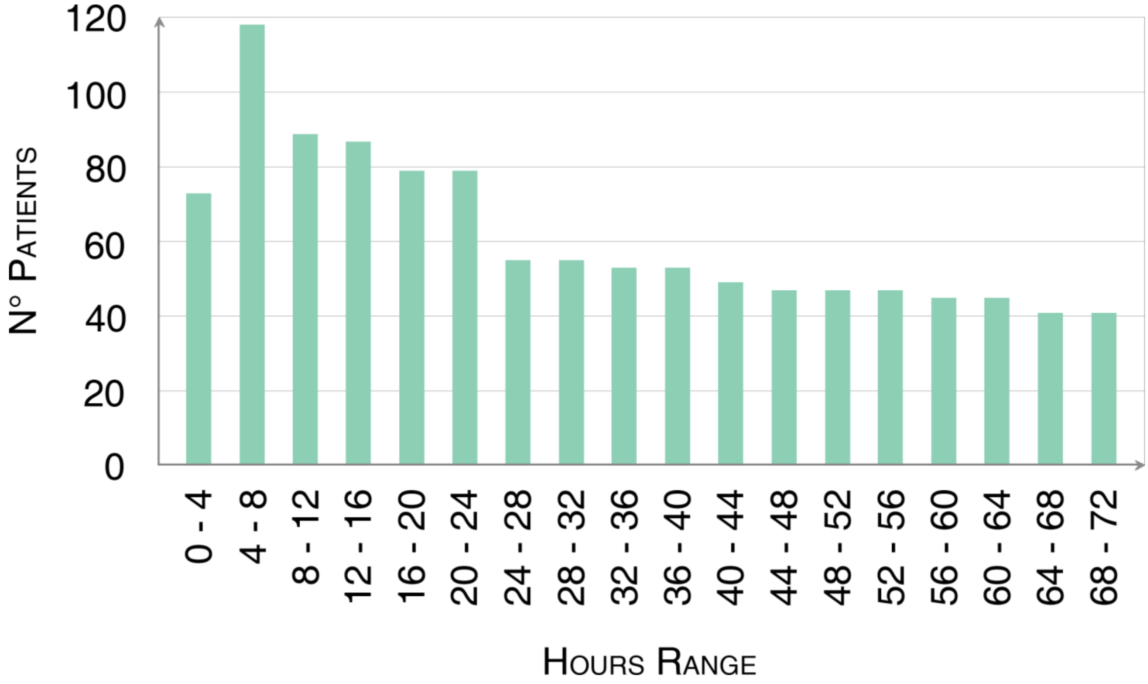


Fig. 30. Ideal City arrivals rates.

Internal

Floor plans, where to exactly place locations and internal path are fundamental (Fig. 31, 32, 33, 34, 35, 36) and the first items to ask for, though . They are not referenced as will of the health directors and in this model they remain the same in any circumstance.

Second hardcore element are the resources. In this research are considered just doctors and nurses for simplicity. Numbers of daily resources are listed on table 5 but talking with some health direction's chief, it turned out they don't know the exact number of doctors and nurses can help during emergencies. Of course they know the total amount of them but they can't appear all together because there must be shifts to give some rest to the staff and the necessities change based on the disaster severity. Last note, usually lack of resources in emergency conditions is not an issue because people want to help and often they are too much compared to the available spaces. As result of this will be the simulation to give the exact number of resources the situation needs.

Afterwards setting up the arrival rate and the simulations' framework, the other relevant information are about the directions that patients have to travel into the hospital according their triage code, how much time to spend in each room and who are the resources to follow them. These interconnections are defined by ETS, already explained into hospital network methodology section and graphically summarized in figure 37.

At this point injured people are divided not just by triage code but also by the time range spent inside the ED. But the last missing input is the casualties rate for each time range. A calibration in normal condition between the real database of incoming patients flow and the ETS database is performed following this rules:

- Patients number in real database for each time range.
- Average number of surgery operation for each operation room $\leq$ 6/day[4]
- Real average time in system $\cong$ Simulated Average time in system
- ETS average time in operation $\cong$ Simulated Average time in operation

[4] Data from https://www.beckersasc.com/lists/100-surgery-center-benchmarks-statistics-to-know.html, consulted on September 11th, 2019.


0
5
10
15
20
25 M
Services Duct
Visiting Room
Visiting Room
Visiting Room
Wc
Anti-
Waiting Room
Waiting Room
Wc
Wc
Phones
Security
Macro-Medicin Entry
Hot Chamber Exit
Control Room
Pharmacy
Triage
Office
Body
Hot Chamber
Clean-up
Anti- Wc
Anti- Wc
Stretchers Deposit
Macro-Surgery Entry
Hot Chamber entry
Pedestrian Entry
Visiting Room
Medication
Visiting Room
Waiting room
Cast Room
Wc
Reports
Anti-

Fig. 31. Hospital A

Medication Room
Wc
Anti-
Changing Room
Deposit
Anaesthetists Office
Wc
Anti-
Observation Point
Body
Deposit
Observation Room
Observation Room
Filter
Isolated
Empty Pots
Stretchers Deposit
Medication Room
Head Nurse Office
Technical Room
Deposit
Visiting Room
Operating Room
Sterilization Room
Surgeon Preparation
Changing Room
Wc
Anti-
Wc
Changing Room
Wc
Anti-
Wc
Deposit
Relax Room
Deposit
Office
Awakening
Tech-nical Room
Depo-sit
Sterilization Area
Deposit Sterile Material
0 5 10 15 20 25 m

Fig. 32. Hospital B


Technical Room
Technical Room
Technical Room
Wc
Anti
Wc
Meeting Room
Calm area
Sterilization Autoclave
Sterilizaton Area
Closet
Operating Room
Steriliza-tion room
Operating Room
Steriliza-tion room
Operating Room
Visiting Room
Closet
Visiting Room
Visiting Room
Empty Pots
Visiting Room
Wc
Patient Preparation
Surgeon Prepara-tion
Patient Preparation
Surgeon Prepara-tion
Patient Preparation
Surgeon Prepara-tion
Wc
Anti-
Closet
Resuscitation Room
Resuscitation Room
Triage
Triage
Deposit
Changing Room
Shower
Empty Pots
Shower
Shower
Wc
Wc
Resuscitation Office
Info Point
Entrance
Head Nurse Office / meeting Room
Anti-
Wc
Anti-
Relax Room
Wc
Physician Room
Changing Room
Observation Room
Wc
Anti-
Clean-up
Waiting Room
Anti-
Wc
Anti-
Wc
Reception
Stretchers Deposit
Waiting Room
Wc
Anti-
Wc
Anti-
Isolated
SARS COntrol
Isolated
Wc
Anti-
Wc
Anti-
Anti-
Wc
Closet

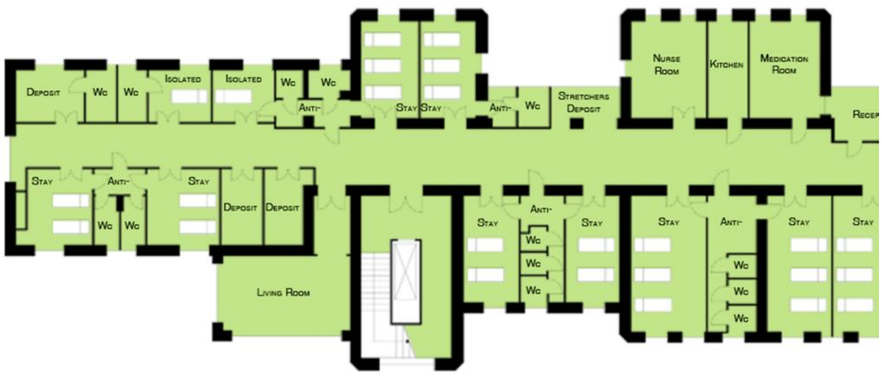

Deposit
Wc
Wc
Isolated
Isolated
Wc
Wc
Anti-
Stay
Stay
Anti-
Wc
Stretchers Deposit
Nurse Room
Kitchen
Medication Room
Stay
Anti-
Stay
Wc
Wc
Deposit
Deposit
Living Room
Stay
Anti-
Stay
Wc
Wc
Wc
Stay
Anti-
Stay
Stay
Wc
Wc
Wc

Fig. 33. Hospital C


0 5 10 15 20 25 M
Reports
Wc
Anti-
Changing Room
Wc
Office
Closet
Control Room
CT Scan
Deposit
Relax Room
Visiting Room
Meeting Room
Visiting Room
Fuse Box
Fuse Box
Changing Room
Digital Angiograph
Control Room
Deposit Dirty
Deposit Clean
Equipment
Clean Up
Anti-
Wc
Reception
Awakening
Surgeon Prepara-tion
Empty Pots
Visiting Room
Visiting Room
Visiting Room
Shock Room
Operating Room
Steriliza-tion Room
Head Nurse Office
Relax Room
Relax Room
Ambulance Exit
Room
Wc
Surgeon Prepara-tion
Awakening
Surgeon Prepara-tion
Awakening
Surgeon Prepara-tion
Changing Room
Operating Room
Sterilization Room
Operating Room
Operating Room
Changing Room
Wc
Wc

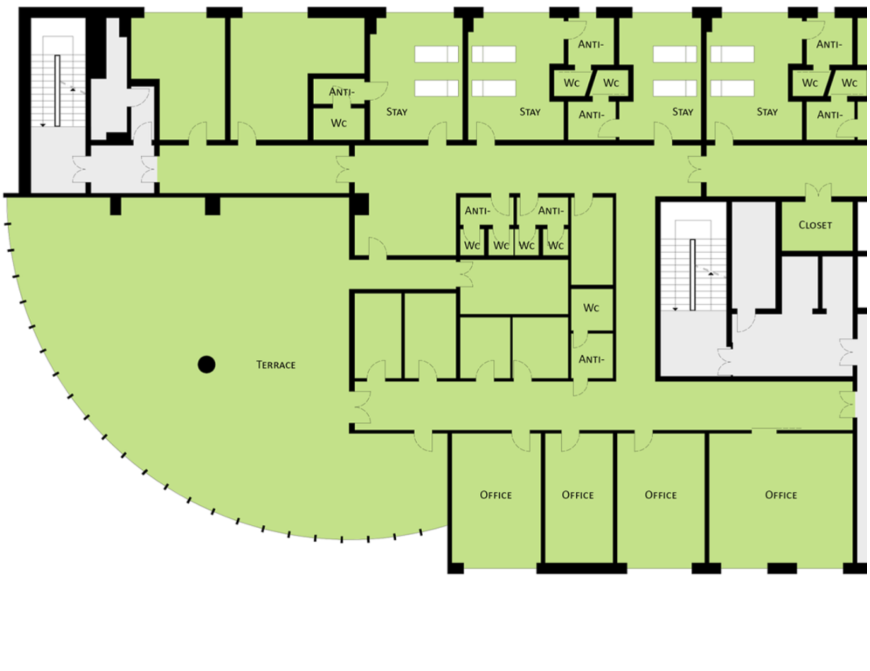
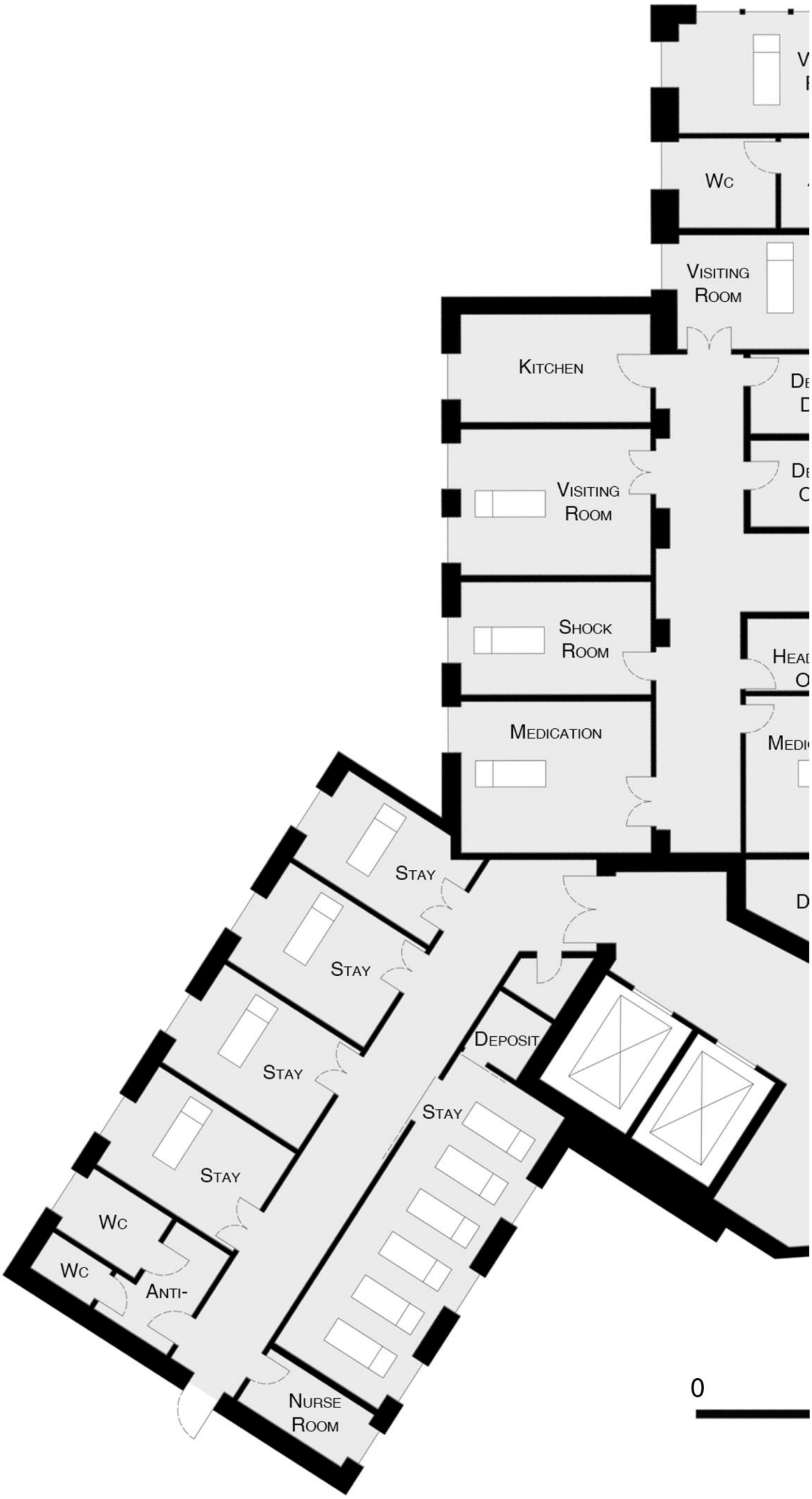

Anti-
Wc
Stay
Stay
Anti-
Wc
Wc
Anti-
Stay
Stay
Anti-
Wc
Wc
Anti-
Anti-
Anti-
Wc
Wc
Wc
Wc
Closet
Wc
Anti-
Terrace
Office
Office
Office
Office

Fig. 34. Hospital D



Wc
Visiting Room
Kitchen
Visiting Room
Shock Room
Medication
Stay
Stay
Stay
Stay
Deposit
Stay
Wc
Wc
Anti-
Nurse Room
0

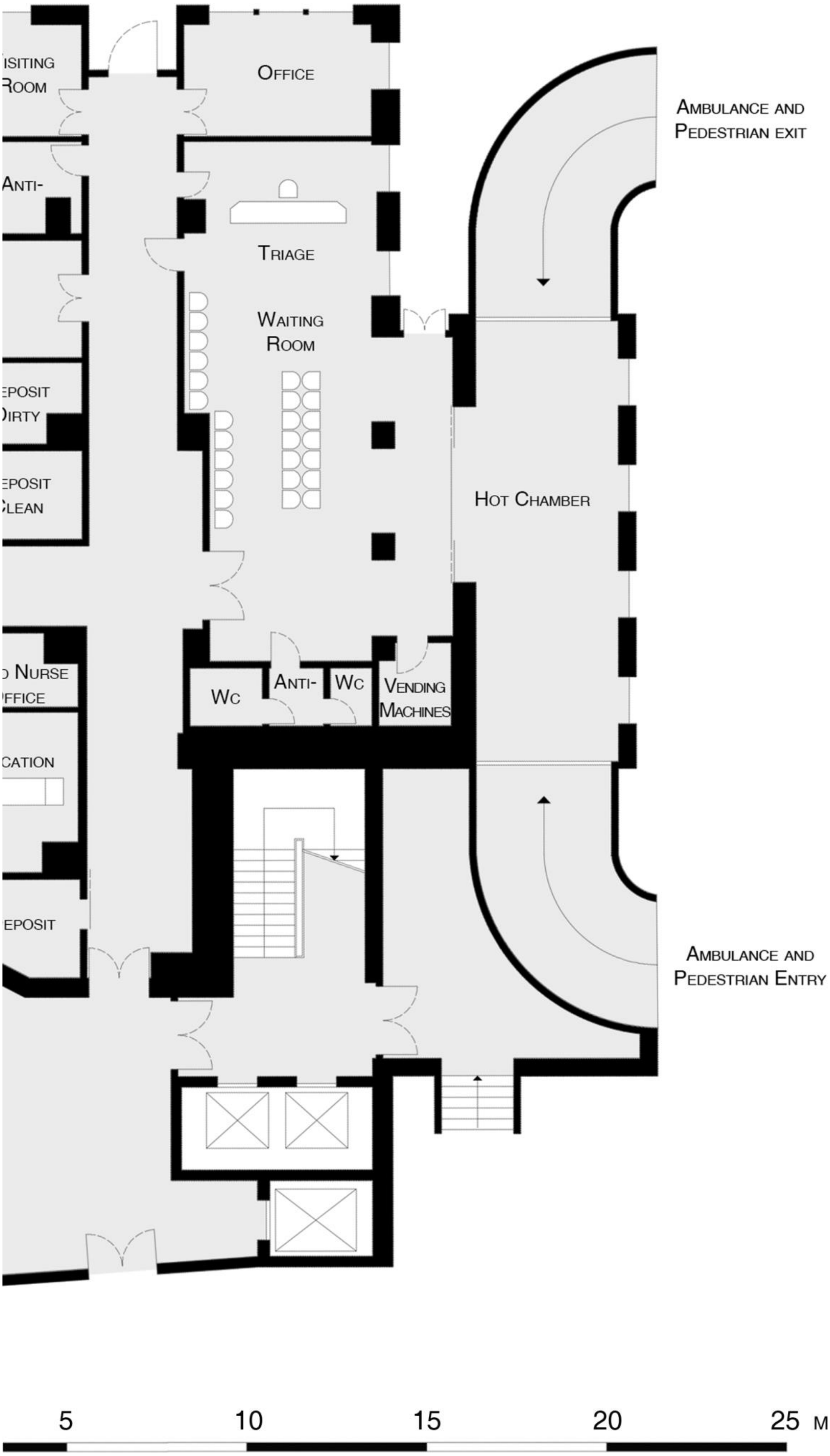


Fig. 35. Hospital E


Hot
Chamber
Exit
Wc
Anti-
Wc
Deposit
Decontamination
Room
Hot Chamber
Anti-
Shock Room
Wc
Stretchers
Deposit
Clean
Deposit
Dirty
Deposit
Intensive Care
Wc
Anti-
Offic
Head
Nurse
Relax
Room
Chief Room
Meeting
Room
Hot
Chamber
entry
Triage
Isolated
Triage
Wc
Waiting
Stay
Stay
Stay
Anti-
Waiting
Room
Reception
Pedestrian
Entry
Wc
Wc
Anti-
Phones
Anti-
Wc
Wc
Police
Wc
Anti-

Fig. 36. Hospital F

	Hospitals		A	B	C	D	E	F	G	H
	Level		DEA II	Base	DEA II	DEA II	DEA II	DEA II	DEA I	DEA I
Resources	 Doctor	Red	1	-	2	2	1	1	-	-
		Yellow	2	-	6	3	2	3	-	-
		Green	2	-	2	2	2	3	-	-
	 Nurse	Red	3	-	8	3	3	3	-	-
		Yellow	3	-	7	3	3	3	-	-
		Green	2	-	3	2	2	3	-	-
		Triage	1	-	1	1	1	1	-	-
	Total		14	-	29	15	14	17	-	-
Locations	Shock room		2	1	2	2	1	2	-	-
	Operating Room		1	0	2	4	1	1	-	-
	Intensive Care		4	3	3	5	2	4	-	-
	Yellow Prim. Ass.		3	2	6	2	1	3	-	-
	Yellow Sec. Ass. I		2	2	9	3	2	2	-	-
	Yellow Sec. Ass. II		19	20	18	11	10	13	-	-
	Green Ass.		2	2	3	2	2	2	-	-
	Exams Room		2	2	2	2	2	3	-	-
	Max Injured in Treatment		35	32	45	31	21	30	-	-

Tab. 5. Total amount of resources and beds in ordinary conditions.

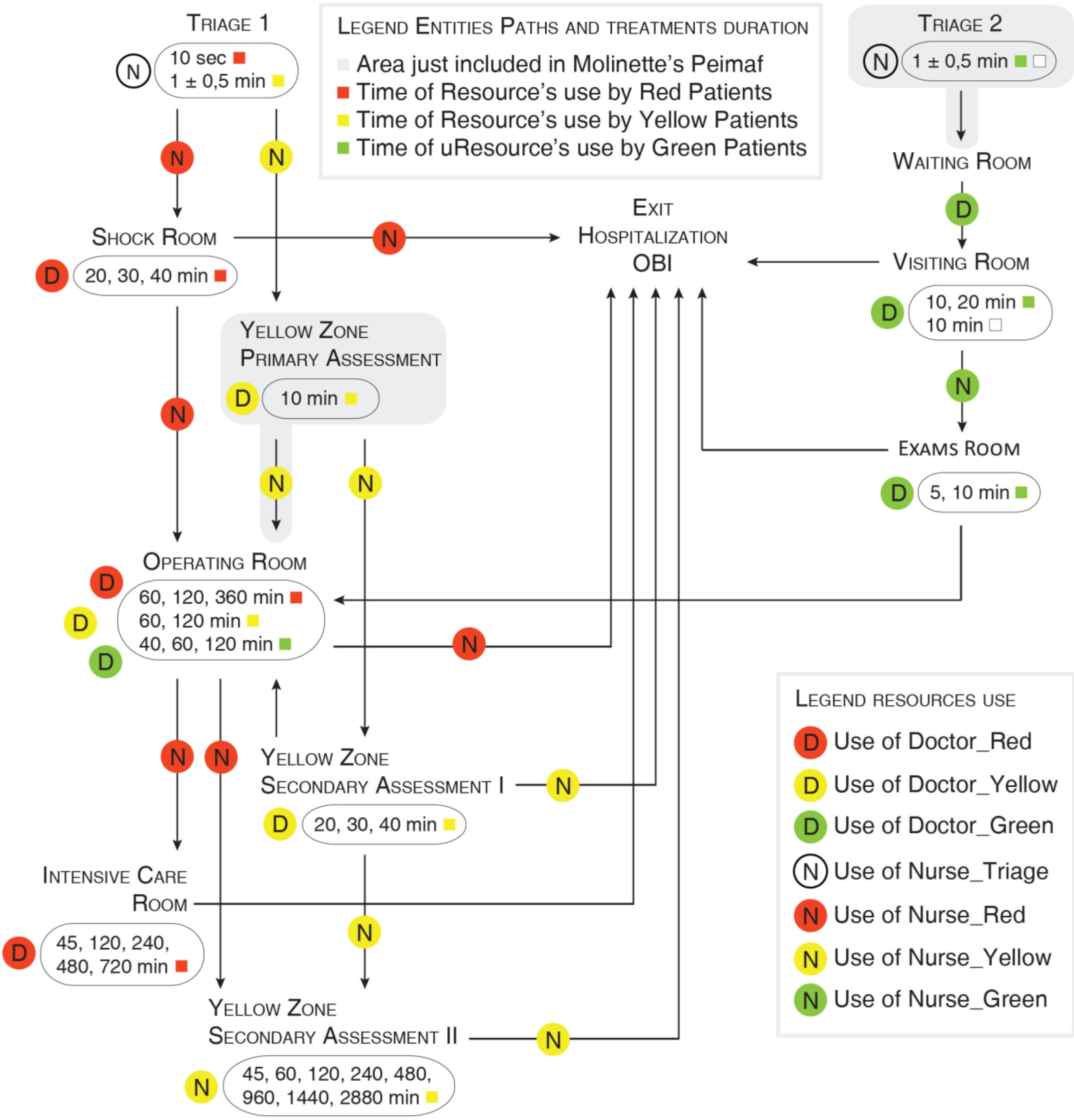


Fig. 37. Path, time in operation, resources use.

