Università degli studi di Milano-Bicocca

Data Science Lab for Smart Cities

Final Essay

The Problem of Emergency Stations Location in Smart Cities

Authors:
Valentina Camagni - 878252 - v.camagni1@campus.unimib.it
Giorgia Rigamonti - 844619 - g.rigamonti16@campus.unimib.it

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Abstract

This work deals with the problem of locating new ambulances to potentiate the emergency health service (called 118) in smart cities. The first part introduces the current Italian first-aid system and defines the main problems associated with it. Then, a focus is dedicated to smart cities, ultra-connected cities dominated by technology in which people's well-being is placed first. Through the use of different systems, data, and information can be collected and used to improve the entire emergency system. In this context, it was decided to investigate the efficacy of the current system in the urban area of Milan, by analyzing data from various emergency missions recorded by an association placed in Arese that covers some additional stationing points in Filzi, Miani, and Amoretti. This analysis showed a significant dispersion of some emergency missions both in space and in time, for which, it was implemented a facility location model aimed at identifying the best points where to place new ambulances to meet the average daily request for medical assistance and safeguard the health of all citizens.

1 Problem Description and Indicators

1.1 The Emergency Medical Service Overview

The Emergency Medical Service connects the citizen with the operational centers of the health alert system and presents itself as an extremely complex system, in which many decision-makers have a say in its organization, and is required to guarantee a quality level of response in terms of response times. It is a system distributed throughout its territory that works under uncertainty and is composed of heterogeneous resources, both human and material, and of infrastructures and procedures that must be strictly followed. In general, the emergency system receives requests for ambulances via a central emergency telephone number and, as can also be seen from the diagram in Figure 1, the response procedure followed by the operators at the center consists of the following activities:

1. Upon the arrival of a distress call, the operator makes an assessment of the type and severity of the situation, attempting to gather the information necessary to assign a code, universally known as Triage to the intervention.
   The codes, associated with a color and ordered by increasing severity, are:
   - *White:* No criticality, absence of risks and trauma;
   - *Green:* Mild criticality, vital parameters in the normal range, no developmental risks, minor trauma;
   - *Yellow:* Medium criticality, alteration of only one vital parameter, trauma without aggravating factors;
   - *Red:* High criticality, impairment of at least two vital parameters, absence of one vital parameter.

   In the case of the green code, ambulances circulate without a siren on and must therefore comply with the highway code like any other vehicle. Only in the case of a yellow or red code mission, there is the use of the siren and consequent emergency circulation permitted.
2. At this point, the operator collects the citizen's personal information and address and sends an available vehicle suitable to handle the nature of the intervention; contact with the crew is maintained by radio or mobile phone.
   In the event that all vehicles are occupied, the call is delayed until a vehicle becomes available. There is a queue to keep track of delayed cases. When processing the queue, the highest priority is considered first, then the lower priority. Calls with the same priority are handled on a first-come, first-served basis.
3. On site, the team provides the patient with the necessary medical care and if further treatment is needed, transport of the patient to a hospital equipped and ready to provide additional treatment is organized. The operator must then notify the destination facility of the patient's arrival.
   If delivery to hospitals is not necessary, the ambulance becomes free again after treatment. Otherwise, at the hospital, the team takes time to deliver the patient.
4. As soon as the team is available, it returns to the station or heads for a new mission.

In particularly complex situations (major accidents, disasters, fires,...), other operations centers are contacted (fire brigade, police, civil protection); if necessary, the operator is required to provide simple and essential first aid instructions while waiting for the ambulance to arrive.