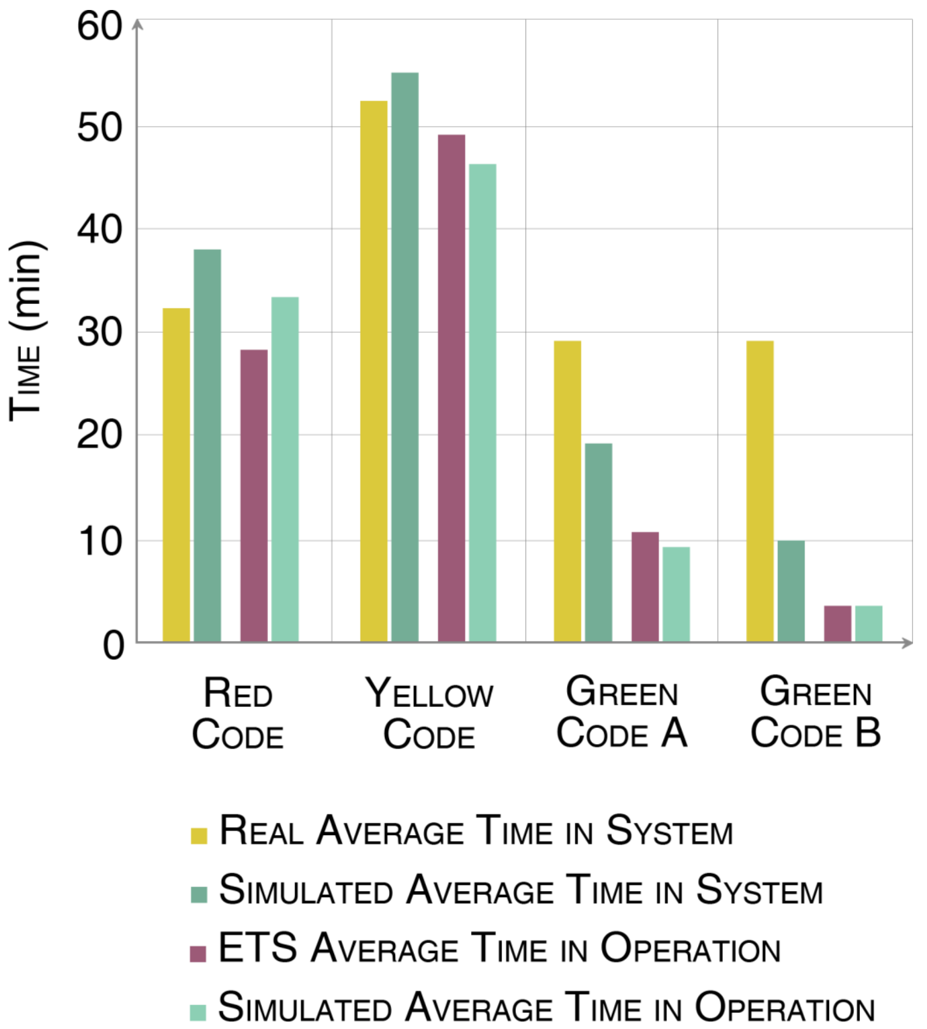


Fig. 38. Calibration to define the patients percentage for each time range

The calibration was made with Giovanni Bosco hospital's model in normal conditions. The results, in figure 38, compare the simulated average time in system with the average time in system found inside the real database, and the simulated average time in operation with the one supposed by ETS.

First and second columns of each severity level, should be similar like the third and fourth. There could be a difference from Real and ETS data for red and yellow code because we have more time range than patients, so the system have to choose which time to assign without respecting the rates. For Green Patients the difference is due to the time spent into the OBI because not having data, it's normal that simulated average times in system are much lower than real ones.

The final patients' distribution for each time range is presented in figure 39 and it is entered into MedModel as attributes and users distributions.

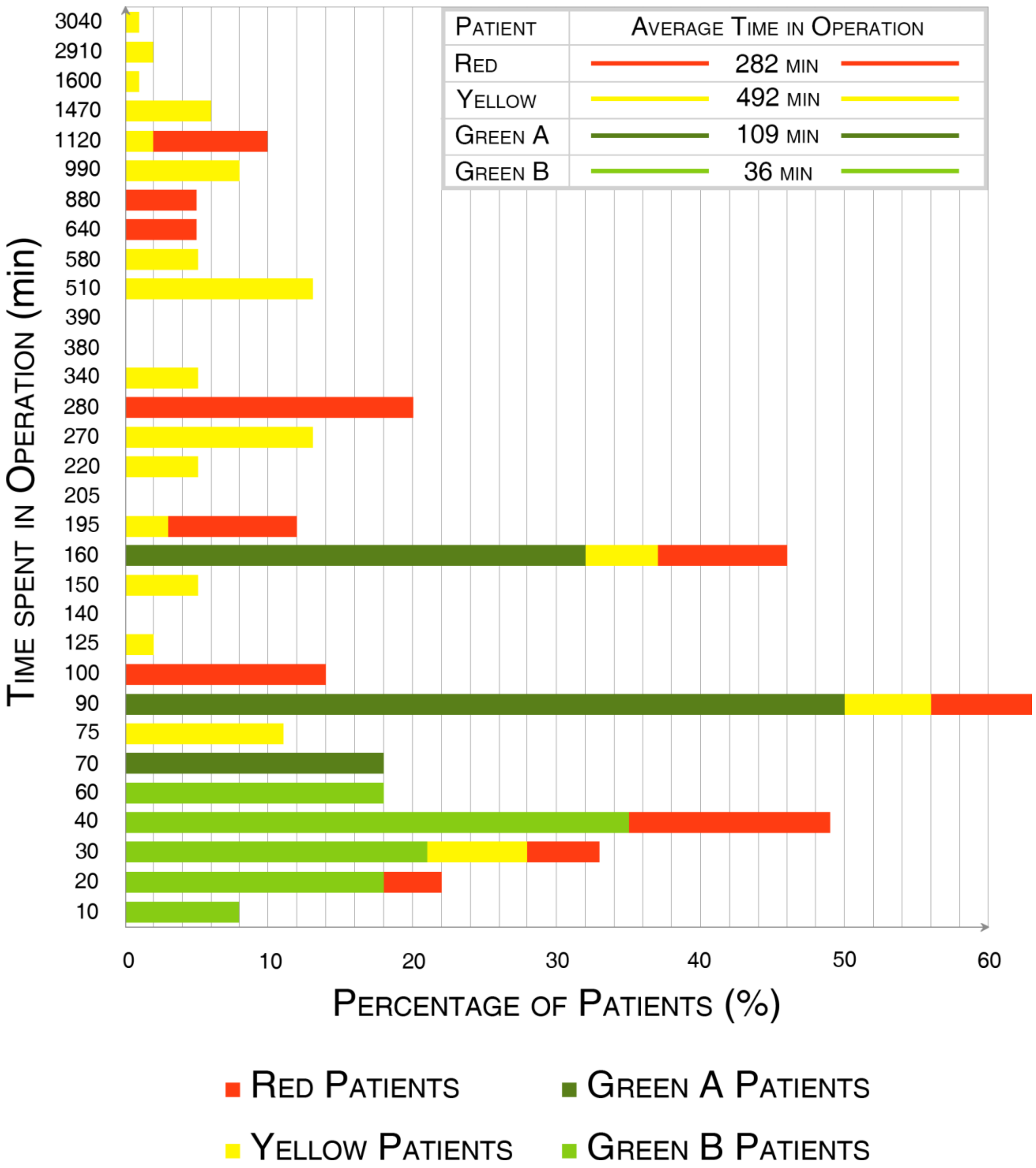


Fig. 39. Patients percentage for each time range

Limitations

- Hospitals are considered fully operational without structural damage.
- Without having Martini and Maria Vittoria data, Giovanni Bosco model was used also for them.
- Despite material stuff are very hardcore for the success of the rescue, in this simulation they are not considered.

Results

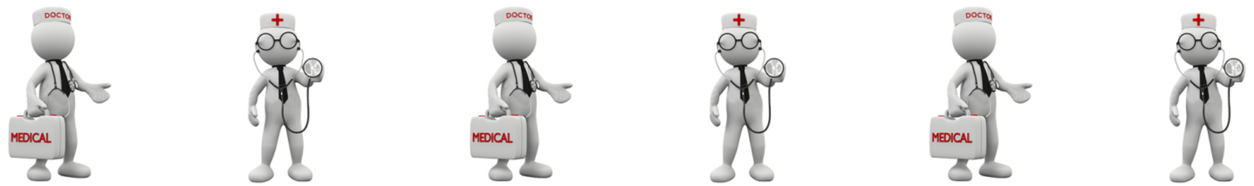
In the next results for each hospital, there are the entities number and resources needed for both scenario, two graph to underline the different average times trend (in system, in operation and waiting) between the two situations and lastly, two tables about the average waiting time subdivided into the time waiting for the resources and for the rooms. The third comparison is important to understand what it could be the problem in a real situation and the relatives solutions.

In the end an overall summary of emergency conditions results is presented. Hospital B and E aren't included because they don't receive patients for different reasons. Hospital D is the only one to be able to absorb the arriving casualties. All the others have problem specially for red and yellow patients while hospital F even for Green A injured people (Tab. 24). Table 25 shows the models results with more added resources. Healthcare facilities with still issues are: hospital F and H. At this point is fundamental a redistribution. Map in figure 48 presents where to direct the excess of patients and table 26 the amount of people for each destination. Hospital F releases 50 red patients and hospital A just 4, granting for each structures, a maximum waiting time of 25 minutes for red patients, 40minutes for the yellow ones and less than 10 hours for the Green ones.

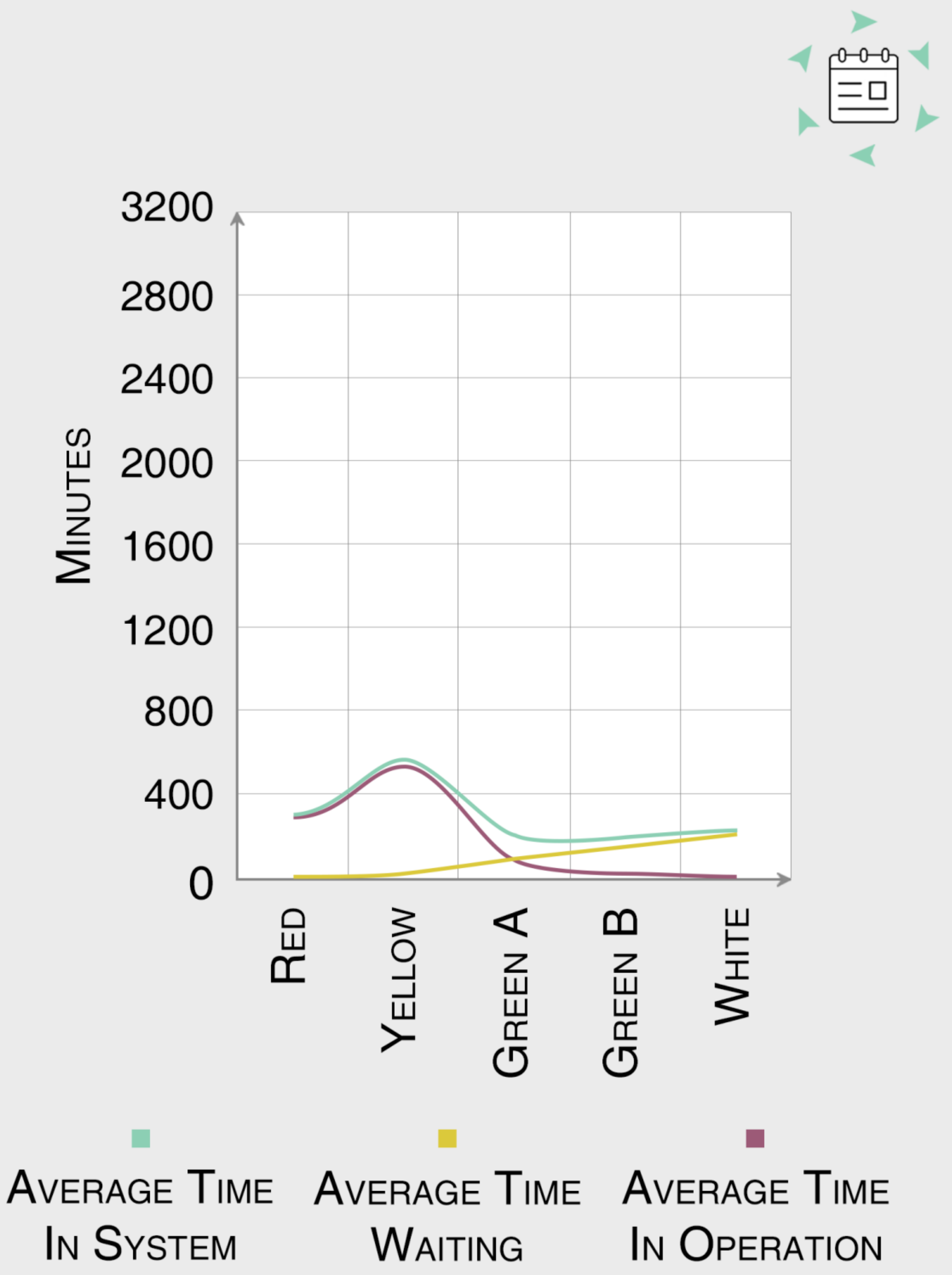
Concluding a final table (Tab. 27) shows the number of doctors and locations to be added minimum in case of emergency. If Turin hospital network is able to reach these numbers, with a certain amount of training for the staff could be involved, it will be able to withstand the earthquake, otherwise an enlargement of the network until the hospitals nearby Turin, is asked.

Hospital A

Entities					
Ordinary	1	14	93	96	[per day]
Emergency	26	21	98	-	[in 3 days]



Resources						
Ordinary	1	3	2	3	2	2
Emergency	**2**	3	**3**	3	**3**	2



Minutes
3200
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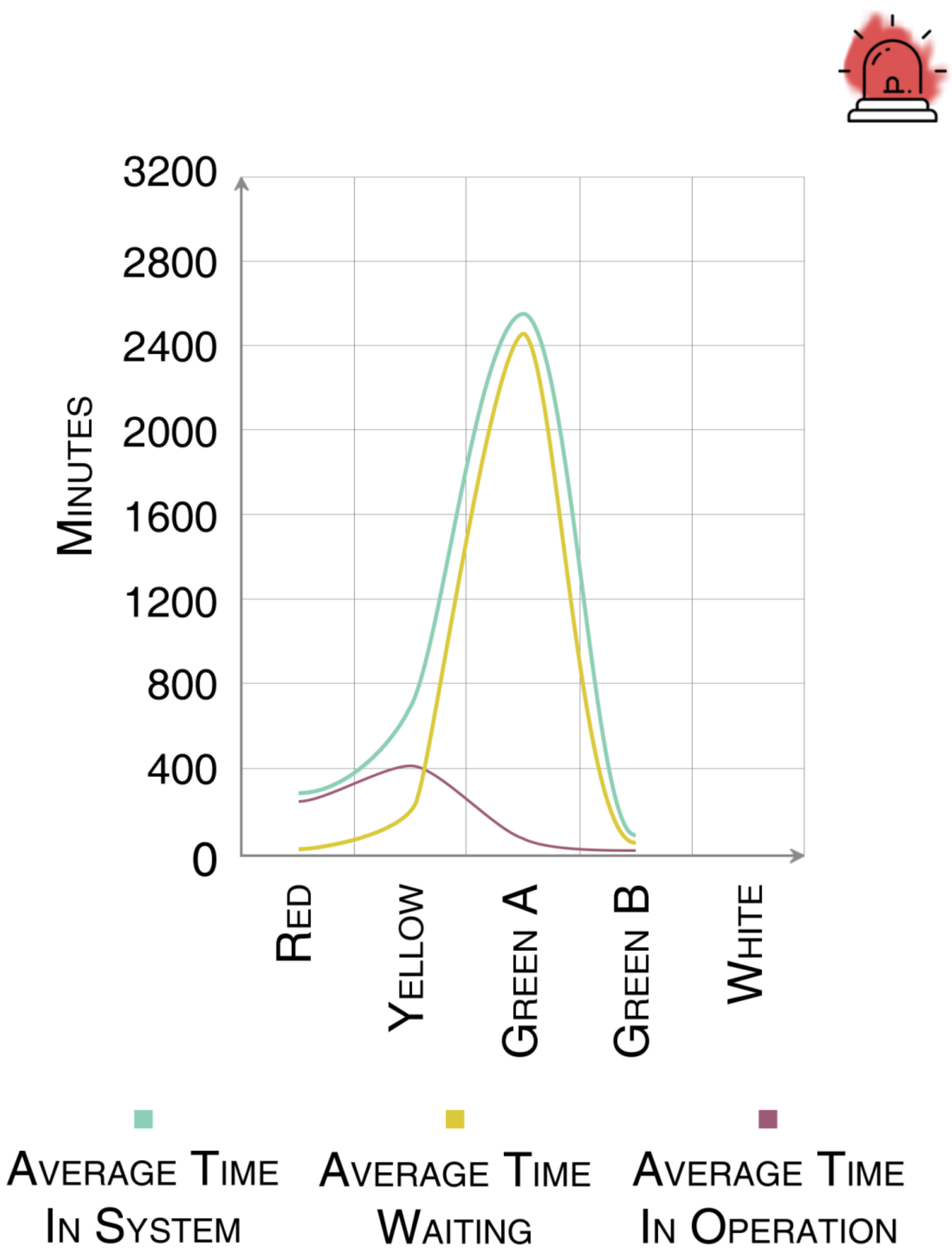
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation



Minutes
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400
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

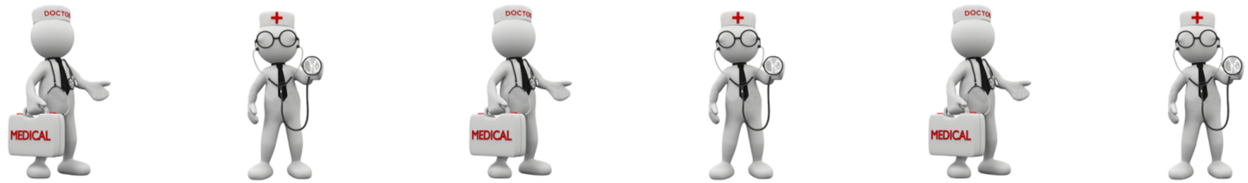
Average Waiting Time (min)					
Resources	3	11	10	1	1
Places	17	14	104	170	215

Average Waiting Time (min)					
Resources	1	6	6	1	-
Places	49	257	2475	77	-

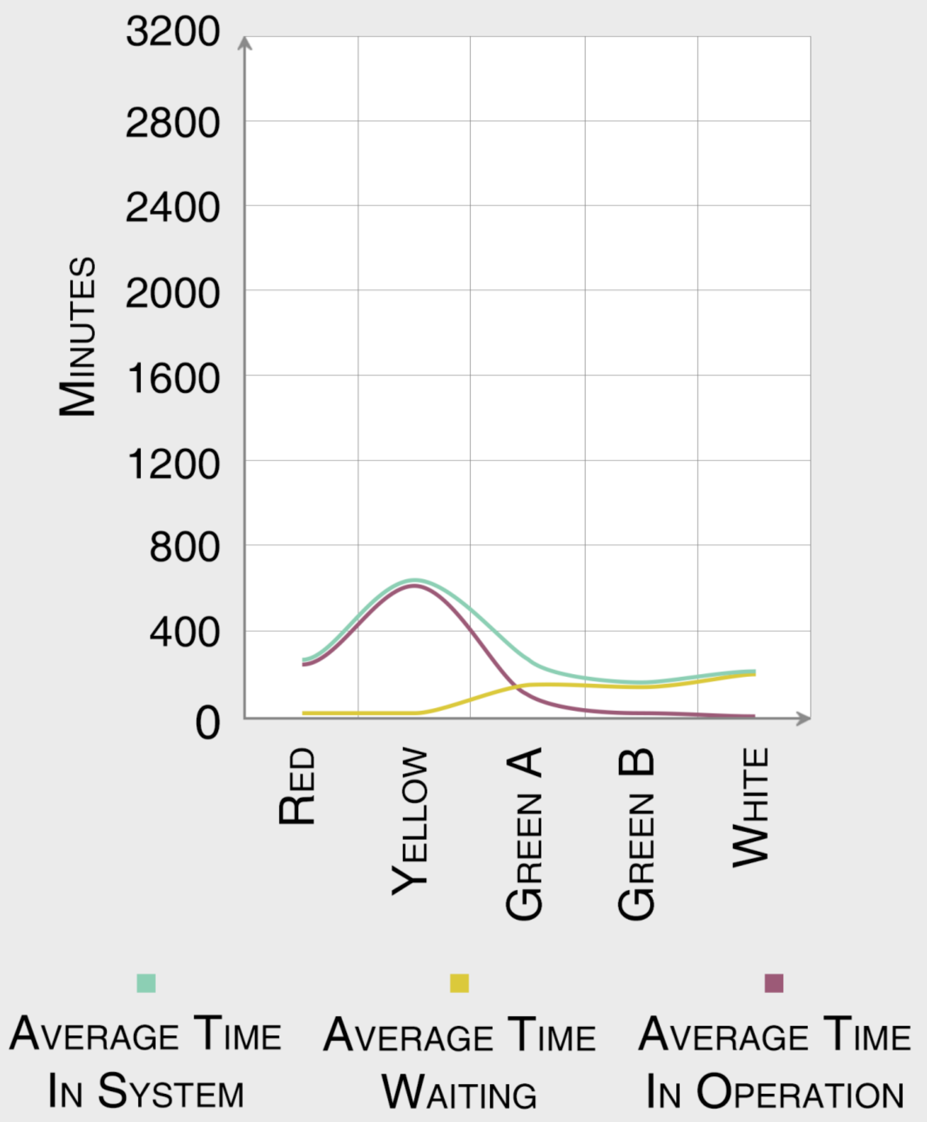
Solution: Find another **room** available **for surgery operations** inside the hospital or set up a **field hospital**.

Hospital B

ENTITIES					
ORDINARY	1	14	93	96	[per day]
EMERGENCY	0	0	0	-	[in 3 days]



RESOURCES						
ORDINARY	1	3	2	3	2	2
EMERGENCY	-	-	-	-	-	-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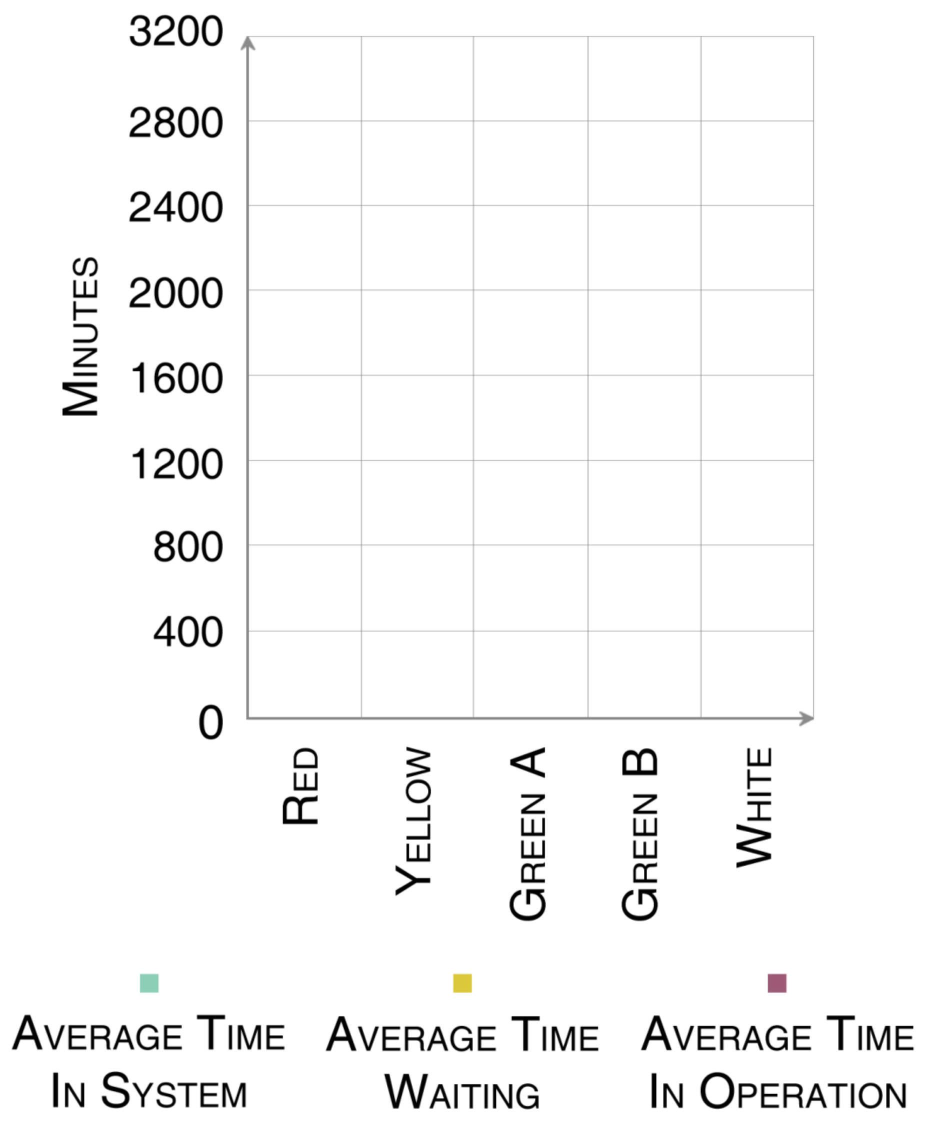
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation


Minutes
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1200
800
400
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

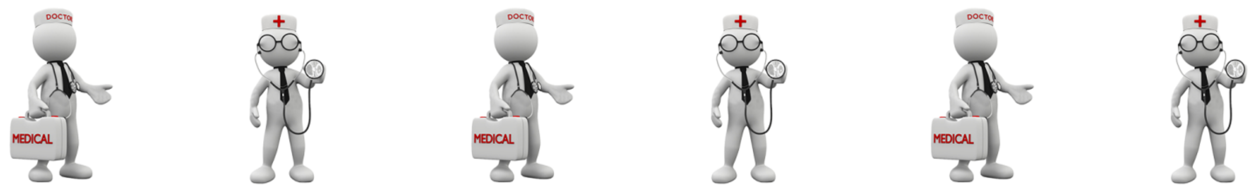
	Average Waiting Time (min)				
Resources	8	14	15	1	5
Places	26	21	149	170	215

	Average Waiting Time (min)				
Resources	-	-	-	-	-
Places	-	-	-	-	-

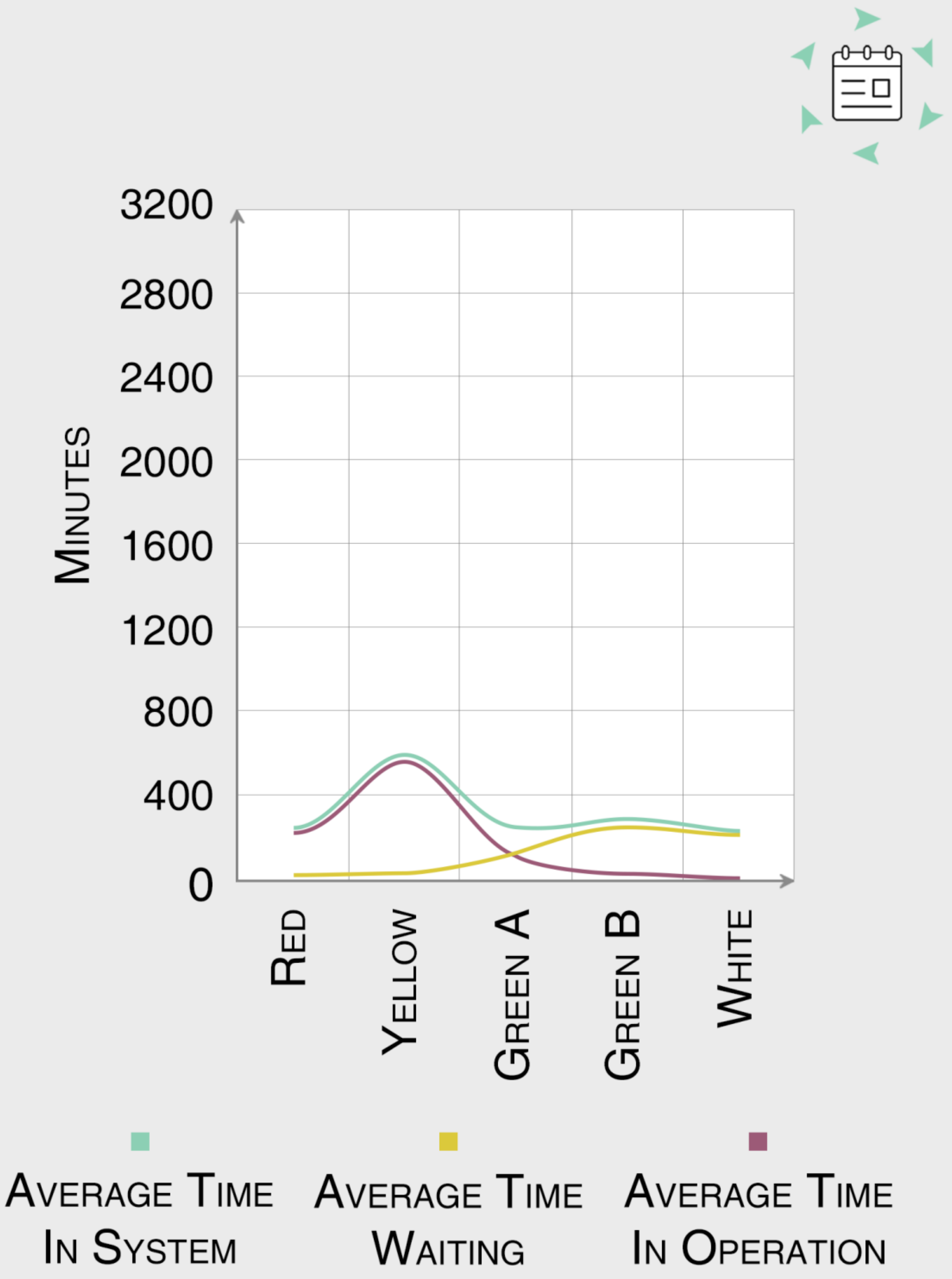
Solution: ED entrance is blocked by debris but the main one of the hospital is not. Thus, **charging** a bit this **ED** could save lives.

HOSPITAL C

Entities					
Ordinary	4	38	137	16	[per day]
Emergency	15	8	103	-	[in 3 days]



Resources						
Ordinary	2	8	6	7	2	3
Emergency	3	8	7	7	3	3


Minutes
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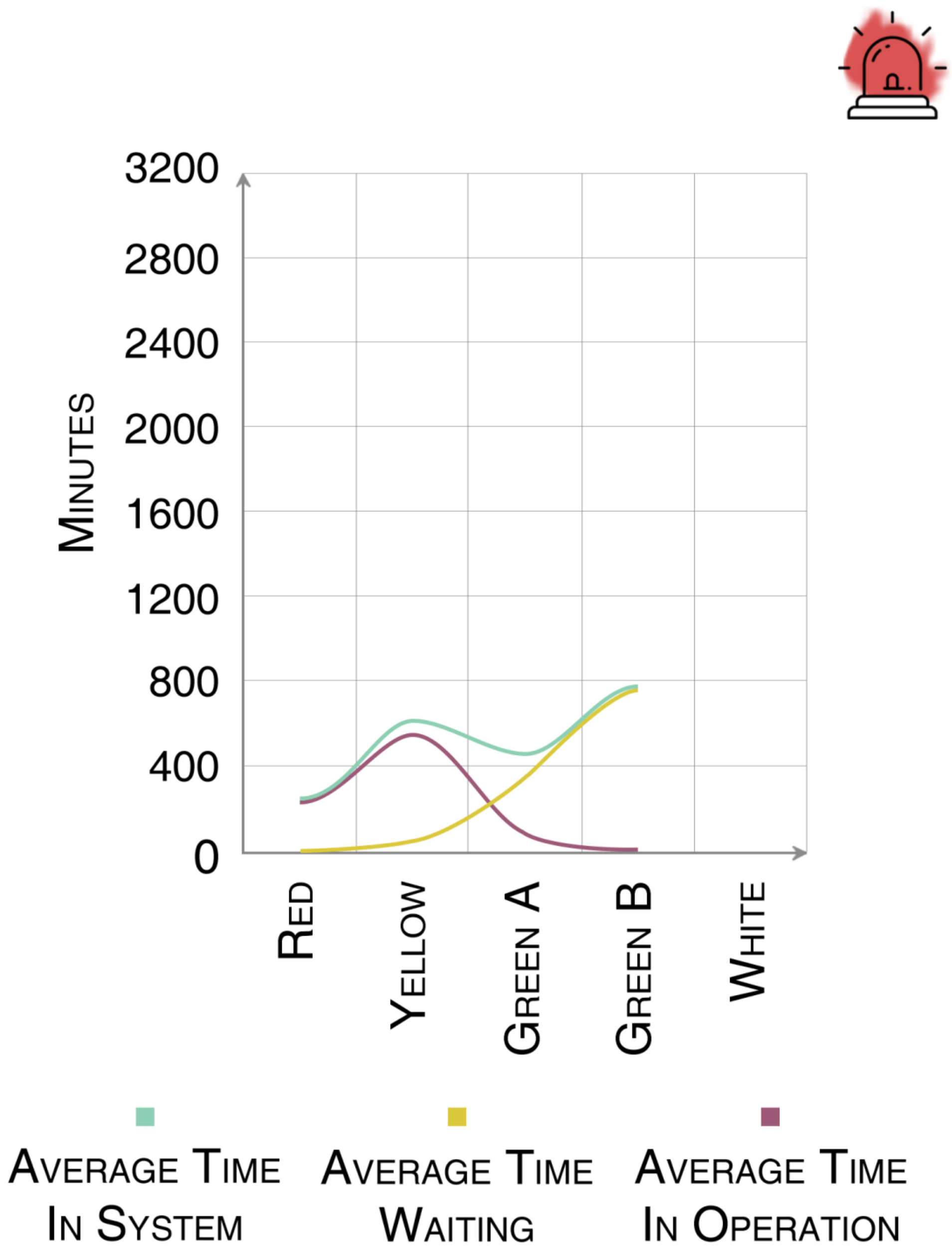
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation


Minutes
3200
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0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

Average Waiting Time (min)					
Resources	7	7	43	14	15
Places	19	17	104	267	190

Average Waiting Time (min)					
Resources	3	7	32	6	-
Places	27	62	340	762	-

SOLUTION: This hospital has one more room in the red area that could become the third **operating room**.

2 Operating Room

	Average Waiting Time (min)				
Resources	3	7	32	6	-
Places	27	62	340	762	-

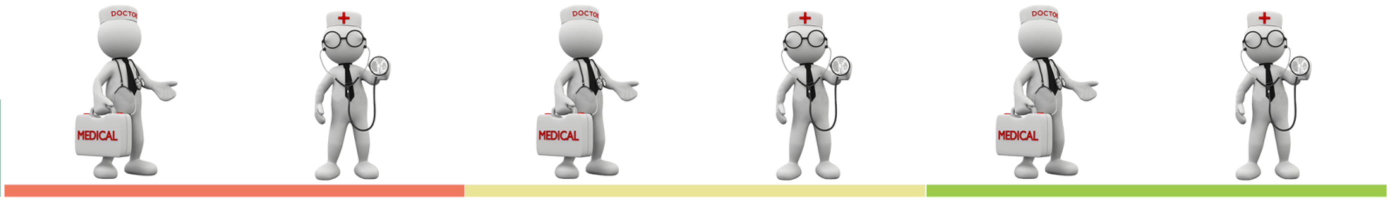
3 Operating Room

	Average Waiting Time (min)				
Resources	3	7	32	6	-
Places	3	16	131	711	-

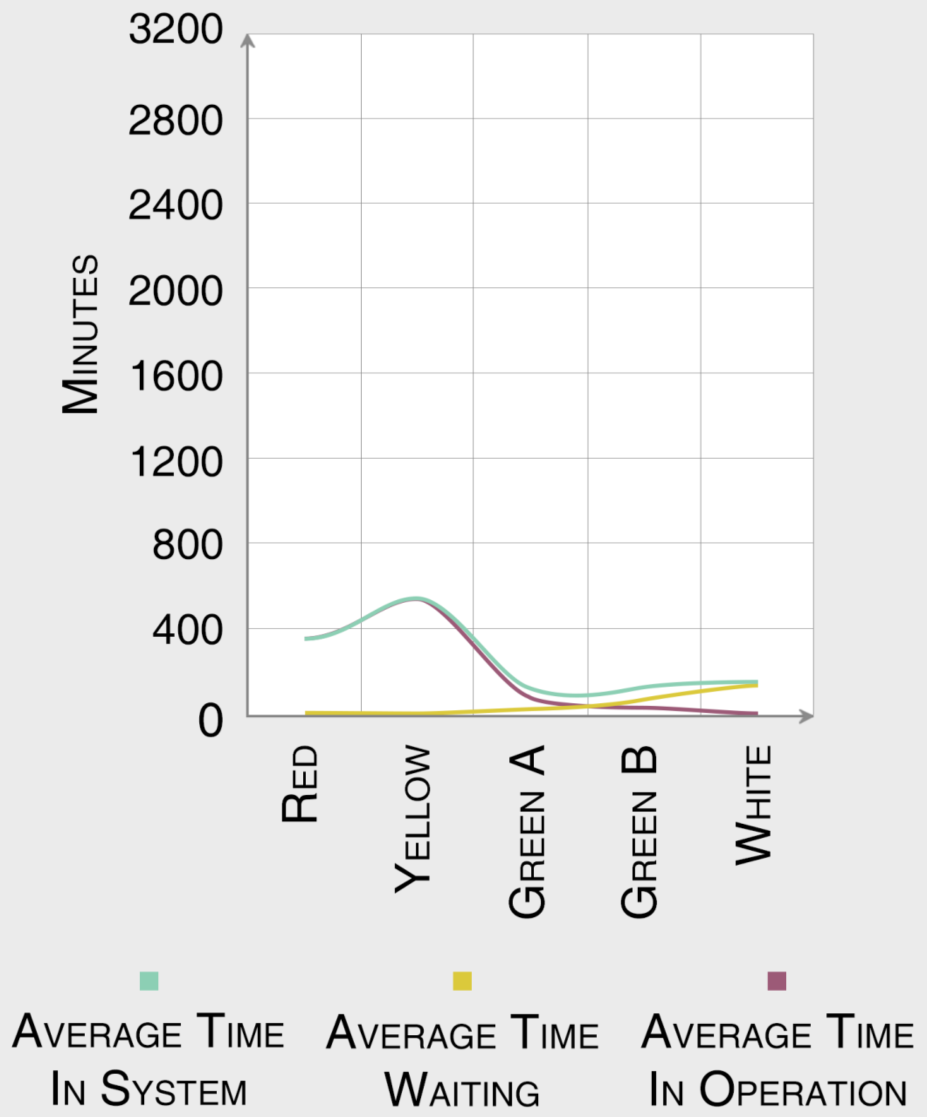
WT decreases by 89% for Red patients, 74% for the Yellow ones and respectively 61% and 7% for Green A and Green B casualties.

HOSPITAL D

Entities					
Ordinary	1	7	56	68	[per day]
Emergency	26	12	73	-	[in 3 days]



Resources						
Ordinary	2	3	3	3	2	2
Emergency	**3**	3	3	3	2	2


Minutes
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800
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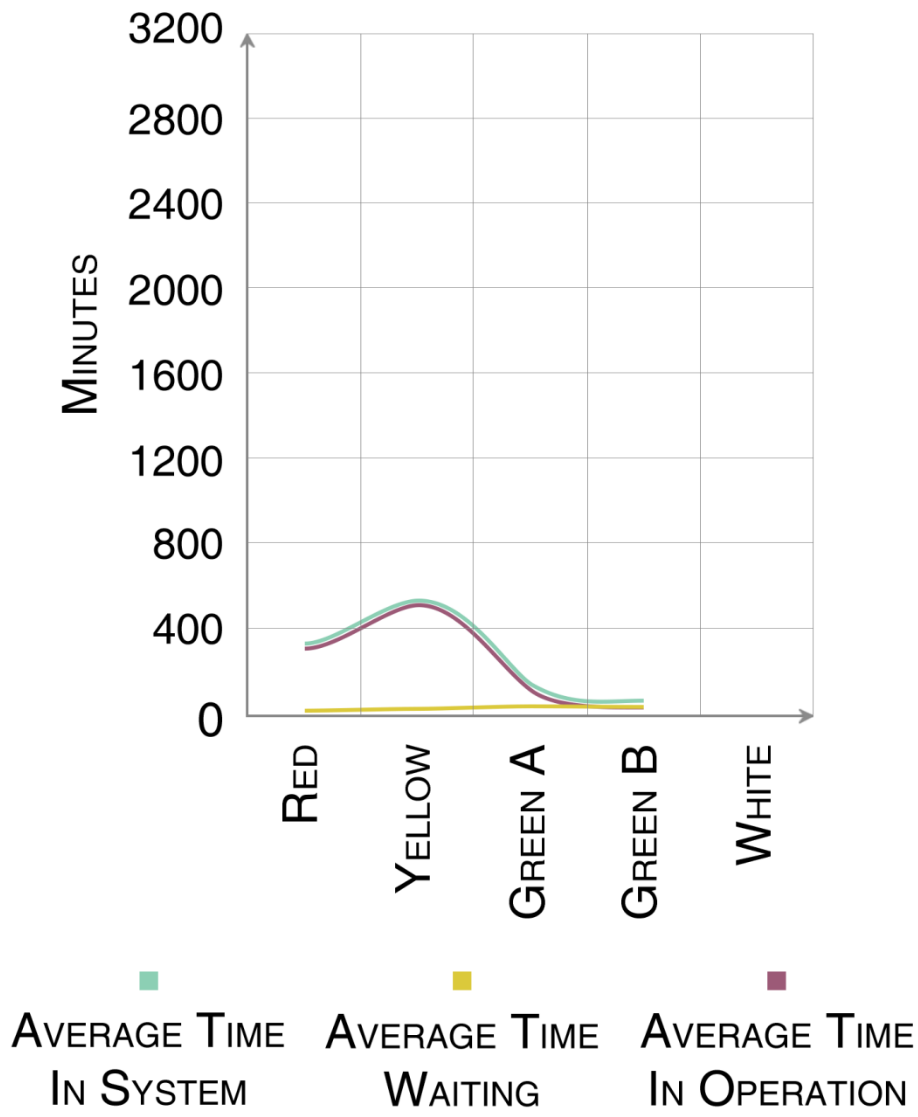
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation


Minutes
3200
2800
2400
2000
1600
1200
800
400
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

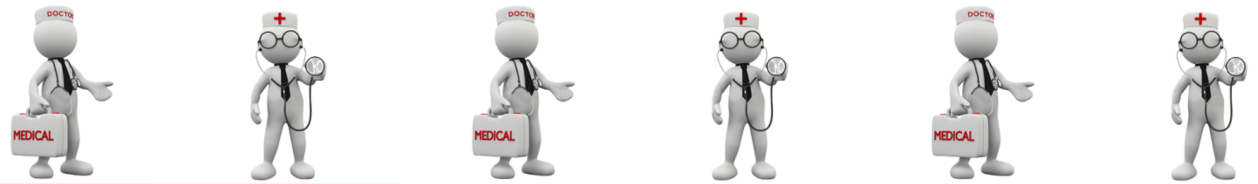
Average Waiting Time (min)					
Resources	1	7	26	2	11
Places	0	1	8	83	123

Average Waiting Time (min)					
Resources	5	12	24	2	-
Places	1	2	5	29	-

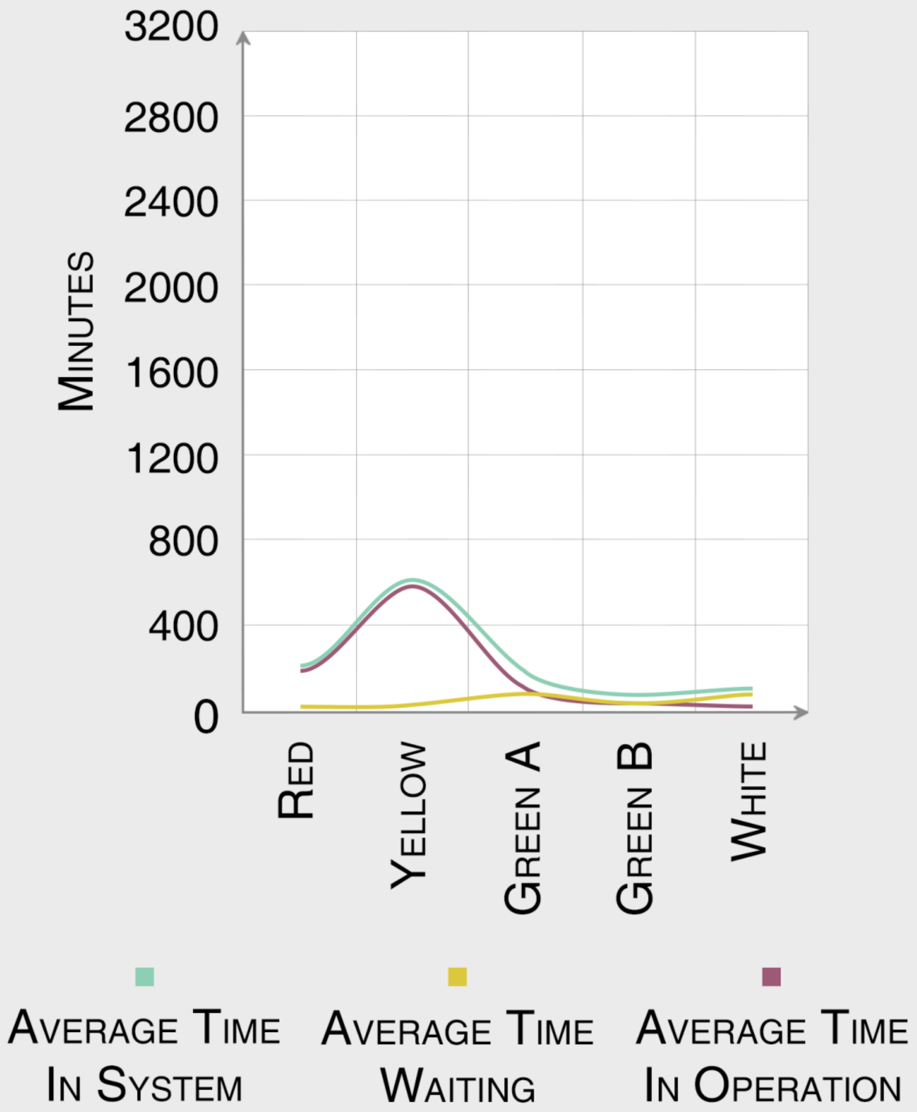
SOLUTION: Receiving less green patients than the ordinary white, their WT decreases so the hospital **can receive** definetely **more green patients**. **Adding doctors**, **also red** and **yellow**.