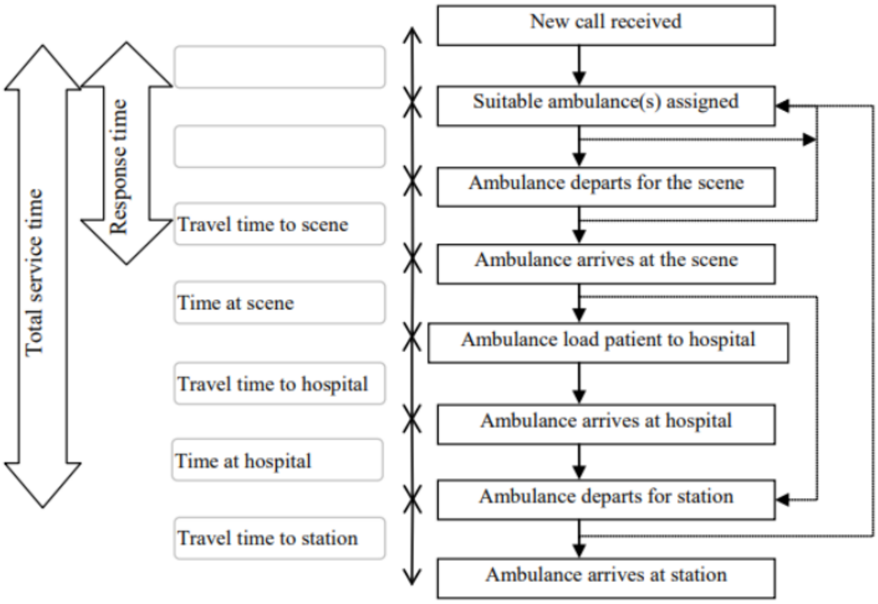

Figure 1: The emergency system schema [1]

As can be seen, the primary resource available to the service is ambulances, some of which are owned by the hospital and some by private voluntary associations. Some of these are owned by voluntary associations under a contractual agreement and are therefore called 'token' ambulances and can be booked by the operations center, which alerts the crews for certain periods of time. They can vary in terms of type, equipment, and working hours and can be freely deployed throughout the territory, and their fee is paid only when they are actually deployed on a mission. Ambulances are associated with their positions, which are not always found in buildings, or headquarters of associations, but are also found in rudimentary places such as parking lots, squares, etc...

1.2 The Emergency Medical Service Problems

Currently, the decision-making process is governed by the experience of the operator who is confronted on a daily basis with a series of problems relating to the sizing of resources, their organization both tactically and strategically, problems relating to user utilization, and improving overall efficiency.
This shows clear signs of inadequacy, such as the fact that:

- Skills, gained through experience in the field, remain the heritage of the individual and are not easily transferable. Often the practitioner himself is unable to explain what decision-making criteria are involved in his choices.
- There is a lack of tools for group decision-making. The decision-maker has expressed the need for support tools that facilitate group decision-making processes, making it possible to formally evaluate the proposals drawn up, analyze their weak points, and ensure that this knowledge is built up collectively.
- Often, experience is not enough: it is well known that when sizing resources, faced with the slightest suspicion of a critical situation, the decision-maker tends to adopt a 'play it safe' attitude, often greatly oversizing the need. This behavior is widely used precisely because it turns out to be the only instrument available to avoid dangerous under-sizing.
- The impact that a formal instrument would have on the political aspect of dimensioning is also quite important. If the decision-maker were in possession of analyses produced by a supporting instrument, requests to the funding authorities for increased resources would be supported by concrete data and thus better understood.

The problems that the decision-maker faces concern the sizing of resources since has to estimate how often will need resources to cope with the future situation. Currently, this process is based on experience: the decision-maker must therefore be able to assess the time of year, the incidence of weather conditions, seasonality,

holidays, extraordinary events and, by combining all these assessments, to determine the number of resources he will need to guarantee an acceptable service.
In addition, if it needs an addition to its own fleet, a request will be made to mobilize the number of vehicles deemed sufficient, and it is also called upon when it is necessary to decide where to set up waiting points, 'pillars' where ambulances are to be deployed.
The capacity to construct these waiting points is limited and their positioning in the territory can heavily influence the overall performance of the service, and in order to cope with emergency calls of various types, the decision-maker must make real-time decisions on the dispatch and transfer of ambulances.
Taking into account the state of the system at a given time and analyzing the effect of possible decisions, many emergency service providers tend to distribute available ambulances in such a way as to reduce driving distances to potential calls.