HOSPITAL E

Entities					
Ordinary	1	15	85	10	[per day]
Emergency	0	0	0	-	[in 3 days]



Resources						
Ordinary	1	3	2	3	2	2
Emergency	-	-	-	-	-	-



Minutes
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400
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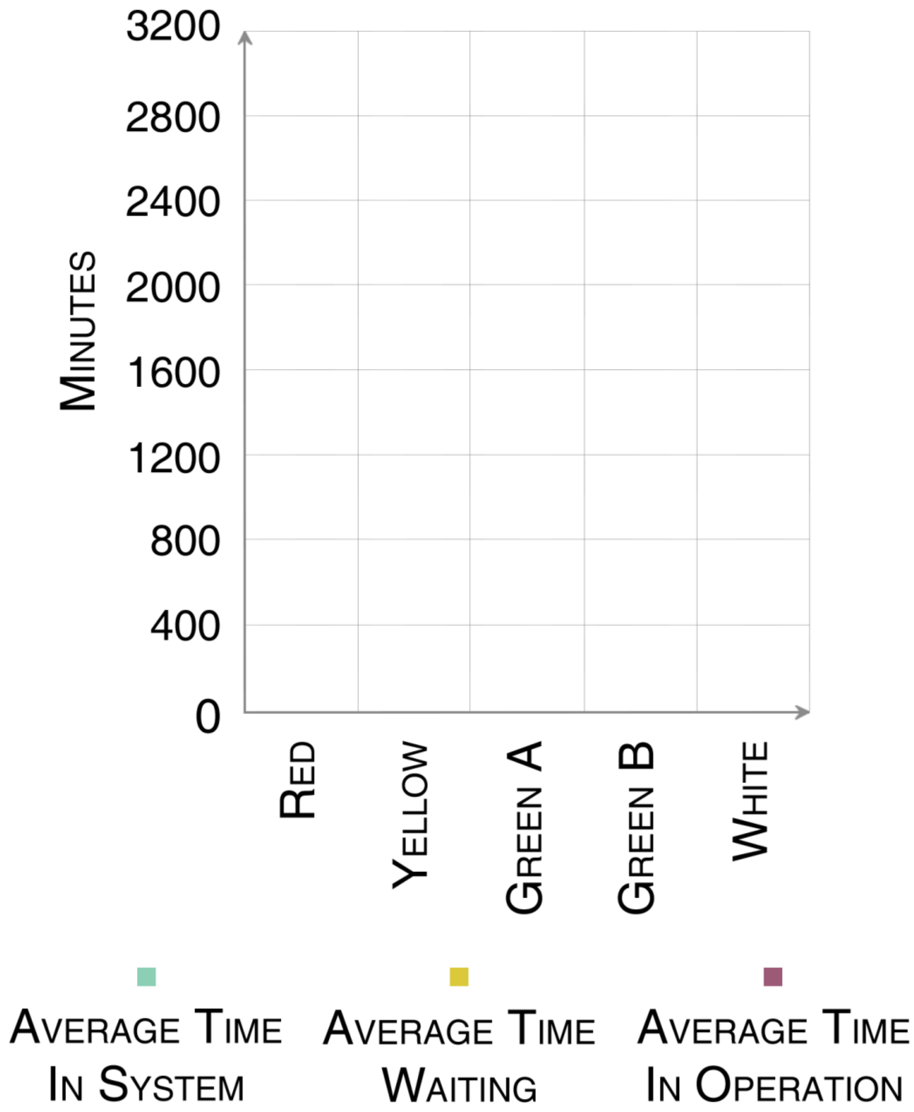
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation



Minutes
3200
2800
2400
2000
1600
1200
800
400
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

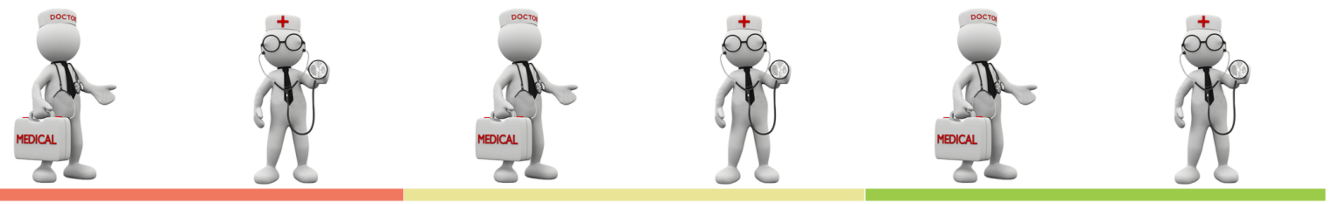
	Average Waiting Time (min)				
Resources	6	7	6	1	1
Places	13	15	69	40	55

	Average Waiting Time (min)				
Resources	-	-	-	-	-
Places	-	-	-	-	-

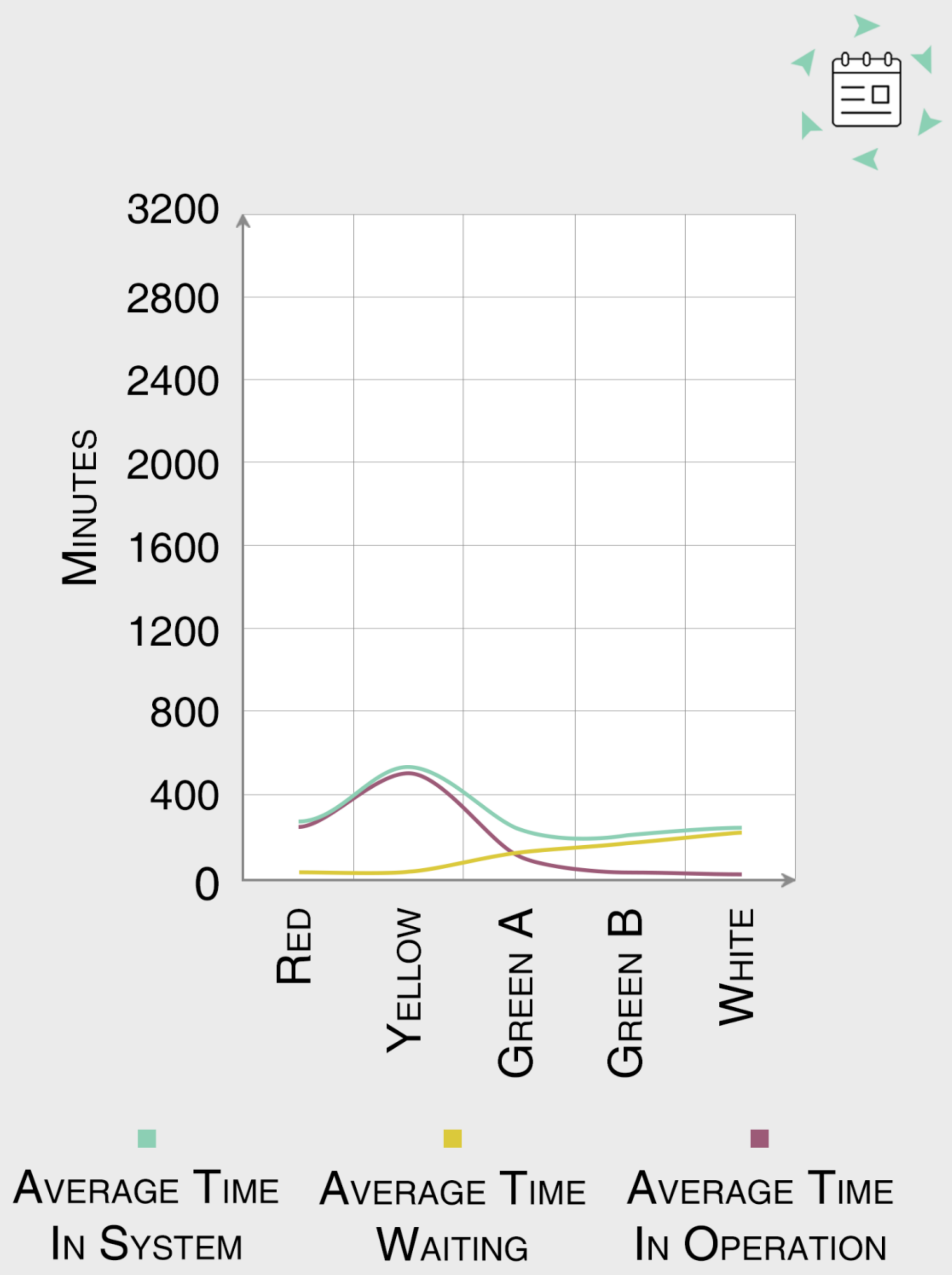
SOLUTION: This is a pediatric hospital thus not all the people can be treat here but, a percentage of **baby patients** arriving at CTO, **can be diverted here**.

HOSPITAL F

Entities					
Ordinary	1	24	114	19	[per day]
Emergency	83	40	293	-	[in 3 days]



Resources						
Ordinary	1	3	3	3	3	3
Emergency	**3**	**4**	**4**	**5**	**5**	**4**


3200
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Green A
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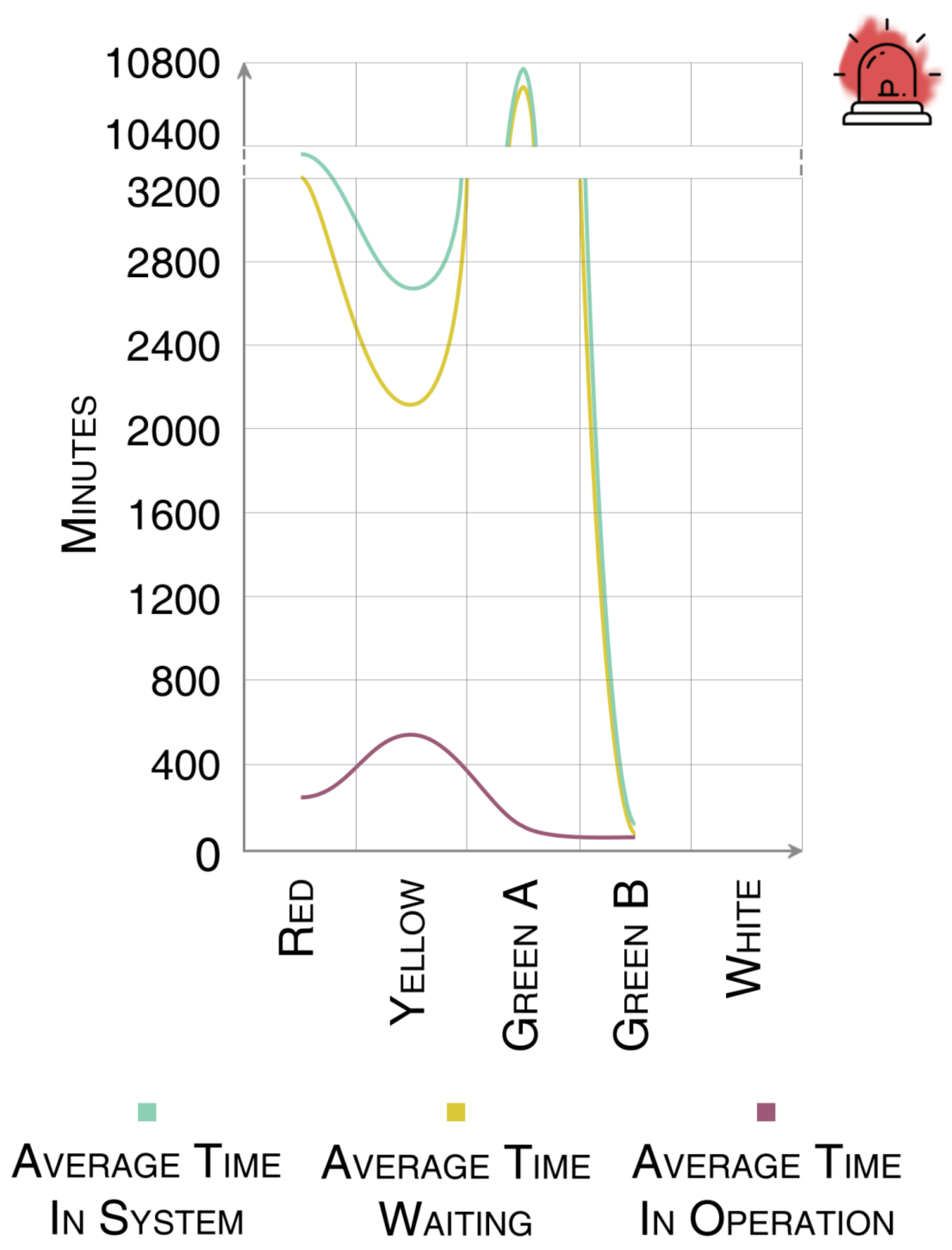
Average Time In System
Average Time Waiting
Average Time In Operation


10800
10400
3200
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2400
2000
1600
1200
800
400
0
Minutes
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

Average Waiting Time (min)					
Resources	8	4	12	3	1
Places	20	22	116	171	218

Average Waiting Time (min)					
Resources	8	4	11	3	-
Places	3238	2140	10561	36	-

Solution: This hospital needs at least two more **operating rooms** and two more ward beds into the **intensive care**.

1 Operating Room
4 Beds in Intensive Care

	Average Waiting Time (min)				
Resources	8	4	11	3	-
Places	3238	2140	10561	36	-

3 Operating Rooms
6 Beds in Intensive Care

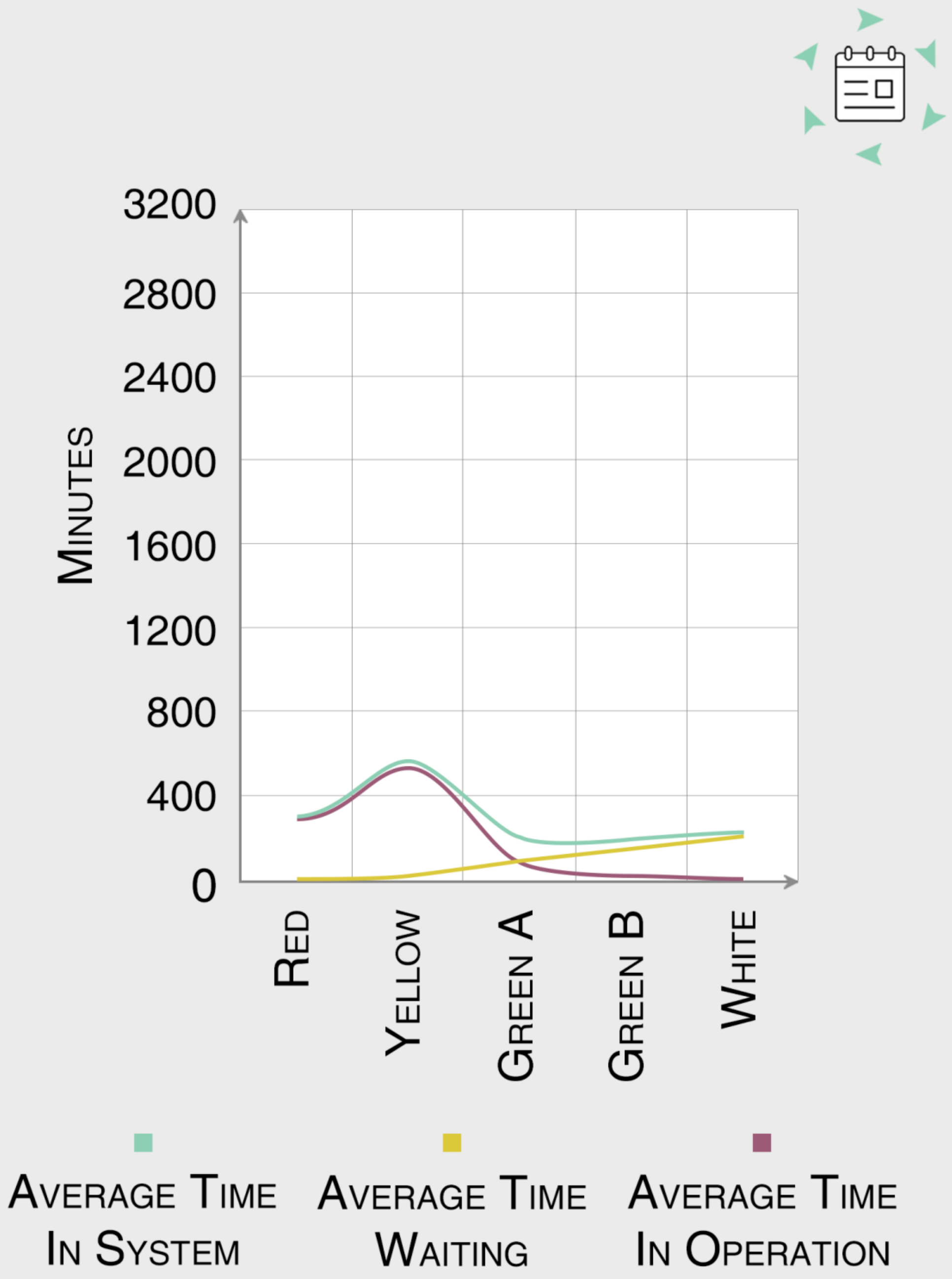
	Average Waiting Time (min)				
Resources	30	4	11	3	-
Places	444	132	2128	36	-

WT decreases by 86% for Red patients, 94% for the Yellow ones and 80% for Green A casualties. A **doctor red** more could help.

HOSPITAL G

Entities					
Ordinary	1	14	93	96	[per day]
Emergency	24	14	92	-	[in 3 days]

Resources						
Ordinary	1	3	2	3	2	2
Emergency	2	3	3	3	3	2



Minutes
3200
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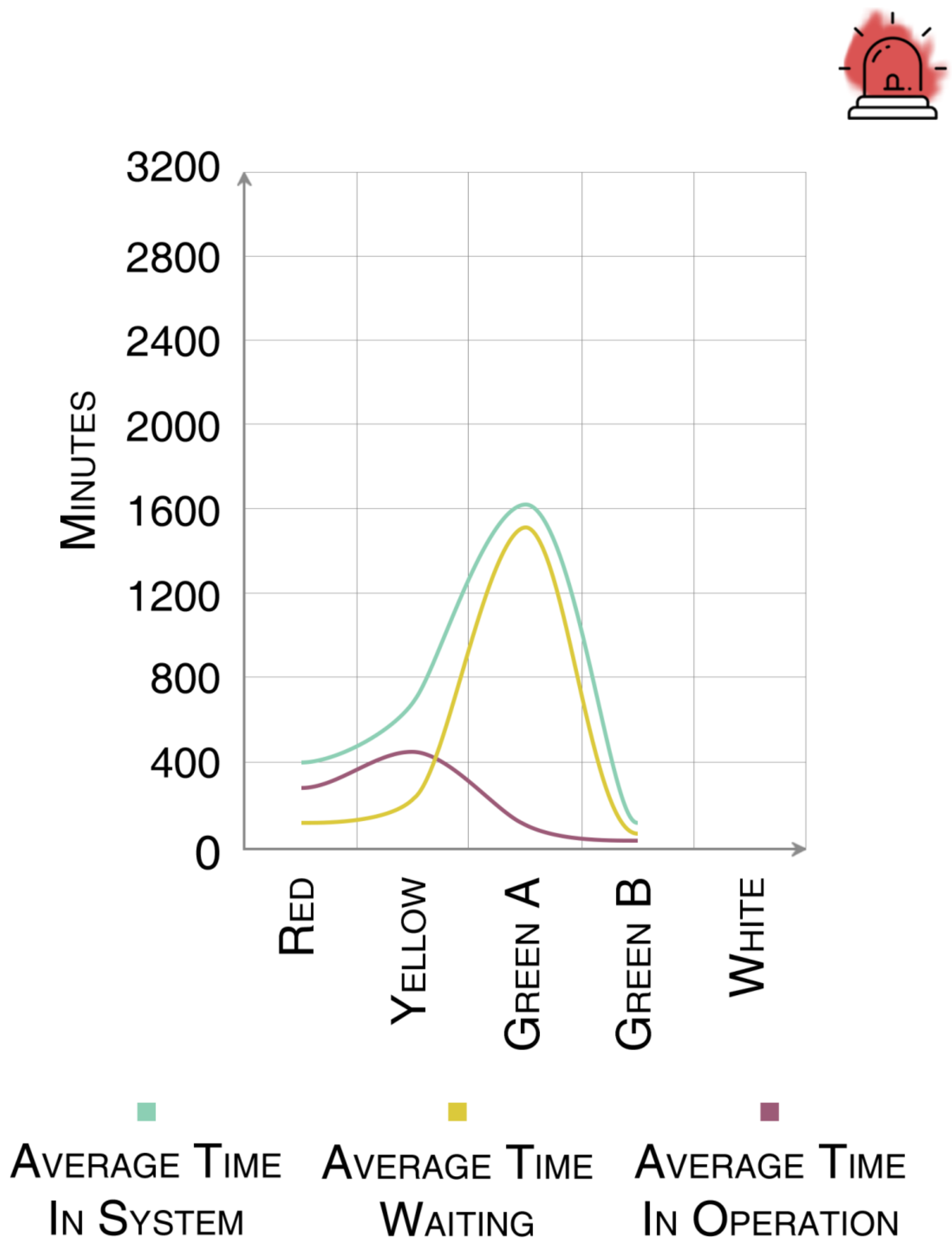
1200
800
400
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation



Minutes
3200
2800
2400
2000
1600
1200
800
400
0
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

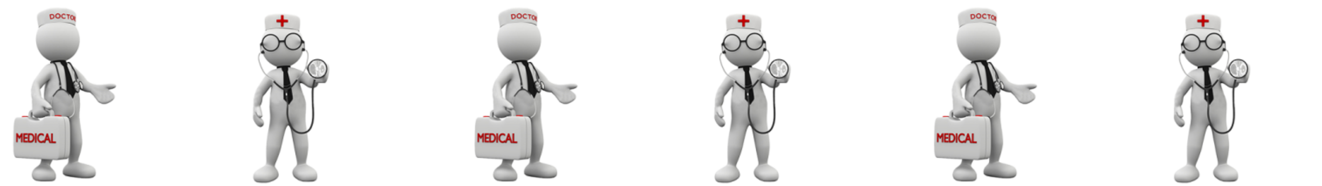
	Average Waiting Time (min)				
Resources	3	11	10	1	1
Places	17	14	104	170	215

	Average Waiting Time (min)				
Resources	1	6	5	1	-
Places	112	233	1513	65	-

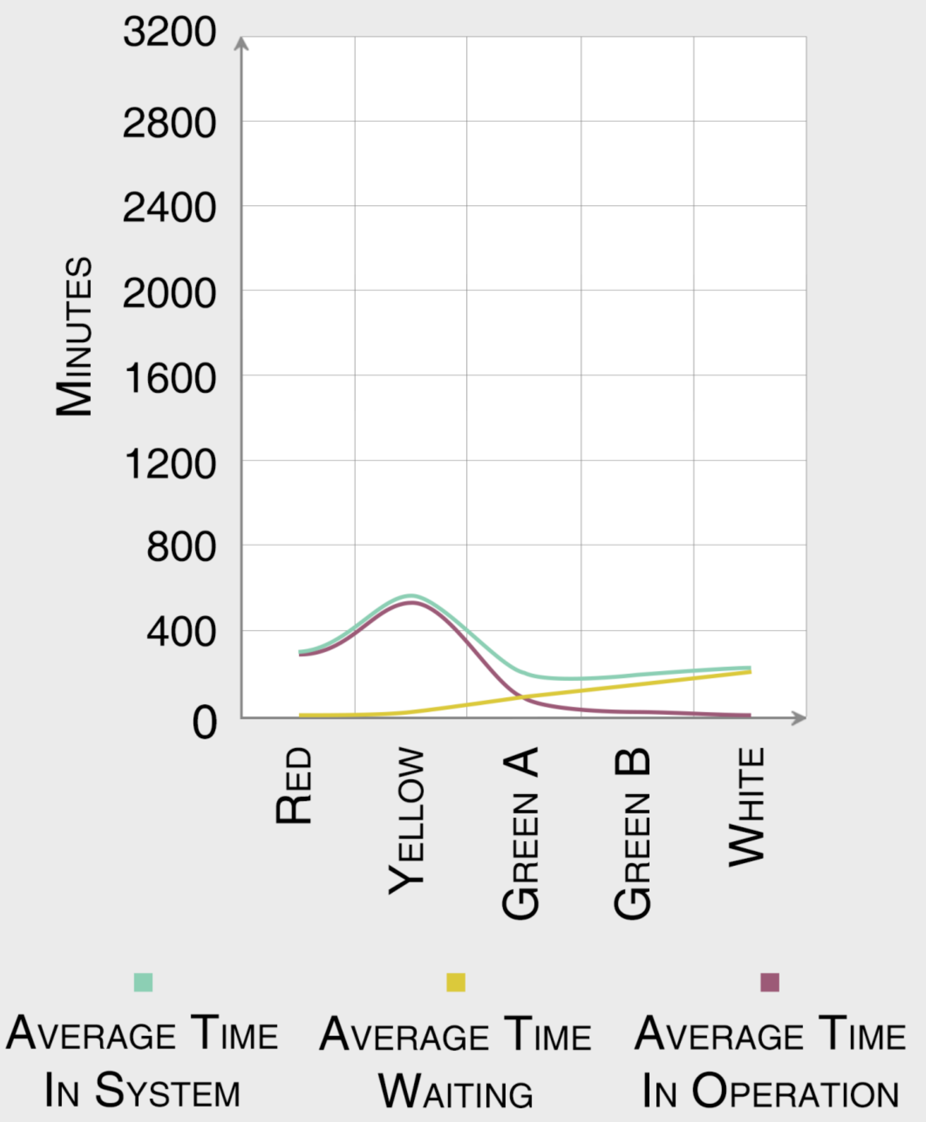
Solution: Find another **room** available **for surgery operations** inside the hospital or set up a **field hospital**.

HOSPITAL H

Entities					
Ordinary	1	14	93	96	[per day]
Emergency	36	11	128	-	[in 3 days]



Resources						
Ordinary	1	3	2	3	2	2
Emergency	**2**	3	**3**	3	**3**	2


Minutes
3200
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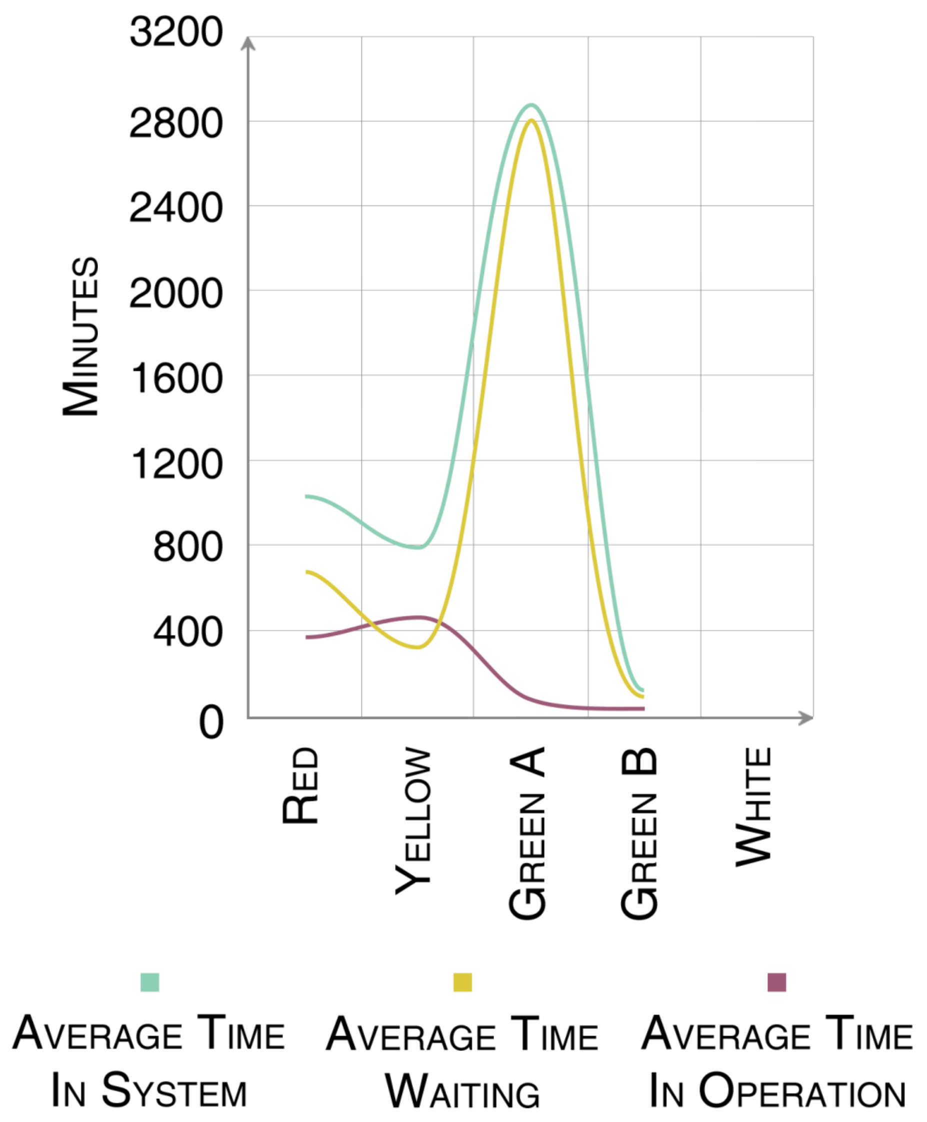
Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation


Minutes
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Red
Yellow
Green A
Green B
White
Average Time In System
Average Time Waiting
Average Time In Operation

Average Waiting Time (min)					
Resources	3	11	10	1	1
Places	17	14	104	170	215

Average Waiting Time (min)					
Resources	1	5	3	1	-
Places	675	313	2806	94	-

SOLUTION: Find another **room** available **for surgery operations** inside the hospital or set up a **field hospital**.

Code	Lower WT	➤➤➤	➤➤➤	➤➤➤	➤	Higher WT	
Red	D	C	A	G	H	F	Hospital
Yellow	D	C	G	A	H	F	
Green A	D	C	G	A	H	F	
Green B	D	F	G	A	H	C	

Code	Lower WT	➤➤➤	➤➤➤	➤➤➤	➤	Higher WT	
Red	6	30	50	112	675	3246	Minutes
Yellow	14	69	233	263	313	2144	
Green A	29	372	1513	2481	2806	10572	
Green B	31	39	65	78	94	768	

■ WT not acceptable

Tab. 24. Summary hospitals results.

Hosp.	Additions	WT (Resources + Places)			
A	1 Operating Room	1+13	7+5	7+28	1+75
C	1 Operating Room	3+3	7+16	32+131	6+711
F	1 Operating Room 2 Bed Intensive Care 1 Doctor Red	30+444	4+132	11 + 2128	3+36
G	1 Operating Room 1 Doctor Red	1+21	8+17	6+91	1+65
H	1 Operating Room 1 Doctor Red	1+35	7+29	7+330	1+92
		[Minutes]			

Tab. 25. Summary hospitals results with additions.

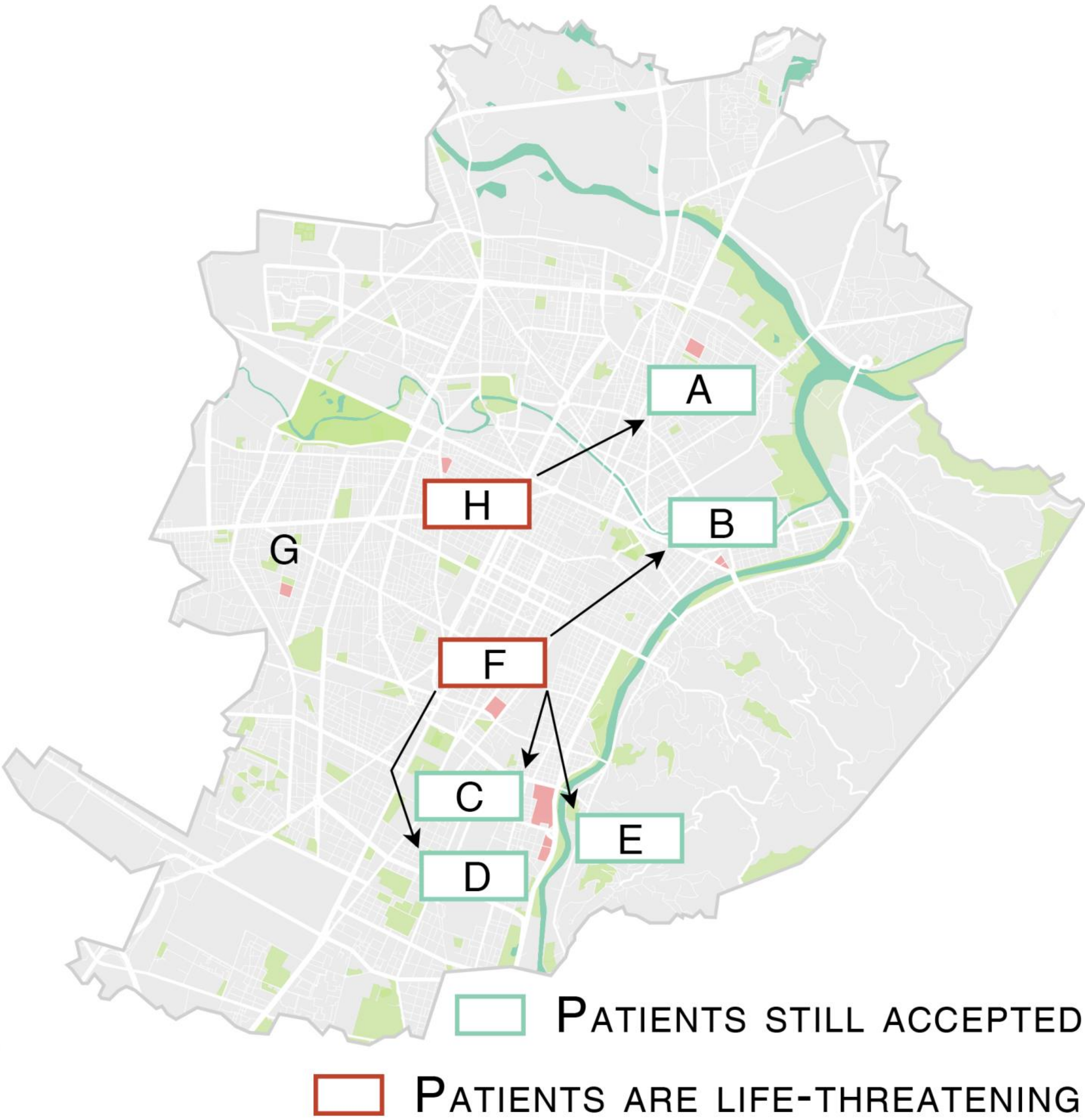


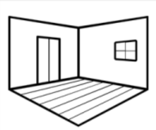
Fig. 48. Redistribution patients map.

Hospitals overwhelmed		Hospitals receiving	Patients extra	Resources extra
F	➤➤➤	D	19	2 Doctor
		B	20	1 Doctor
		E	6	-
		C	5	-
H	➤➤➤	A	4	-

Granted a **maximum WT** of **25 min** for red patients, **40 min** for yellow patients and less than **10 h** for Green ones.

Tab. 26. Patients and resources extra for receiving hospitals.

Resources		Hospitals A	B	C	D	E	F	G	H
 Doctor	Red	1+1	1	2+1	2+1	1	1+3	1+2	1+2
	Yellow	2+1	2	6+1	3	2	3+1	2+1	2+1
	Green	2+1	2	2+1	2	2	3+2	2+1	2+1
Total Doctors		8	5	12	8	5	13	9	9

Locations		Hospitals A	B	C	D	E	F	G	H
	OR	1+1	1+1	2+1	4	1	1+2	1+1	1+1
	IC	4	4	4	5	2	4+2	4	4
Total Beds Red		6	6	7	9	3	9	6	6

Tab. 27. Total extra resources and places needed.

Future Researches

- Discuss the results with each hospital to better calibrate the models.
- Working on a city-scale maxi-emergency plan for Turin where the hospitals got to start collaborating on this topic and better training their staff.

Conclusions

The aim of this thesis was twofold. First to understand deeply the complexity of emergencies involving transportation and hospital networks after an earthquake, and second to explore the urban consequences of this phenomenon at the expense of human lives, using the case study of Ideal City as test bench. One of the main points of this work has been to contribute to the existing research field in its weaker parts. In this final section I would like to highlight my contribution to the topic.

Cities in general have to face possible emergency conditions every day and often they are not prepared for lacking of money or simply because interiorly they hope never could happen. Especially in Italy there aren't large-scale emergency plan and people are not trained enough to withstand stress and make up their mind to save as many lives as possible without hampering the rescue. That's the reasons why simulation model got to be studied and because it is the cheapest way to start doing the first step towards the prevention.

The results show as Ideal City could be able to overcome the difficulties with organization and coordination. The problem during not ordinary situations are people shocked and their ability to think clearly and fast, the right information to make to arrive to destination and to put them together and in order.

Nevertheless the city is affected by collapsed buildings, people are able to arrive to the closest hospital by 30 minutes maximum but firstly, not always is enough to save casualties and second, these times don't keep in consideration time lost by the operative center to be updated and to organize a plan. If this type of event happened, knowing the area of the city probable more affected, thanks to the model, the dispatcher could be more intelligent to distribute less severe patients to another hospital, not necessarily closer, even not having a general framework of the catastrophe. But ultimately, to reach a hospital is not the first problem. What pretty worries is the time to find the injured people under debris, quite impossible to predict.

As regards the Ideal City hospital network, not all the structures are located in the best way. Major hospitals are placed in the newest area, and so with stronger structures, at the expense of the old ones. But Ideal City is not very congested as big city, for this reason a lot of patients could even arrive to the second or third closest healthcare facility without compromising their lives. Anyway the worse issue concerning all facilities but hospital D, is the number of operating rooms. If the hospitals in emergency circumstances aren't able to grant, at least, an extra one belonging to another department but dedicated for the ED, a failure in the system is mandatory.

In summary, we have presented a new tool for Italy, which combined two known methodologies, personalized for this case study and applied for the first time in a single simulation. In any case, the research field about cities resilience and networks performance after a seismic event is still very open to new contributions, especially on traffic methodology side and on input information for hospitals.

Concluding, George Box in 1987, states "essentially, all models are wrong, but some are useful" because there are a huge amount of variables impossible to be exactly predicted but studying, trying and experimenting, models can become hardcore. According Jack Cohen et al. (2003) in fact, models are lies, children's stories to teach and nothing is wrong with it. "Science progress consists of telling lies more and more convincing to children increasingly sophisticated".

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A

Collective Action in Communities Exposed to Recurring Hazards: The Camp Fire, Butte County, California, November 8, 2018

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1. Introduction

California faces a continuing crisis. As environmental conditions increase the frequency and severity of wildfires and populations move into areas prone to wildfires, social and economic losses escalate exponentially (NBC News, 2018). California now experiences wildfire events throughout the year, and the risk is spreading nationally, increasing in the western states of Washington, Oregon, Arizona, and Colorado and in the southeastern states of Florida and Alabama as well. The total economic cost of the 2017 California wildfires alone was estimated at $18 billion, with the ensuing social costs of interrupted schooling, housing, transportation, business operations adding time and trauma to the recovery (Pierre-Louis, 2018). The immediate costs of the 2018 wildfires in California tallied at nearly $25 billion (Governor Newsom's Strike Force Report, 2019). These escalating costs are unsustainable. Determining new models for how communities can identify and reduce the risk of wildfires is essential for the millions of residents – men, women, children -- who live at the urban/wildland interface. Building the capacity for collective action to reduce this massively complex problem is a task that only the whole region can solve.

The Camp Fire, November 8, 2018, represents an instructive case study of the size, scale, and costs of wildfire risk in California. This report summarizes the findings from a Quick Response study of the Camp Fire, conducted with support from the National Science Foundation administered through the Natural Hazards Center, University of Colorado, Boulder. The interdisciplinary research team from the University of California, Berkeley included three faculty researchers and four graduate students in engineering, public policy, architecture, and computational modeling. The research team collectively made six field trips to the fire-damaged region to interview decision makers at federal, state, county, city, and town organizations who were actively engaged in response and recovery operations for the fire. The research team also reviewed news reports, agency documents, official emergency plans, and documented visual observations of the damaged area.

This report will undertake five tasks in analysis. It will first characterize briefly the wildfire risk to the Town of Paradise and Butte County and review the organizational plans and preparedness actions taken by the responsible organizations prior to the event. Second, it will present a preliminary timeline of the event, documenting the severity of the actual event against plans and resources available. Third, the report will assess the dynamic conditions and processes that shaped actual performance during this event. Fourth, it will present a model of traffic simulation as an example of exploratory research to design alternative strategies for managing evacuation on a regional scale in future wildfire or hazardous events. Finally, it will discuss possible strategies for mitigating wildfire risk in a changing ecological, economic, and social climate.

2. The 2018 Camp Fire: Context and Measures Taken to Reduce Wildfire Risk

The ferocity of the Camp Fire can only be understood by setting the event in the context of the physical geography, terrain, and climate of the region. The Town of Paradise is aptly named, nestled in a pine forest, bounded by a canyon with the Sierra Nevada mountains rising behind the town and a view of the Sacramento Valley stretching below. Yet, this idyllic location is uniquely susceptible to wildfire, as summers get longer and hotter, parched pine needles fall from the trees, and winds blow fiercely through the Jarbo Gap, the canyon that separates the ridge on which the town is built and the mountains behind. Any ignition can be deadly.

Responsible officials and townspeople in Paradise are well aware of the risk of wildfire. Cal Fire, California's state agency responsible for fire detection, prevention, and preparedness, had organized training exercises based on wildfire hazards in the region for twenty years. Butte County had experienced wildfire events previously, most recently in 2008, and county and town officials had used these events to review the risk and develop detailed plans for preparedness and evacuation. The Town of Paradise had developed a detailed plan for evacuation of residents, identifying 14 zones in the town and specifying the order in which residents would evacuate, to allow time for the 26,682 residents to leave safely over the four routes out of town. All residents were counseled to know their zone and the order of zones for evacuation, if necessary. Pamphlets were distributed to households to inform them of the Ready, Set, Go program for evacuation. The Town Council scheduled town meetings to engage residents in developing individual and neighborhood evacuation strategies. Emergency services personnel conducted simulated evacuation exercises using the contraflow strategy to allow residents to practice driving on all four lanes of the highway out of town.