This gives rise to the problem of the optimal management and location of ambulances in the area by which the degree of coverage is defined. The latter, in fact, is a measure that serves to indicate the degree to which an ambulance service can meet the demand for emergency medical assistance in a given area. Consequently, achieving a high degree of coverage is crucial for ensuring timely access to emergency medical services and this may depend on the number of available ambulances that can reach the area within a certain time, workload, and ambulance utilization.
The degree of coverage of a given territory must be optimized so that the available vehicles are positioned to cover as many areas as possible.
To this end, time plays a key role: the phases of an ambulance call are marked by different types of time, such as the time spent on the phone examining callers, the time spent selecting vehicles to handle the emergency, the time spent contacting the chosen team, the time spent preparing the team, the time spent travelling, the time spent at the scene and the time spent in hospital.
It is, therefore, necessary to minimize the time interval between the arrival of an emergency call and the time when the assigned ambulance reaches the patient, especially in the case of highly critical emergencies where the survival of the patient is put first as every minute delay in response time reduces the survival rate by 7-10%.
Therefore, usually, in the case of medium- and high-criticality requests for which a triage code of yellow and red respectively has been assigned, an arrival time of eight minutes or less is preferred, and consequently ambulances must be located in such a way that potential emergencies can be reached efficiently.
Added to this are the time needed for operators to reach the scene and the travel time to the hospital, both of which are dynamic with respect to traffic conditions and travel speeds that depend on the priority of calls as ambulances can only use lights and sirens to speed up travel in the case of high priority calls.

Moreover, the distribution of healthcare facilities, such as hospitals, trauma centers, and specialized treatment centers, can influence the degree of coverage: ambulance services must consider the proximity of these facilities to determine the optimal positioning of ambulances. Ensuring that ambulances can efficiently transport patients to the appropriate healthcare facilities is essential for timely and effective care. Usually, the simplest rule adopted for hospital selection is to transport patients to the nearest hospital although, in reality, this rule often cannot be applied as there are hospitals that differ in speciality and size as some hospitals specialize in treating children or the emergency departments of some hospitals are not open 24 hours a day.
There is also the time during which the ambulance is unavailable, i.e. the interval between when the ambulance is busy responding to a request for first aid and when it becomes free. The latter, however, may vary depending on whether or not the patient is taken to hospital in the first place. If so, the time the ambulance is used increases and depends substantially on how well-equipped the hospital is and how long the hospital itself is waiting. Consequently, the longer the ambulance is occupied in a given service, the lower the coverage rate of the area in which it has been assigned, also causing significant delays in response times to other emergency services.
For this reason, the population density of an area should also be considered, since if an area has a higher population density, it generally requires more ambulances to adequately serve the population. Urban areas, for example, may require more ambulances due to the high concentration of residents and, therefore, a greater likelihood of emergencies.
In addition to this, the geographical characteristics and infrastructure of an area can also be added, as areas with difficult terrains, such as mountains or remote rural regions, may require additional ambulances or specialized response teams to overcome logistical challenges and reach patients in a timely manner.

1.3 Ambulance Location in Smart Cities

An emergency medical service system is a service that provides acute pre-hospital care to patients with illnesses and injuries. It exists to fulfill the basic principles of first aid, which are to preserve life, prevent further injury, and promote recovery. The key factors for the successful treatment of an injury are: early diagnosis (a member of the public finds the incident), early notification (emergency services are summoned), timely response (emergency services arrive quickly at the scene), good on-site care (appropriate treatment is provided), in-transit care (the patient is assisted on the way to the hospital), transfer to definitive care (the patient is transferred to the care of a physician). Overall, the optimal location of ambulances in smart cities has a profound impact on city dwellers: it improves emergency response times, increases survival rates, enhances community well-being, and fosters a sense of safety and trust among residents.

Leveraging technology and data-driven approaches, smart cities strive to provide efficient and accessible emergency medical services for the benefit of all city dwellers.
Since the beginning of the 2000s, technology has undergone rapid development and started to play a crucial role in every field of human life, such as communication, business, entertainment, and health. Today, people demand access to the information they need in the shortest possible time and need to live in a comfortable, environmentally friendly, fast, and clean environment. Added to this is the fact that the population is steadily increasing, and, according to United Nations expectations, the total number of inhabitants in cities will double in the next three decades, and consequently the number of needs has also increased and will increase in many areas.
These kinds of demands and needs have contributed to the development of smart cities: the term smart city refers to a set of Internet of Things (IoT) devices that collect and use citizens' big data to make their lives easier, more productive, and safer.
The analysis and processing of big data from increasing IoT devices is very important for smart city management and its main purpose is to reduce costs and resources by providing a comfortable and healthy environment.
As can be seen from Figure 2, among the main ingredients that make up a smart city there is smart health, i.e. the provision of smart healthcare: smart hospitals, smart ambulances, rapid response to patients, and finding the quickest route to the hospital are key elements of the system.