Yet, an unusual confluence of events on November 8, 2018 overwhelmed the plans and protocols enacted to protect the region and enable the residents of Paradise and the surrounding towns and cities to manage the risk of wildfire. It is useful to acknowledge the network of formal plans and policies for wildfire risk reduction developed by the State of California, Butte County, and the Town of Paradise, as they are evidence of the investment of time, thought, and effort that had been made to counter the risk. Essentially, three major types of planning activities undergirded the response operations for this extreme event. First, the set of federal frameworks for emergency planning developed by the Federal Emergency Management Agency (FEMA) outline a common set of goals and emergency support functions for all fifty states in the United States (U.S.). These frameworks represent a formal set of organized plans that structure emergency support functions for all types of hazards. The frameworks were developed at the federal level but are intended to structure and coordinate response operations across all jurisdictional levels – federal, state, county, city and town -- for the nation. The five frameworks include: Prevention, Protection, Mitigation, Response, and Recovery (Federal Emergency Management Agency, 2019). Consistent with the federal frameworks, each jurisdiction develops its own emergency plan to reflect the specific hazards and resources that characterize its hazardscape (Cutter, 2016).

The State of California, subject to a range of natural hazards – earthquakes, wildfire, floods, landslides, and drought – has developed the Standardized Emergency Management System (SEMS) to ensure a common set of terms, functions, and operations procedures across the 58 counties and their component municipalities

(California Emergency Management Agency, 2009). This inter-jurisdictional network of emergency plans provides a common framework for operations and training in emergency events that exceed the resources and capacity of a single jurisdiction and require collaboration and shared response operations across multiple jurisdictions. Similarly, Butte County has developed its county-wide plan that outlines procedures and resources available to monitor and manage risk within its geographic and environmental boundaries. The Town of Paradise, within Butte County, developed an emergency plan with a focus on wildfire, recognizing the geological/meteorological/climate-related risks to the community (Evacuation Plan, 2018. Cal Fire, Butte County, Unit 35, Paradise.).

The second type of planning activities focused on developing the communications infrastructure, protocols, procedures for detecting and reporting risk of emergency incidents and mobilizing timely response operations to bring incidents under control as quickly and efficiently as possible. Central to achieving effective coordination in rapidly escalating emergencies, communication is dependent upon the technical infrastructure that enables it. Although California has a state-wide 911 system, in which emergency calls can be made by telephone from any location in the state, calls are routed through a voice-over-internet-protocol (voip) system to a public safety access point (PSAP) closest to the site of the reported incident. There are 437 PSAPs statewide in California, which provide a comprehensive network of local access points. Calls received at the PSAPs are then transmitted over commercial telephone services or agency radio channels to local jurisdictions and agencies to mobilize response operations. In extreme events, commercial telephone services are vulnerable to damage or disruption from hazards, as cell towers are damaged or transmission lines downed. Agency radio systems have cross-over channels between some agencies, not all. Even so, in an intensely developing event, access to a shared radio channel, for example, between Police and Fire agencies, can become difficult, as many personnel attempt to communicate messages at once. Or, if a critical agency does not share a radio channel and the commercial phone systems are down, it becomes extremely difficult to coordinate actions under urgent conditions. Organizational coordination is constrained by the technical infrastructure that enables it.

A third set of activities central to building the capacity of a community to respond collectively to an extreme event is the informal development of a sense of shared community and informed commitment to reduce risk. These activities are often set by the example of local leadership in articulating a clear vision of risk for the whole community and outlining a set of actions that can be taken by all residents to reduce that risk. For example, the Town Council in Paradise held town meetings to engage residents in the process of developing and reviewing the evacuation plans for the town. The Butte County Sheriff's Office organized a "Truck or Treat" event for Hallowe'en in 2018, and invited community residents to bring their children, dressed in costume, to visit the Office, meet the personnel, and see the equipment and vehicles that help to keep the community safe. These informal interactions between public agencies and community residents in nonemergency times forge a bond of trust among residents and between residents and public officials that is crucial in enabling community residents to act collectively in uncertain situations. This bond rests upon an awareness of shared risk and a clear understanding of credible actions that can be taken to reduce that risk for the whole community. A list of organizational partners and other organizations that contributed to response operations in the Camp Fire is included in Appendix A.

3. Preliminary Timeline and Critical Decision Points in Response Operations

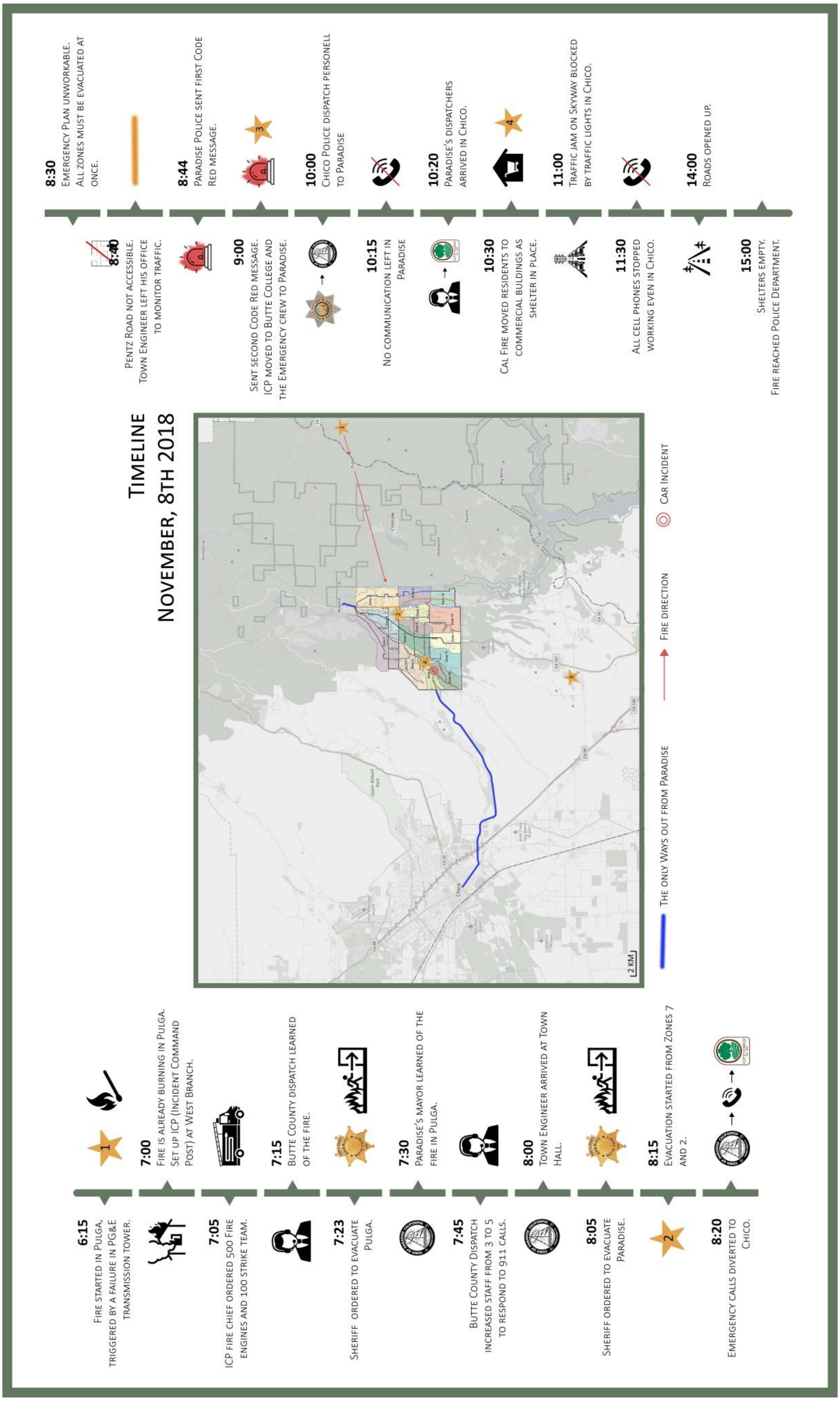
An abbreviated timeline of critical points of decision is shown in Figure 1. The times and events listed were cited in interviews by participants in the events but are not taken from official records. We requested the 209 incident status reports for the Camp Fire that were maintained by Cal Fire, but we were informed that since the case was under investigation, those reports would not be available until the investigation was closed. When the 209 incident reports are available, we will request them to do a more systematic analysis of the time, direction, and interaction among agencies documented by inter-agency communications, and model possible alternative strategies under different conditions of time, access, and types of equipment.

The rapid progression of events that characterized the Camp Fire in Butte County, California represented an extraordinary alignment of physical, meteorological, and ecological conditions that overwhelmed the capacity of the network of organizations that had anticipated and planned for an extreme wildfire event. As the timeline in Figure 1 above shows, the fire, ignited by sparks from a faulty transmission tower managed by Pacific Gas & Electric Company, the utility company that provides electrical power to Northern California, started spot fires in the forested area near Pulga, an unincorporated community on the west side of the Feather River Canyon (Serna and Luna, 2019).

Emergency crews initially set up an Incident Command Post at West Branch near Pulga to contain the fire, but hot, dry winds picked up embers, and within an hour, carried them across the canyon to threaten the Town of Paradise, some 20 miles away by direct flight. In Paradise, ecological conditions, including 237 days without rain and a beetle infestation in its pine forest, had left the town dangerously vulnerable to wildfire, with dead timber and dry pine needles providing ready fuel for the flames. These conditions proved far more complex and dynamic than anticipated by the deliberate planning process or that the physical conditions could overcome.

Wildfire is a known risk in Butte County, and residents of the region had experienced a major wildfire in 2008. The question is how to reduce that risk under changing conditions. The local Fire Department in Paradise, Unit 35, Butte County, operates within the larger network of Cal Fire, the statewide fire protection agency, and developed a detailed plan for evacuation of residents by zone in case of fire. The Paradise Town Council held town meetings to introduce the plan to town residents, and engage them in evacuation exercises, given the limited number of routes out of town. The townspeople had practiced 'contraflow,' driving in one direction out of town; Paradise earned the reputation as a 'fire-safe community'. Figure 2 shows the map of Paradise with the 14 designated evacuation zones and four routes out of town. Zones 2 and 7 were designated as the zones to evacuate first, using Pentz Road to Oroville. Pentz Road, closest to Feather River Canyon,

Figure 1. Timeline of critical events showing progression of the Camp Fire, Butte County, November 8, 2019.



was quickly engulfed in flames and rendered inaccessible. As the fire spread, Clark Road became inaccessible, leaving only two viable routes out of town. All efforts by emergency personnel and townspeople focused on evacuation. As the fire advanced through Paradise, the townspeople recognized the extreme risk and moved quickly to rescue themselves and their neighbors, acting collectively to help each other. Although 85 lives were lost in this deadly fire, 99% of the population of Paradise evacuated safely in a remarkable display of self-organizing collective action for the benefit of the whole community.

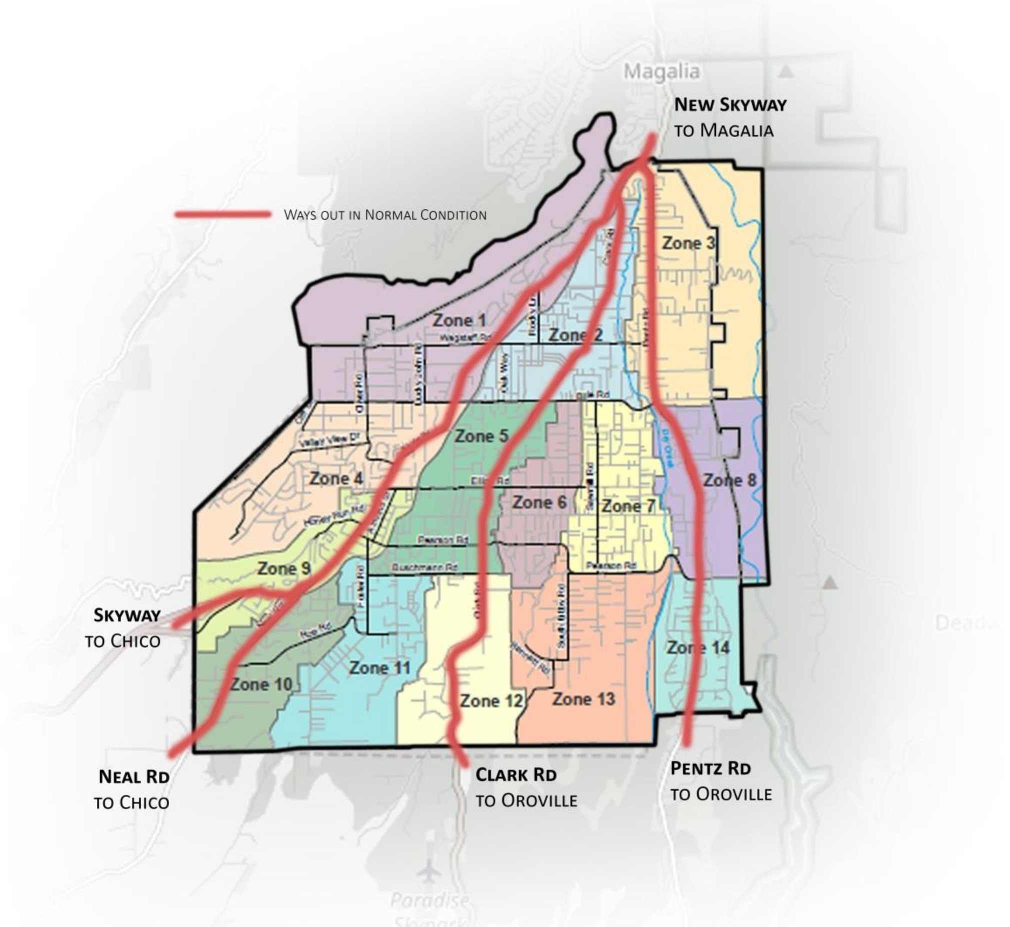


Figure 2. Map of Paradise showing evacuation zones and routes out of town.

4. The Dynamics of Wildfire

The central question echoing through this study is how did a spot fire ignited by a relatively modest electrical spark in wildlands escalate so quickly into the catastrophic fire that devastated Paradise and burned 153,336 acres of wildlands, communities, and forest in Butte County? What dynamic interactions among natural, physical, ecological, technical, and human conditions triggered and amplified this event? What innovations or insights gained from this event would reduce risk in future scenarios as human communities move increasingly into wildland areas? Four areas warrant special attention, although surely there are others. These four areas include:

Complexity and dynamics at the socio/technical/wildlands interface

The rapid series of events illustrated by the timeline shown in Figure 1 demonstrate the complex interactions among the terrain, winds, temperature, and forest that created a natural environment highly susceptible to fire in Butte County. Add to the fragile natural environment a flawed technical system that has the capacity to ignite flames, and the risk grows. Mobilize resources over distances in a rural region, and the time required for travel limits immediate action. With every minute of delay, the ignition escalates until it reaches a threshold point that defies human intervention. The fire then feeds itself, and enters a transition phase that consumes any natural, technical, or human phenomena in its path. This pattern of ignition and escalation of wildfire in social and human environments is not new. What is new is the capacity to bring together a range of knowledge, skills, technologies, and disciplines to create a shared base of knowledge for all organizations, jurisdictions, and actors involved in this process. While planning for organizational and community response is essential, the complexity of this environment requires a deeper knowledge of the science underlying the hazard of wildfire, recognition of the interactive consequences of the changing environment, and adoption of innovative technologies to monitor and model changes in the underlying conditions that precipitate wildfire. Further, both evolving knowledge and technologies support an iterative process of review, reflection, and redesign for the organizational programs designed to engage residents at the wildland interface in adapting their actions to the changing environment.

Public agencies have the legal responsibility to lead this task, but they cannot do it alone. Actions taken in response to fire ignition build on the degree of preparedness, organizational capacity, technical infrastructure, knowledge, and training in place before the fire breaks out. Building resilience to wildfire requires the full commitment of all organizations and jurisdictions, business entities, community groups, and households to monitor the risk and adapt their actions accordingly. Understanding the depth and complexity of wildfire risk in a changing socio/technical/ecological environment is the first step toward managing this risk more effectively.

Communications

As the timeline in Figure 1 shows, communication among multiple agencies, jurisdictions, and communities at risk is fundamental to alerting communities to danger and mobilizing response operations rapidly. The basic communications infrastructure available to emergency personnel in California is effective for managing routine, daily emergencies. In urgent, catastrophic events as in wildfire, when the technical infrastructure that supports the statewide 911 system is also under threat, the communications system, by definition, is vulnerable. Without communications, the capacity to mobilize coordinated inter-organizational, inter-jurisdictional response operations drops. The loss of cell towers as the fire advanced in Paradise sharply reduced communications as town residents faced the most urgent tasks of evacuation. The planned roll-over of 911 dispatch calls from Paradise to Chico to Butte County facilitated the region-wide communications process, but for residents reliant on cell phone access, the loss of communications at the most critical time left them dependent on their own resources, their immediate neighbors, and local personnel. Further, the volume of calls in such an event escalates ten-fold beyond normal operations. For example, Butte County Dispatch reported 2800 calls logged on November 8, 2018 by midnight; 1400 incidents were created in all call areas of the County. For the period, November 8 – 30, 2018, Butte County Dispatch logged over 30,000 phone calls. One dispatcher had 563 calls in a 12-hour shift, or approximately 47 calls per hour. This volume of activity places extraordinary mental and emotional demands on the dispatchers who create a vital human connection between the changing dynamics of the fire and the callers seeking assistance.

Communications is fundamentally a sociotechnical process that enables humans to engage in informed, coordinated actions. In a catastrophic event like the Camp Fire, the limitations of the technical infrastructure, hardware and software that enable humans to exchange information over distance in timely mode quickly become apparent under the stress of the actual event. The functionality of the communications system is a measure of performance for the overall response system. Yet, communications within the larger response system is composed of multiple points of interaction – hardware to software, software to human operator, human operator to sender and receiver. Each of these points comes under stress in an extreme event, and the capacity of the communications system to maintain its interdependent functions depends on workable connections among all points. If any one point fails, the communications system falters.

Extreme events become testing grounds for communications systems, and response operations in the Camp Fire provided a rigorous test. Cal Fire, the state fire protection agency, had primary responsibility for managing operations in this event, but established a collaborative working relationship with relevant state agencies through the State Operations Center activated by the California Office of Emergency Services. Other state agencies mobilized for response operations included the California Highway Patrol, California Department of Fish and Wildlife, California Department of Justice, California National Guard, and California Department of Health and Human Services. Cal Fire uses a radio system that has a common platform with law enforcement, and emergency medical services, agencies that serve as first responders in urgent events. The possibility of cross-agency communication is critical in a fast-moving event, but it also has the disadvantage that in intense activity, if too many personnel try to use the system simultaneously, the resulting chatter blocks communication for anyone. In the Camp Fire, public agencies used any and all modes of communication to alert residents to danger: radio, cell phone, internet, social media platforms such as Facebook and Twitter. The Paradise Police Department sent two Code Red messages to all residents, alerting them to the fire and ordering a mandatory evacuation of the town. The national emergency alert systems – Wireless Emergency Alert (WEA) and Integrated Public Alert and Warning System (IPAWS) – were not used as both systems require internet access and broadband spectrum that were not available. Throughout Butte County, residents exchanged messages via social media to send and share updates on the changing situation when cell phones failed or radio systems were not available.

The mix of communications systems revealed breaks in the available networks that warrant review. Importantly, the California Highway Patrol (CHP) does not share a common platform with Cal Fire and local law enforcement agencies, such as the Butte County Sheriff's Office or Chico Police. This was a critical break in the process, as law enforcement agencies were managing the evacuation of the Town of Paradise and other small communities. Other breaks already noted included the collapse of cell phone communication in Paradise and parts of Chico and the transfer of 911 dispatch services from Paradise to Chico to Butte County.

Evacuation

As already noted, evacuation became the only strategy possible for the Town of Paradise and other small communities in Butte County, given the rapid escalation of the wildfire. Yet, the actual evacuation was constrained by the physical network of roads, the limited time available for residents to leave safely, and the number of people and vehicles that could move through the available routes. Evacuation is primarily the responsibility of law enforcement, and the local police departments of Paradise and Chico, as well as the Butte County Sheriff's Office were actively engaged in initiating the process. In this event, the intensity of the fire demanded that all emergency personnel support evacuation, so fire and emergency medical personnel worked directly with police to assist local residents. Local residents also joined this effort. A newly-elected Town Council member directed traffic at intersections; residents with extra space in their vehicles offered rides to neighbors who needed assistance. In one particularly critical situation, approximately 200-300 residents were stranded in Paradise unable to leave, with the fire advancing around them. Local fire personnel directed the group to the Walgreen's drug store, recently built with fire-resistant construction, and ushered the whole group into the building to shelter in place. Outside, fire personnel circled the building with their engines to protect it. Inside the building, personnel took fire extinguishers off the shelves and used them to cool the building and protect the people inside. Such decisions were not written in any emergency plan but were made by quick-thinking first responders who recognized the risk, searched for available resources, and took prompt action to protect the residents of the Town.

Self organization in the community

Throughout the intense activities of this extreme event, there is a remarkable demonstration of translating cognition of risk into shared action for the benefit of the community. Emergency personnel demonstrated extraordinary courage in risking their own lives to protect residents of the community. Public personnel worked long hours under intensely demanding conditions to provide the best services possible. Local leaders set the example for informed, collaborative action to protect the community. Ordinary residents understood that message, and translated it into action in their own ways, helping one another, staying calm, and focusing on the primary goal: enabling the entire community to evacuate safely.

In many respects, this capacity for self organization under threat is the goal of community resilience. In the case of the Town of Paradise and Butte County, several factors likely contributed to its development. The active planning processes that the Town of Paradise, Butte County, and the State of California had undertaken prior to the fire likely contributed significantly to creating an informed understanding of the risk of wildfire in the community. Prior experience with wildfire in Butte County in 2008 and in adjacent counties likely led to increased awareness of residents regarding the vulnerability of the region. The recent experience of evacuation from the threat of collapse of the Oroville Dam created a practice scenario for evacuation in extreme events for public personnel. This event was referenced several times by local law enforcement personnel as a learning experience regarding the complexity of interactions for multijurisdictional events and the coordination required to carry them out successfully. Active engagement by local leaders who understood the physical and technical characteristics of the region, and the limitations these characteristics imposed upon formal plans reinforced a vision of responsible leadership that enabled personnel in the field to take timely, informed action based on direct observation of risk and the resources available.

The events documented in the Camp Fire demonstrate vividly that self organization indeed occurred in the Town of Paradise and surrounding jurisdictions. The capacity to recognize risk and translate that cognition into collective action under existing conditions is the goal of a resilient community. It is also the area where research and modeling may offer possible strategies to assist communities in building that capacity. As part of this study, our research team developed a simulation of traffic patterns in the region as a means of exploring possible alternatives for evacuation in future events or in other communities that confront similar physical/ecological/meteorological risks.

5. Paradise Traffic Simulation

In an effort to understand the cascading effects of the Paradise Camp Fire, a countywide traffic simulation was performed to identify network vulnerabilities due to limitations in road capacity. For the purpose of this analysis, the traffic simulation is carried out by modeling a set of vehicles that find each vehicle's instantaneous fastest path to evacuate in a transportation network (Casey et al., 2017). The advantages of this study's framework over many of the commercially available traffic simulation tools are the flexibility, performance, and evacuation-specific nature of the model. This temporo-spatial parallel computing tool can simulate regional-scale infrastructure networks with hundreds of thousands of links and millions of trips traveling near real time (McElwee et al., 2019).

The framework for the traffic simulation can be summed up in three main steps shown in Figure 3. In the first step (road network generation), the road network is generated based on data from the OpenStreetMap (OSM), an open source editable map of the world using volunteered geographic information. The entire Butte County road network can be downloaded from the OSM by querying the data within the bounding box [39.361, -122.431, 40.071, -120.981]. A graph object is then created based on the downloaded data for shortest path calculations in the later stage of the traffic simulation. The Butte County's road network consists of 31,653 vertices (road intersections in graph terminology) and 75,559 edges (road links between two intersections). In addition to the vertices and edges, the OSM data also include attribute information, such as road types, lane counts and speed limits for each road link. Capacity for each road can then be determined based on the attribute information. During step two (travel demand modelling), an hourly Origin Destination (OD) matrix is constructed for the assumed travel demand. Most commonly the travel demand is informed by the survey data, such as the California Household Travel Survey (CHTS) or the Census Transportation Planning Package (CTPP) (Vo et al., 2017). Due to the limited time for this case study, intracity and intercity travel demands are constructed simplistically according to the population in each municipality in the Butte County. Table 1 lists the numbers of trips for the five largest municipalities (Chico, Paradise, Oroville, Oroville East, and Magalia) and the remainder of Butte County in the base scenario (i.e., no evacuation). These trips do not necessarily represent peak hour travel demand on a specific weekday; however, it is acceptable for testing regional scale modeling. Finally, in step three, shortest path calculations for each OD pair are completed using Dijkstra's Algorithm. Volume-delay curves are incorporated in the simulation to model the impact of increased congestions and delays on road links given their fixed capacities. Further details of the model can be found from the open source GitHub repository: https://github.com/cb-cities/sf_abm for San Francisco.

Figure 3. Framework of the traffic simulation steps.

The traffic simulation experiment design consists of two scenarios. The first one is the base scenario that represents the ordinary day peak hour traffic in the study area, i.e., no evacuation is considered. The second one is the evacuation scenario, where all residents in the wildfire affected municipalities (Paradise and Magalia) seek to evacuate to nearby towns (Chico, Oroville and Oroville East). For the base scenario, 14,293 trips (10% of all vehicles in the Butte County, disaggregation to municipalities shown in the last column in Table 1) are simulated to represent the peak hour traffic across Butte County. The maximum link volume is 1,592 vehicles over a one-hour time step. Figure 4(a) shows the resulting link volume or number of vehicles per link with yellow links representing little to no traffic and darker green links representing high volume roads. For the Town of Paradise, Skyway Road, Neal Road, and Clark Road are identified as high volume links connecting Paradise to Chico, Oroville, and the rest of Butte County.

In the evacuation scenario, additional traffic is considered due to the evacuation of Paradise and Magalia residents. The total travel demand of the evacuation scenario equals to 39,360 trips, including 28,151 vehicle trips representing the evacuation of 26,218 Paradise residents and 11,310 Magalia residents (75% car ownership is assumed), as well as 11,479 non-evacuation vehicle trips in other areas of the network. This represents an additional 25,337 vehicles traveling on the network compared to the base scenario. The 28,151 vehicles originating from Paradise and Magalia are split with 33.3% of trips to Oroville, and the remaining 66.7% of trips to Chico. The new maximum link volume is 19,631 vehicles, which represents an increase of more than 6 times the original maximum link volume under the base scenario. Figure 4(b) shows the link volume results for the Paradise evacuation scenario. One feature worth highlighting is the shift in traffic on previous high link roads like Neal Road to Skyway Road and the importance of Highways 99 and 149 in the evacuation.

These simulations are not intended to reenact exact conditions for peak hour travel or the Camp Fire specifically; however, they do aim at offering insights into potential bottlenecks and the impact of evacuation on surrounding communities. This underscores the importance of communication especially across city boundaries. Future simulations will be aimed at the impact of contraflow on evacuation as well as closing certain roads such as Pentz Road on affecting route choice and travel time on the day of evacuation. Additionally, modeling traffic buildup in Chico as a result of limited communication between Paradise and Chico on traffic congestion is also of interest. Implementing contraflow will offer insights on the minimum amount of time needed to evacuate Paradise under ideal conditions. Additionally, by overlaying fire intensity over time and the transportation network, it is possible to create a more realistic evacuation due to closed roads for the Camp Fire scenario. The flexibility, speed, and simplicity of this traffic model are very useful in a variety of applications and are tailored towards understanding regional scale implications of various travel scenarios.

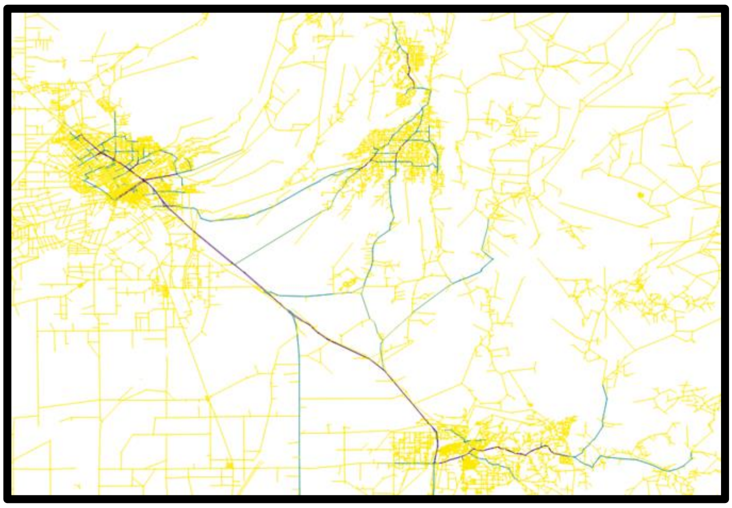
Table 1. Population, assumed car ownership and peak hour travel demand in Butte County Municipalities

Municipality	Population	Number of Vehicles**	Peak Hour Trips***
Chico	86,187	64,594	6,459
Paradise	26,218	19,668	1,966
Oroville	15,546	11,544	1,154
Magalia	11,310	8,483	848
Oroville East	8,280	6,199	619
Rest of Butte County*	43,336	32,473	3,247
Total	190,877	142,961	14,293

* Total Butte County Population of 190,877 based on 2010 American Community Survey (ACS).

** ACS data for single vehicle ownership for Butte county (75%).

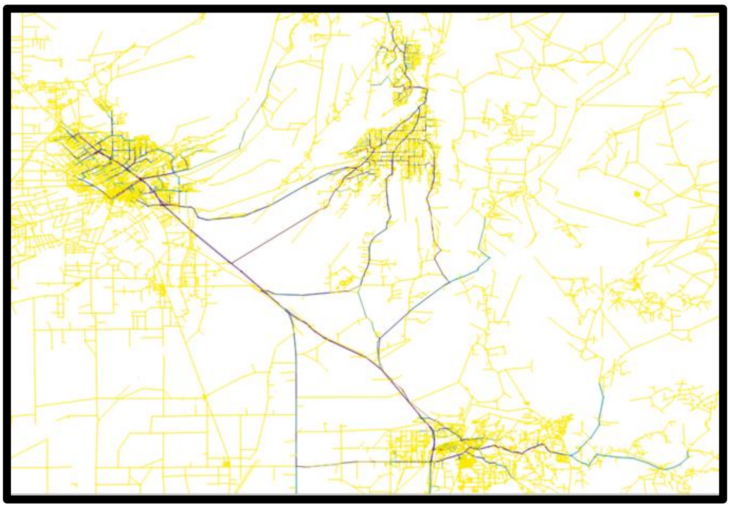
*** Assumed 10% of all the vehicles are traveling during peak hour.



(a)

14.293 trips (Assumed Peak Hour Travel)

Maximum link volume: 1.592



(b)

39.630 trips (Evacuation and background Traffic)

Maximum link volume: 19.631

Figure 4. Traffic volume distributions on the Butte County road network. (a): Base scenario, normal peak hour traffic and no evacuation. (b): Evacuation scenario (evacuation vehicle trips from Paradise and Magalia, plus normal peak hour traffic in other parts of the Butte County).

5. Renewal, Recovery, and Redesign

The traffic simulation offers an innovative approach to rethinking the design, construction, and management of traffic on a regional scale for the Town of Paradise. Other types of modeling may be productive to explore the most cost-effective means of rebuilding major infrastructure for the damaged community. There are serious reasons to question whether the fragile location of the town warrants rebuilding. The interdependent consequences of the wildfire are still unfolding. For example, seven months after the fire, there is still no piped water in the Town of Paradise. The intense heat of the fire damaged the fragile water infrastructure, as it warped the shallow PVC (polyvinyl chloride) piping that provided water to the Town. Chosen for its flexibility, low cost, and resilience during seismic events, PVC piping had the opposite effect in wildfire. The PVC infrastructure, although buried underground, failed under the intense heat and leached chemicals into the water flowing through the pipes, contaminating the water, making it undrinkable and thereby creating a secondary disaster. The cost of replacing the entire water infrastructure for the Town of Paradise has been estimated at $500,000,000, an enormous sum for a small community. Further, since the Paradise Irrigation District that manages the water system for the Town is a private company, this cost is not eligible for federal reimbursement under the Stafford Act, which provides reimbursement for public infrastructure. Yet, rebuilding the water infrastructure for the town is essential for all other aspects of recovery: homes, businesses, schools, hospital services are all dependent upon ready access to water. The major question is how, when, and whether this process could be undertaken. For many residents of Paradise, the goal of rebuilding is not in question. Rather, exploring alternative strategies for reconstruction and finance through modeling and creating a wider range of access to resources and knowledge to support this effort becomes essential to the recovery process.

7. Conclusions and Recommendations

Reviewing the conditions, operations, and consequences that characterized this devastating event, five conclusions can be drawn in reference to mitigating the risk of wildfire in other communities.

1. Changing wildfire risk requires adaptation in budget and capacity for collective action

The events of the Camp Fire documented in unambiguous detail the effects of a changing climate on the forest and grasslands of Butte County, with increasing risk of wildfire to the built environment and communities of the region. The need for increased monitoring of sensitive conditions such as temperature, flammability of ground cover, technical infrastructure for communications, water, and power all require public investment in the science and technology of managing wildfire risk. While public agencies have the legal responsibility to lead this effort, effective risk reduction will require the collaborative effort of private companies, research institutions, and nonprofit organizations as well. For states like California, Arizona, Colorado, Oregon, and Washington, building collaborative models of risk reduction and dynamic operations that scale to changing exposure would be an invaluable investment in collective capacity to manage wildfire risk. Such effort will be expensive, but far less expensive than the billion-dollar costs that are likely to ensue if no action is taken.

2. Cognition to action – Informed residents of communities at risk will take responsible action to protect the community as a whole.

A major resource for communities exposed to wildfire risk is an informed, responsible population. The actions taken by ordinary residents of Paradise and surrounding communities demonstrated unequivocally the capacity of local residents to take informed action to protect themselves, their neighbors, and their community facilities. Investment in programs of public education regarding wildfire risk, voluntary training, and access to multiple modes of communication enable community residents to build a degree of shared knowledge to recognize risk and act collectively to reduce risk for the community.

3. Learning from prior experience.

Translating insights gained in other, relevant, large-scale, complex events for application to wildfire risk reduction increases the capacity of community organizations to act in coordinated effort to reduce shared risk. Several interviewees in this study referenced the experience of the Oroville Dam evacuation as a constructive rehearsal for the coordination needed in a large-scale evacuation effort as required for the Town of Paradise and surrounding communities.

4. Intersection of science, technology, and human organizations creates a new, interdisciplinary science for managing wildfire.

The rapidly changing, dynamic conditions that propelled the Camp Fire to its full, destructive impact in Butte County in November 2018 demonstrated decisively that no single discipline, no single organization could anticipate or manage to contain such a wildfire alone. It was the intersection of drought conditions, high winds, topography, and a faulty technical system that drove the fire, but these conditions were accelerated by a limited road network for the region, limited equipment and trained personnel, and repeated disruptions in communications that inhibited coordination among organizations and people. To overcome these constraints, it is essential to reconsider the hazard of wildfire as generating a complex system of interacting systems that can learn and adapt to rapidly changing risk conditions.

5. Need for innovative approaches, new technologies, organizational designs and science

This study of the Camp Fire has demonstrated that a detailed command of the science underlying forest and grasslands management, well-designed sensors to detect change in ecological conditions, systematic data collection and analysis of both technical and organizational capacity, regular monitoring of changing conditions, and innovative modeling are essential to anticipate potential strategies for managing the known risk wildfire that generates unknown consequences for communities at risk. Building the capacity to anticipate and reduce the cost of wildfire to urban communities will require steady, consistent, leadership and effort in confronting markedly changing firescapes.

To a significant extent, this process has already started in California. The proposed plan of Governor Newsom for public investment in wildfire risk reduction and planning (California Governor's Office, 2019) addresses this need directly. Engaging the scientific and technical resources of the ten campuses of the University of California would be a beginning step in building the knowledge base for a statewide map of wildfire risk and resources. But such a process would require continuing research, community engagement, and collective action across the state, a bold, but important step to reduce wildfire risk.

Acknowledgements

This study has been conducted with support from the Quick Response Program administered by the Natural Hazards Center, University of Colorado, Boulder for the National Science Foundation. We acknowledge, with thanks and appreciation, the staff of the Natural Hazards Center in facilitating this study. We further give warm thanks and appreciation to the public officials and staff from the following organizations who gave their time and shared their experience with us: Cal Fire; California Office of Emergency Services; Unit 35, Fire Department, Police Department, Public Works Department, and Mayor, Town of Paradise; 911 Dispatch Office, Sheriff's Office, and Fire Department, Butte County; City of Chico Police Department, Federal Emergency Management Agency, Individual Assistance Program and Small Business Administration. These officials are not named to protect their confidentiality, but we are grateful for their thoughtful insights into the very dynamic, complex problem of wildfire risk reduction.

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Appendix A.

Cooperating Agencies in Response Operations, November 8, 2018:

The following agencies were listed by Cal Fire as cooperating in the response operations to the Camp Fire, November 8, 2018:

California Department of Transportation
California Department of Corrections and Rehabilitation
California Highway Patrol
California Office of Emergency Services
National Weather Service, California Conservation Corps
Butte County
City of Chico.

Agencies Responding to Requests for Comments, Recommendations, Strike Force Report, April 12, 2019:

The following agencies, departments, regional and local government entities, and non-governmental partners responded to CAL FIRE's request for comments and recommendations on draft copies of Governor Newsom's Strike Force report in writing or through conversation, March-April, 2019.

Governor's Office of Emergency Services
Governor's Office of Planning and Research
California Natural Resources Agency Strategic Growth Council
Office of State Fire Marshal
California Air Resources Board
California Department of State Parks California Department of Fish and Wildlife
California Department of Public Health California Energy Commission
California Public Utilities Commission California Department of Transportation
California Department of Industrial Relations
Sierra Nevada Conservancy University of California Berkeley

University of California Cooperative Extension (UCANR)

Humboldt State University

California Forest Management Task Force

US Forest Service PSW Research Station

Natural Resources Conservation Service

North Coast Regional Water Quality Control Board

Central Valley Regional Water Quality Control Board

Lahontan Regional Water Quality Control Board

Los Angeles Regional Water Quality Control Board

California Fire Chief's Association California Environmental Justice Alliance

Morongo Fire District

The Nature Conservancy Resources Legacy Fund Pacific Forest Trust California

League of Cities California Fire Safe Council

The Red Cross

California Licensed Foresters Association Sierra Forest Legacy

Trinity County Fire Safe Council

Lower Mattole Fire Safe Council and Mattole Restoration Council

Watershed Research and Training Center ForEverGreen Forestry

The Fire Restoration Group

Mendocino/Humboldt Redwood Company

Green Diamond Resource Company Sierra Pacific Industries

California Cattlemen's Association Town of Portola Valley

Appendix B.

Field Activities, Camp Fire Study, January – March 2019.

Study Team, University of California, Berkeley:
Three faculty: Kenichi Soga, Civil and Environmental Engineering; Louise Comfort, CITRIS, Mark Stacey, Civil and Environmental Engineering.
Four graduate students: Millard McElwee, Jillian Dressler, Bingyu Zhou, Civil and Environmental Engineering; Chiara Ecosse, Architecture

Six field trips; 11 interviews conducted for study: additional meetings attended in reference to study.

Trip # 1: January 15, 2019, Sacramento, CA.
Interviews:

1. **California Office of Emergency Services.** Two personnel: Operations Chief; Branch Manager, CA 911 Emergency Communications,
2. **Cal Fire:** Deputy Director, Communications.

Trip #2: February 12, 2019. Town of Paradise.
Interviews:

3. **Cal Fire, Butte County Unit 35, Town of Paradise.**
4. **Paradise Police Department**.

Trip #3: February 21, 2019. Town of Paradise.
Interviews:

5. **Public Works Department**, **Town of Paradise**
6. **Mayor, Town of Paradise**

Trip #4: **March 12, 2019, Sacramento, CA.**
Joint Interview: Joint Federal/State Disaster Field Office

7. **FEMA and Cal OES staff**; four personnel; two programs: Individual Assistance; Small Business Administration

Trip #5: March 26, 2019, Butte County, Cities of Oroville and Chico.

Interviews:

8. **911 Dispatch Center, Butte County Sheriff's Office, Oroville, CA**
9. **Chico Police Department, City of Chico**. Four personnel.
10. **Office of the Sheriff, Butte County**, Oroville, CA
11. **Fire Department, Butte County** Oroville, CA

Trip #6: March 17, 2019. Reconnaissance Trip, Jarbo Gap

Meetings attended; visits made:

1. **February 12, 2019. Disaster Recovery Center, Public Information Officer, FEMA**.
2. **February 12, 2019. Town Council Meeting, Town of Paradise, Town Hall. 6:00 p.m.**

   Speakers: Department of Employment and Social Services, Butte County

   Paradise Unified School District

   Small Business Administration

   Comcast

   Paradise Irrigation District

   Pacific Gas & Electric Company

   California Office of Emergency Services

   Chamber of Commerce
3. **February 21, 2019. Conversation, Town Hall: Urban Design Associates;** organizer for community planning meetings, Town of Paradise**.**
4. **March 12, 2019. Lecture and Presentation**, **Thom Porter, Chief, Cal Fire,** University of California, Berkeley

Appendix C.

2018 Camp Fire Quick Response Study
Interview protocol

Hello, my name is ______________, and I am a researcher from the University of California, Berkeley. Our research team is currently doing a Quick Response study of collective action in communities exposed to recurring hazards. We are focusing on the Camp Fire in Northern California, November 8, 2018.

This study is sponsored by the National Science Foundation and administrated through the Natural Hazards Center, University of Colorado, Boulder. Your responses will help us to summarize the experience of organizations that operated during in this wildfire, and its impact on the organizations and the community. We ask for approximately 30 minutes of your time. Your responses to this survey will remain completely confidential, and you may stop the interview at any time.

A. <u>First, I'd like to ask a few questions about when your organization first recognized the risk from the Camp Fire:</u>
   1) When did your organization first learn of the risk of the fire?
   2) How did your organization learn of the fire? By what means of communication? From what source?
   3) What steps did your organization take to prepare for the fire, and which unit was directing emergency operations?
   4) What actions did your organization take to avoid the fire?
   5) What was the impact of the fire on your organization? Were personnel able to return to their homes? To work?
   6) How soon was your organization able to resume normal operations after the fire?
      a. What were the resources, services, and policies were available to your organization?

b. What resources, services, and policies were not available that would have helped your organization in this process?

B. Next I'd like to gather some information about your organization's emergency response capacity.

1) What type of emergency communication systems does your organization use?
2) What emergency response plans did your organization have in place before the fire?
3) How well is your organization's response plan integrated into the local city, county, or regional plans?
4) What alternative strategies did your organization prepare, if emergency demands became more urgent (e.g. alternative sites, logistics of operations, transportation, insurance)?
5) Which, if any, of these alternative strategies did your organization use during and after the fire?
6) Has your organization been involved in other extreme events? If so, how many? What type?

C. I now have a few general questions about the disaster.

1) What actions by which organizations does your organization deem most effective for the affected areas?
2) What type of support from which agencies does your organization consider essential to resume basic operations in the community?
3) What partnerships – not necessarily by name, but rather "service" or "work effort" – did your organization find more helpful or essential?
4) What federal policies were most relevant for your organization's needs in getting the community back into operation?
5) What state policies were most relevant to your organization's needs, and how did these policies differ, if at all, from federal policies?
6) What innovations did your organization develop to assist you in this recovery process?

7) What policies and procedures are still needed to aid community recovery, from your organization's perspective?
8) How effective would your organization assess the assistance provided to the community before, during, and after the fire?

D. Finally, I'd like to collect some basic information about the size and type of your organization:

1) Where is your organization located?
2) What type of organization is it (e.g. public agency, private business, nonprofit organization, school, hospital, or other)?
3) On which other organizations does your organization depend for normal operations (including utilities and transportation services)?
4) What other organizations depend on your organization's services?
5) How many members/employees/clients does your organization have? Has this number changed after the fire, and in what ways?
6) What, approximately, is your annual operating budget? How was this budget changed after the fire, of at all?
7) What type of support, if any, did your organization receive from other partners or business organizations?

-- Is there anything else that you'd like to add?

Thank you very much for your time! Your participation is invaluable to this study.

B

Full Scale Simulation

Introduction

On 14th September Marconi Airport in Bologna, organized a full scale simulation in cooperation with Maggiore Hospital, that envisaged respectively the activation of PEA (airport emergency plan) and PEIMAF (Internal Emergency Plan for Massive Influx of injured).

During the day I participated at initial briefing (Fig. 1b) with all medical staff to better figure out what I would see and listen at Operative Center in the afternoon.

What follows is an overview of an organization as more complex as bigger is the event. To assess in broad term the scope of the emergency, there are some indicators like: Is the event confined or in open space? How much is it wider the area (2.500 m^2, 10.000 m^2 or more)? Is the weather good or doesn't? Is it day or night? How far is the first hospital? Is the way until the victims easy, difficult or only for experts? How long to identify the area and the typology of the event?

In this case, being into an airport and not having to face a terroristic attack, the rescue organization is easier than in other situation, but seeing the operative center's staff in action, I can state that in every case it is anything but smooth.

Fig. 1b. Initial briefing.

Crush zone

First step for an airport is define in which way to intervene according to the type of accident: activating a sanitary or an aeronautic emergency plan. The first includes single indispositions, injuries or traumas. The second foresees the PEA activation to assist one or more aircraft but it doesn't contain procedures for terroristic attacks. Our case is the last one and to ensure that rescue operators have some reference point for reacting, there are three levels of crisis. PEA is activated already with crisis alert which indicate a doubt on security of an aircraft or for at least one of his occupants. Then there is the state of emergency, with whom there is the awareness of a danger and rescue means are alerted. The last is the moment of the incident[4] where we have the certainty that an harmful event is happened, therefore rescue means intervene. These are triggered respectively with blue light and two tone sound, orange light and linear sound, red light and intermittent sound (Fig.2b).