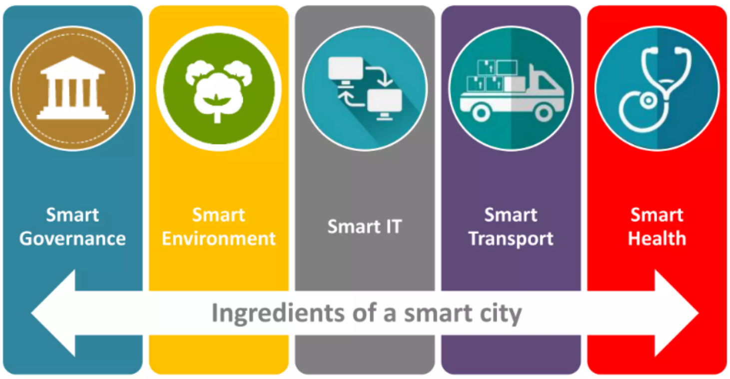

Figure 2: The main components of a Smart City [2]

In particular, rescue operations in smart cities are also supported by the use of advanced technologies and data-driven approaches:

- *Smart monitoring:* Smart cities use various sensors and IoT devices to monitor public spaces and collect real-time data. These systems can automatically detect unusual activity, such as accidents or incidents, and alert authorities for immediate action. In addition, there are also applications that connect different stakeholders, such as citizens, emergency services, and authorities, through which incidents can be reported and rescue operations accelerated.

- *Location-based services:* Smart cities use advanced GPS technologies to track the location of rescuers, vehicles, and people in distress. This information enables the precise location of the incident and the efficient dispatch of emergency services. In addition, navigation systems can provide optimal routes for rescuers taking into account real-time traffic conditions, ensuring faster arrival and timely medical assistance.

- *Remote medical assistance:* Smart cities explore telemedicine and remote medical assistance for initial triage and orientation during emergencies. Through video consultations and remote diagnosis, medical professionals can provide immediate advice to people, helping them stabilize the patient before physical help arrives.
- *Pre-hospital data sharing:* Smart cities facilitate the sharing of patient information between ambulances and hospitals. Paramedics can transmit vital data, such as medical history, allergies, and current medication, to the receiving hospital before help arrives. In this way, hospital staff can prepare the necessary resources and simplify subsequent medical interventions.
- *Stakeholder collaboration and coordination:* determining optimal ambulance locations involves coordination between multiple stakeholders, including emergency services, healthcare providers, traffic management authorities, and city planners. Effective collaboration and communication are essential to align strategies, share data and make informed decisions collectively.

By studying emergency patterns, authorities can identify hotspots or areas with higher accident rates and by considering historical data, real-time information, predictive models, and traffic management systems, smart cities strive to optimize the location of ambulances with the aim of ensuring efficient coverage, reducing response times and improving emergency medical services, ultimately improving patient outcomes and saving lives.
The optimal location of ambulances in smart cities can have a significant impact on city dwellers as by strategically positioning ambulances, response times can be minimized, increasing the chances of timely medical intervention and leading to better patient outcomes. In addition, this helps to reduce pressure on emergency services and allows better utilization of limited resources ensuring complete coverage of the city, including high-density areas and remote regions, providing better accessibility to emergency medical services for all city residents, regardless of their location, thus instilling a sense of security and reassurance among city residents, alleviating anxiety, and improving the general well-being of residents.