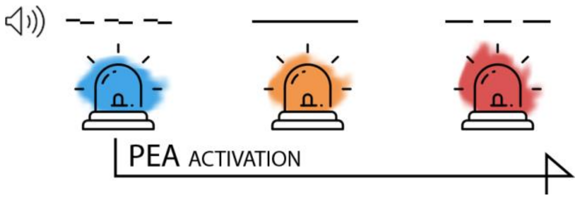

Fig. 2b. PEA activation phases.

The head figures that must to be assigned to manage the emergency and their connections are explained in the scheme below (Fig. 3b).

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[4]Event, associated with the use of an aircraft, veryfing between boarding of the first costumers intent on flying and landing of the last person, in which:

a) one person has serious or mortal injuries not caused by natural disease, or by herself or other people, or by clandestine hidden outside of the zone normally accessibles at passengers or cabin crew;
b) aircraft is damaged or has structural breckdowns requiring an important reparation or the replacement of the element. With the exception for engine, propeller, wingtips, aerial, tyre, brake, or fairing failure;
c) aicraft is disappeared or completely inaccessible.

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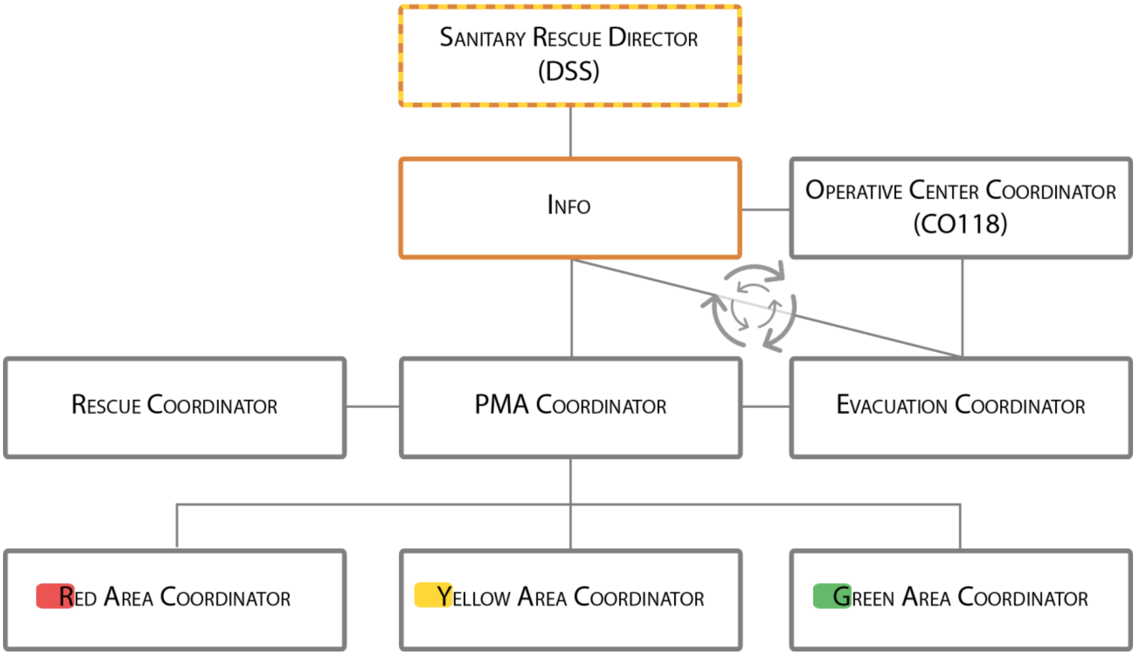

Fig. 3b. Medical disaster management.

The entire situation is coordinated by CO118 because it is the only point of contact between all interested organization.

On the ground all have to refer to DSS. His tasks are strategic: assessment of the event (typology, risks, dimensions, victims), coordination of health's operations, verify security's conditions of rescuers, organize PCO (Continuity Organization Plan), activation and organization rescue's chain (from the rescue until the hospital), triage organization and control, subdivision of injuries in different hospitals in accordance with CO118, verify the balance of the event, keep in touch continuously with Info.

Info is the right-hand of DSS because handles the communication network and he often is the liaison between DSS and the other coordinator. His job is tactic.

Then there is the responsible for evacuation that have a logistic role. He registers incoming means and assigns them the radio code, organizes a boarding area close to PMA and a helipad, sorts patients at the evacuation means and in accordance with CO118 assign the destination hospitals, keep in touch continuously with Info.

AT PMA coordinator converge all notices about injuries to stabilize before to send them to the evacuation area. DSS/Info, CO118, Evacuation, PMA have to perpetually keep up.

During the simulation the participants were aware of first procedures until the state of emergency (Fig. 4b), then it was all to find out.

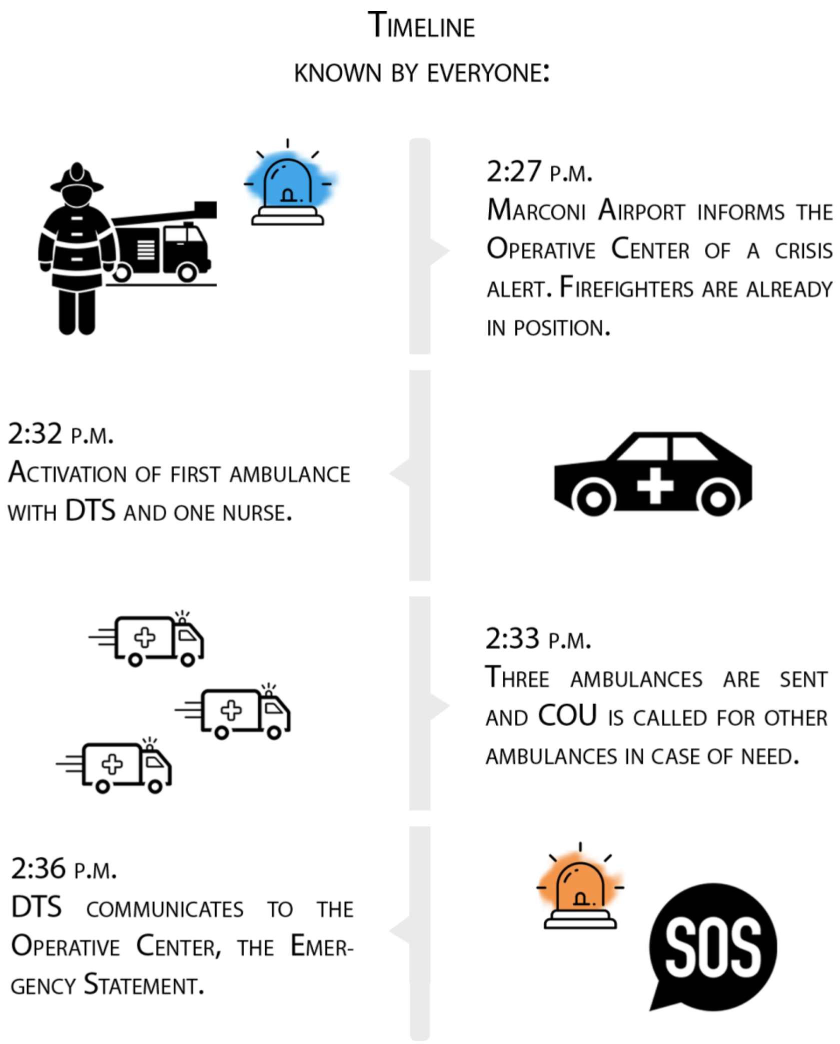

Fig. 4b. Timeline initial rescuers' action.

At this point, just after calling the state of incident, a Grid Map (Fig. 5b) establishes if the emergency lies within the jurisdiction of the airport or doesn't, by referring to the red circle drawn. In every case the 118 have been already informed and the dispatcher will contact the PTE (emergency territorial postings) to concur methods of intervention of the first ambulance and to decide whether to grant access to external means. Also the hospitals have to be inform, but they are the last link in the chain so they have more time to prepare and they can activate their PEIMAF (Internal Emergency Plan for Massive Influx of Injuries) only when the incident is confirmed.

Fig. 5b. Grid map.

The incident simulated was an airplane broken in two parts into the airport jurisdiction. The initial situation is described with the scheme on the next page (Fig. 8b). At first the firefighters are the only one to have the permission to get into the crush zone (Zone 1) to make it safe. DTS (Rescue Technical Director) is in charge until the declaration of “Safe Area” and then he entrusts the management of aeronautic emergency to 118. He is recognizable thanks to the red helmet instead of

Fig. 6-7b. Full scale simulation in action.

black (Fig.6b). The new manager is called DSS (Rescue Sanitary Director) and is distinguishable from the bib with orange and yellow square (Fig.7b).

To intervene on the event area after making it safe, there is obviously a schedule to keep:

1. Reconnaisance
2. Sectorisation
3. Integration (PMA)
4. Triage and recovery
5. Triage, clinic assessment and stabilization
6. Evacuation

Firsts step are the reconnaissance and sectorisation. At the advanced command line with the firefighter, there is Red 1, the car with DTS that define the limit of the crush zone and establish when White 1 with DSS and one nurse can be escorted by airport vehicles until injured. Even later, all incoming sanitary means, must be accompanied with maximum speed permitted of 30 km/h. After 10 minutes from the incident, DSS has to handle and transfer the information' flow to Operation Center (C.O.118) while the nurse will take out of the crush zone by bus, all people walking, until an area inside the airport, designed for this purpose. News of primary importance are reported by METHANE Protocol (Fig. 9b).

The designate, first, have to identify himself, and to clarify if the accident status is declared or in standby, then to collocate the event on the Grid Map, to precise the typology of emergency and her potential of effective hazards, to stabilize the access always with a tail wind to go inside, to give an approximate injuries' number and only after, their severity, and last, to list the emergency services already in place and those necessary.

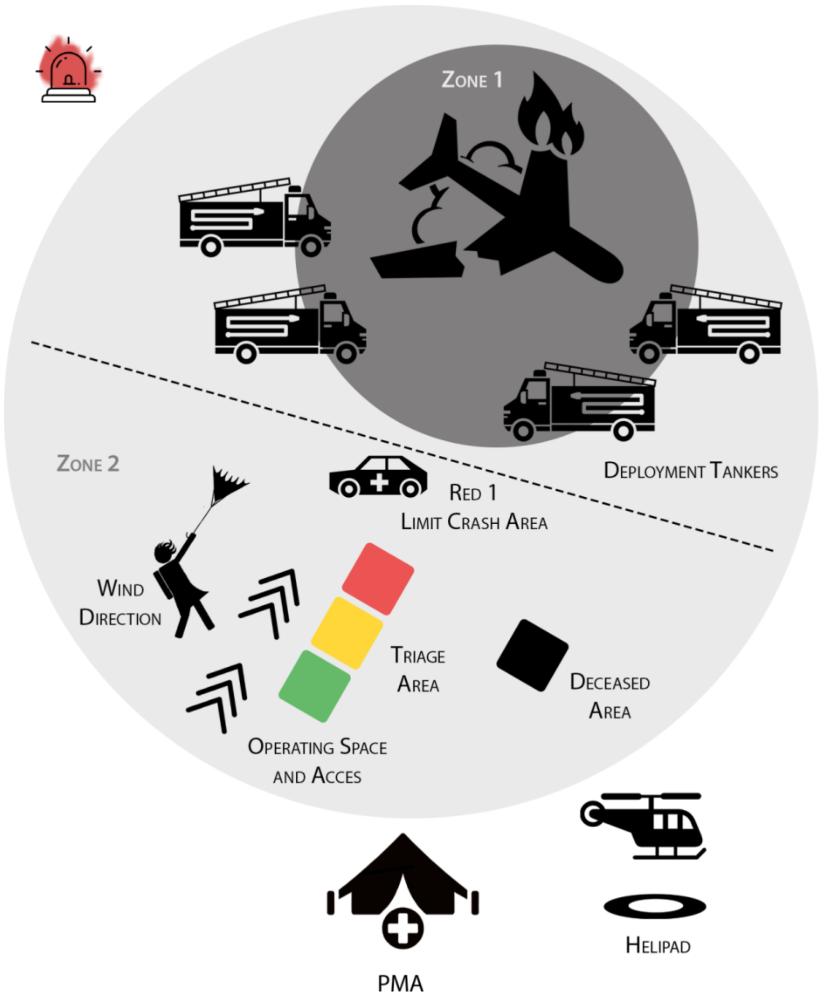

Fig. 8b. Crush area organization.

Fig. 9b. Methane protocol.

Fig. 10-11b. Triage area.

Consequently, the first ambulance starts to make the triage[5] and direct the patient to the respective area triage delimited by plastic sheets or ribbons (Fig. 10-11b). The second, sets up the Advanced Medical Post, outside zone 2 to protect him from evolutionary risks.

One of the first principles to learn about emergency is that, not all victims can receive immediately treatments and it is normal take a choice. Having a mismatched between necessity and resources, the Triage is the instrument able to distribute a limited quantity of resources to an high patients' number.
So, the first question, everyone at this point ask when he is in the middle of chaos, is "Who do I start?". MARCH protocol (Fig. 12b) answer at this, giving an array in order of importance, of patients who apparently could die first and therefore, they need an immediately triage to be properly cured. So, the first people to be treated are those having a massive bleeding, because it often kills patients at first. In succession there are airway to clear, respiration and circulation problems, and the last, hypothermia.

MASSIVE BLEEDING
AIRWAY
RESPIRATION
CIRCULATION
HYPOTHERMIA

Fig. 12b. March protocol.

After getting the idea of the patients' condition in a few seconds, the rescue can start. Triage made at crash area must be really fast and it follow the protocol called

[5] Triage is a french military concept, resulting from "trier" that means "to choose". In fact it was a method to choose which person were easier to treat, in this way they could come back to the battle as soon as possible.

"Start", namely Simple Triage And Rapid Treatment (Fig. 13b). This type of triage need to answer at maximum four question to define the color. If patient can walk, is a green code. If he can't, he could be black, red or yellow. If he doesn't breath, it gets assigned the black code. The yellow code is for who has a respiratory rate less than 30/min, has radial pulse and follows orders. If there is even one negative answer, the code to be assigned is red.

Fig. 13-14b. "Start" triage and PMA structure.

The PMA (Advanced Medical Station) (Fig. 14b) is an area where injuries can be stabilized and triage can be retook, before being sent to the proper medical facility. There are different area: access for green codes and yellow/red codes, a separated exit, an area for patients died and one to do second triage called SORT. Pay attention, it is different from the field hospital (useless in this case) because in the PMA, all injuries sail through, in the other one, they remain to be cured. A field hospital is rigged up only when there is an humanitarian emergency and any hospital can accepted more injuries or is the hospital itself that needs to be evacuate.

Triage SORT classified patient according to three parameters: heart rate, blood pressure and Glascow scale. Every measure correspond to a number from 0 to 4. Summing all points, the code is black if there are any point, is red from 1 to 10, 11 correspond to the yellow and 12 to the green.

The part until patients' transport into PMA zone, is called "Piccola Noria". "Grande Noria" is the phase of evacuation, namely the patients' transport until hospitals.

This stage is managed by a specific operator having logistical matter. He address all ambulance and helicopter to the right hospital according to some logical written in documents and protocols. Red codes has to go to the closest hospitals DEA of II level, yellow codes to the nearest hospital DEA of I level like first choice otherwise to those of II level, and green codes to the furthest DEA of I level not by sanitarian means. In most case also the pathology is important to decide the health care facility.

The ambulances have to make again the triage, but this time with numbers from 0 to 4 because sometimes originally an injured could walk, therefore he has been assigned a green code, but then he has grown worse because of a broken artery, and he becomes a code 3 or even 4.

To transport a patient by Helicopter we need another figure called MEDEVAC (Medical Evacuation) (Fig. 15b). They are a team that deals the act of taking a sick or injured person to a hospital in a helicopter or plane. They have to assess the severity of injured, to looking for an ambulance which pick up the patient until the rendez-vous point, to inform CO and to discharge the ambulance at the end of service.

Fig. 15b. MEDEVAC calling to exchange information with the operative center.

Hospital

When injured arrive at the hospital, they are subjected to another fast triage according ETS methodology and they received necessary treatment. Except this, phase in-hospital wasn't foreseen in the simulation because they couldn't stop one hospital for one entire day.

Operative Center

All received calls, are filtered through POF otherwise the line would be occupied unnecessarily. Then, the calls approved are passed to the dispatch. In normal conditions, someone of them, handles incoming calls, the other the ambulance's distribution. After filling out patient's sheet and having assigned a color code, a table pop up with all the ambulance and their progress: a) acceptance call b) departed c) arrived d) departed with injuries e) arrived at hospitals. If the ambulance is green has on board only rescuers, if it is blue carries nurses and if it's white has also physicians. The ambulances with a stain behind are late on the deadline set. In emergency conditions, some dispatch (not more than two or three) deal only that

Fig. 16b. Operative center board and actors playing into the plane.

event. Their job is to coordinate all, they are the only point of contact with all interested organization. Below the indispensable board to try to put together the several information (Fig. 16b).

Remarks

At the end of the simulation a couple of observation really important are pop up to improve the system. The first was the need of much time to fill out the intervention sheet for each patient and although it is necessary, to save life is more. The second one is the urge to be trained because in the middle of chaos, the transmission of information to operative Center was most times approximate and not clear. This reason makes to waste a lot of time trying to make the number of patients and ambulances works. The last is that the software used by dispatcher need some update to speed up some steps.

Aknowledgements

Many thanks for this experience to 118 Emilia Romagna, especially to Alfonso Flauto, the head of all this, but also to the firefighter, participants and to, sometimes, too good actors. “He’s a too good actor or he is a real no game?”.

Aknowledgment

Negli ultimi due anni ho affinato l'arte dei piccoli passi e ho imparato che se non sai da dove iniziare, dove finire e come rigirarti nel mezzo, l'unica cosa che si può fare, dopo una dovuta giornata a letto a commiserarsi, è iniziare a muoversi: con impegno, costanza e testardaggine, vi assicuro che prima o poi si arriva al traguardo.

Questa tesi non è solo la fine di un percorso accademico, è la conclusione di un capitolo della mia vita durato sei anni, i quali in un modo o nell'altro, hanno in gran parte contribuito a determinare la me di oggi. Il mio lato eternamente insoddisfatto sarà sempre lì a fare capolino, ma quando riguardo indietro, sorrido. Qualche volto è passato, qualcuno è ancora qui con me, qualcun altro magari se ne andrà e in futuro forse sarà sempre un #mai una gioia, ma questa volta posso dirmi felice.

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Vi auguro di avere un papà che vi incoraggi ad uscire dalla vostra zona di confort solo per prepararvi meglio al mondo degli adulti e una mamma concorde ma che tacitamente vi aspetterà come il Natale.

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Vi auguro di avere degli amici che vi regalino un abbraccio, una telefonata o un pensiero, non importa dove geograficamente localizzati e che continuino a volervi bene nonostante i periodi di stress-antipatico cronico.
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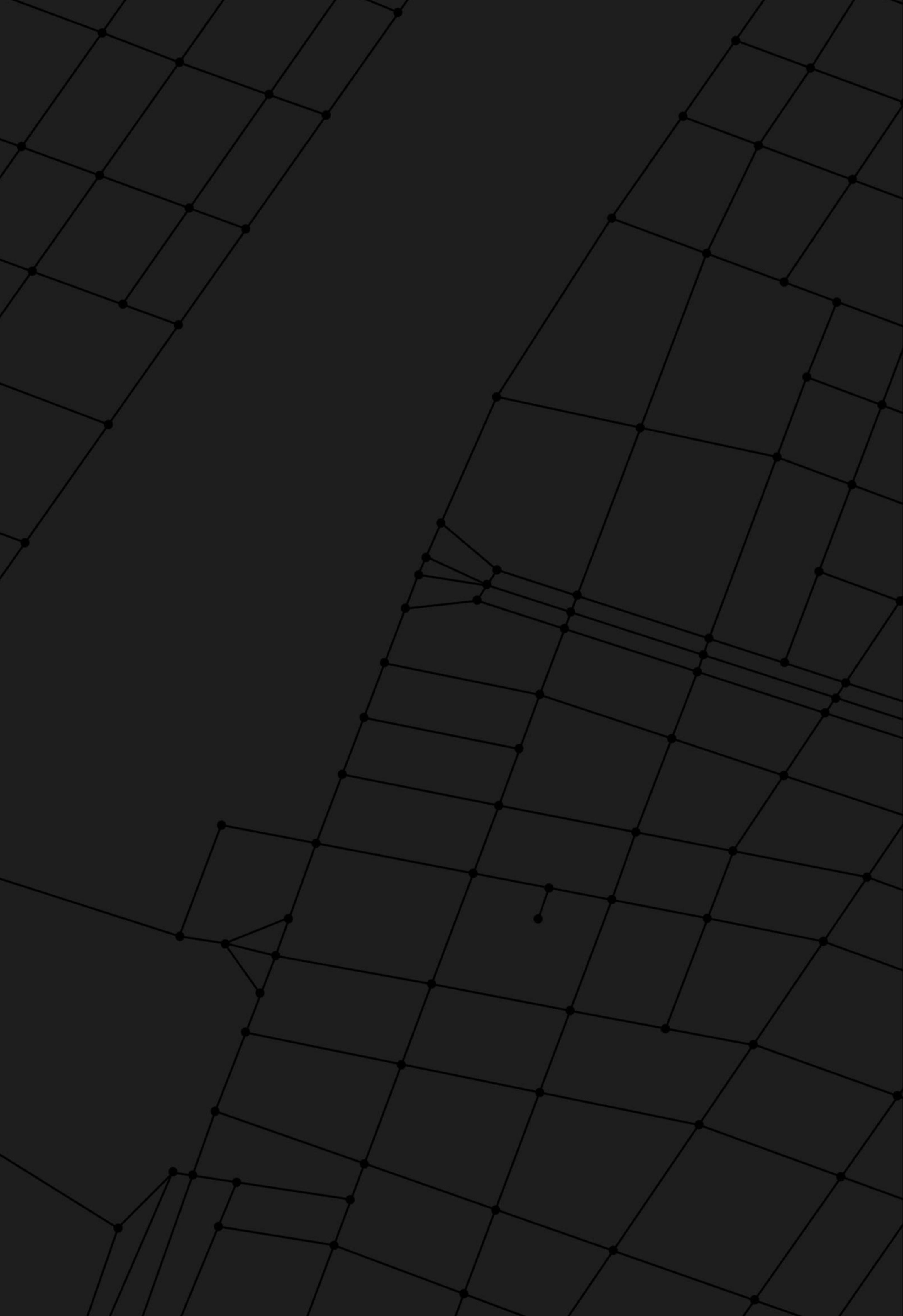
Grazie a tutti.

Chiara



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