1.3.1 First Aid Challenges

Although smart cities offer many advantages in terms of infrastructure and technology, there are several challenges and considerations regarding first aid in these environments. Despite advances in smart city technologies, public awareness and knowledge about first aid may still be limited. Many people may not be equipped with the necessary skills to provide immediate assistance during emergencies: it is crucial to prioritize public education and awareness-raising campaigns to ensure that residents understand the importance of first aid and know how to respond appropriately while also overcoming any language and cultural barriers that may arise as cities become increasingly multi-ethnic, multi-lingual and multi-cultural.
Furthermore, although smart cities may have advanced healthcare facilities and emergency services, the availability and accessibility of first aid resources may vary in different areas, and it becomes essential to ensure that first aid supplies, such as automated external defibrillators (AEDs) and first aid kits, are widely distributed in public spaces and that people can easily access them.
Emergencies are dynamic and can occur anywhere and at any time, and while historical incident data may provide information on past trends, they may not fully capture emerging or unpredictable patterns. Smart cities need to develop adaptive models that can take into account real-time data and rapidly changing emergencies to dynamically adjust the positioning of ambulances.

In addition to this, the development of these models requires the use of technologies that are constantly collecting and processing large amounts of data related to emergencies and first aid, for which data quality assurance measures and regular updates are essential in order to conduct robust analyses and make informed decisions.
The data collected may also contain sensitive and personal information for which privacy and protection should be guaranteed. Data governance frameworks and robust security measures must therefore be in place to safeguard people's privacy and comply with data protection regulations.
Always relying on data and derived analyses, one must remember that ambulances are limited resources and that smart cities must balance their positioning to meet the needs of the entire city.
As mentioned above, optimizing ambulance locations requires the consideration of various factors that must be properly balanced to ensure equitable coverage. Consequently, the optimal location of ambulances may require investments in infrastructure, such as ambulance stations, vehicle maintenance facilities, and communication systems for which smart cities need to assess the financial implications of creating and maintaining an efficient

emergency network.

Adding to all these challenges is the fact that smart cities rely heavily on technology, including mobile applications, emergency alert systems, and online platforms, to facilitate emergency response and first aid, but may run into technical problems, connectivity issues or power outages, which may affect the availability and reliability of first aid support. Backup systems and alternative communication channels should be in place to ensure the continuity of first aid services.

Addressing these challenges requires a comprehensive approach that combines robust data analysis, collaboration with stakeholders, continuous monitoring, and adaptive strategies. Smart cities must invest in technologies, policies, and partnerships that support the optimal location of ambulances, taking into account the unique characteristics and needs of their communities, while safeguarding the safety and well-being of their residents.

2 Data Analytics, Optimization, and Policy Suggestions

2.1 Aim

In this section, we analyze the problem of locating new ambulances focusing on the urban area of Milan with the aim of potentiating the emergency health service (called 118) in the context of smart cities.
In particular, in this context, the operation center is located at the Niguarda Ca' Granda Hospital and collects a wide amount of data describing the services coming from throughout the region, from the instant in which a call is received by the operator to the time an ambulance leaves the hospital after the service. Although Italian law states that yellow and red emergency calls must be answered within a mandatory time of 8 minutes in urban areas, currently only around 60% of emergency calls in Milan are served within this recommended time [3].
Thus, with the intent of investigating the current performance of this system and providing suggestions for better management of emergency calls, we searched for a database collecting the history of the 118 activities. More precisely, for each rescue operation we were interested in spatio-temporal data, i.e. geo-referenced information about the paths computed by the ambulance and the timetables describing the duration of each phase of the mission.
For the region of interest (Lombardia), the *Agenzia Regionale Emergenza Urgenza* (AREU) constitutes the repository of all those information, but, the process of data delivery, due to the sensitivity of healthcare data, is subjected to severe guidelines that require a quite long and complex approval procedure. For this reason, this project is totally based on our personal knowledge of the 118 system coming from voluntary activities and it is focused on the activity of only one association devoted to first aid placed in Arese: Misericordia di Arese.
The data repository system of the call center of Misericordia Arese is based on a web app called *EmmaWeb* that stores information in an unstructured way, therefore the first step has been to construct a dataset answering to our needs. For the sake of completeness, only data regarding missions carried out in the previous 7 days are available to Misericordia Arese operators after the username/password login to the web app. Because of this, we periodically enriched our dataset with incoming new emergency operations, covering a time duration of 1 month: from 27 May 2023 to 27 June 2023.
The aforementioned data have been combined with additional information available at the official website of AREU [4] about how many missions per province of Lombardy have been satisfied on a specific day, classified with respect to the color code. Scraping activity has been adopted for this purpose in the time window considered in this study.

Since the observation window of this analysis is limited to 1 month and given that the considered missions are only the ones satisfied by a single emergency provider, this work simply aims to give a very small insight into the capability of the current system to fulfill the time-requirements which should characterize a smart city. From the spatial point of view, instead, this dataset covers not only the area of Arese but also 3 other areas of Milan since this association guarantees 3 stationing points:

1. **Filzi** that covers the *Milano Centrale* quarter with the stationing of the ambulance in Piazza Quattro Novembre;
2. **Amoretti-Lessona**: that covers the *Quarto Oggiaro* quarter with the stationing of the ambulance in Via Amoretti;
3. **Miani**: that covers the *San Cristoforo - Barona* quarter with the stationing of the ambulance in Piazza Guglielmo Miani.

While the first one is an H12 convention, that stays active for 12 consecutive hours, the last two are H8 conventions, thus they cover the area for a smaller period of time. To achieve the objectives, it is focused on 2 main activities:

- A Descriptive analysis of the rescue operations satisfied by Misericordia Arese in the 4 stationing points (including **Misare**) in the considered time window, in terms of different aspects: the time needed to complete a mission that combines both the time to reach the patient location, the one for the rescue and the time spent in the hospital, the reason of the call and the spatial distribution of the call locations with respect to a specific stationing point;
- The implementation of an optimization model to determine the best new ambulance stationing points among potential sites for a better accomplishment of the 8 minutes requirement.

2.2 Datasets

The dataset we were able to construct contains spatiotemporal information of 483 emergency calls, among which 102 served by **Misare** stationing point, 211 by **Filzi**, 105 by **Amoretti - Lessona** and 65 satisfied by **Miani**. Each call is characterized by 31 descriptors:

- Date
- Mission ID
- Patient Location
- Patient Address
- Building Floor (if the field 'Place' is different from street)
- Ambulance ID
- Convention
- Stationing Point
- Color Code firstly assigned by the 118 operator receiving the call
- Color Code for the transportation to the hospital (if the field 'Refusal to Transport' is not True)
- Medical reason of the call
- Patient age
- Patient gender
- Patient citizenship
- Place (house, street, etc.)
- Refusal to Transport (True or False)
- Destination Hospital
- Total travelled KM
- Mission duration (in MIN)
- Time of mission receipt
- Ambulance departure time from the stationing point
- Arrival time of ambulance to the patient location
- Departure time to the hospital
- Arrival time to the hospital
- Departure time to the stationing point
- Mission end time
- MSA (True or False) that indicates the presence or not of the *Mezzo di Soccorso Avanzato* equipped with a doctor and nurse
- Police (True or False) that indicates the presence or not of the Police
- VVF (True or False) that indicates the presence or not of fire fighters
- CC (True or False) that indicates the presence or not of Carabinieri
- Note

One of the common challenges while dealing with geospatial data is turning address data into coordinates values so that it could be mapped, analyzed, joined with other data sources and so on. The service history dataset contains different fields which allow an event to be geographically located in the area. However, there is a difficulty to resolve ambiguities regarding street names: for example Via Giacomo Leopardi can be indicated with its full name as well as Via G. Leopardi, Via Leopardi G., or just Via Leopardi. This lack of reliability can lead to a serious localization error, together with the errors in assigning the name 'street', 'avenue', and 'square' to the address. For this reason, it was decided to use a robust geocoding algorithm, which could overcome the ambiguity given by the low accuracy of the data stored in some history instances. In particular, for this purpose, the *Nominatim* tool has been exploit. It makes use of *OpenStreetMap* data to find locations on Earth by name and address. The same procedure has been repeated to find the latitude and longitude coordinates of all the hospitals visited by the ambulances under consideration.

For the scraping activity, the *requests* library was used to retrieve the HTML code from a specific URL and the *BeautifulSoup* library to parse and extract the HTML tree. Having inspected the web page, the data of interest were identified within the 'table' tag. The final dataset extracted in this way reports, for each day of the considered time window, the total number of events carried out by the 118 in Milan and its division in green, yellow, and red emergency call codes. A mean over the 30 days will provide the average number of missions completed per day in the province of Milan.

In order to accomplish our optimization task, the shapefile containing the map of Milan divided in NIL (*Nuclei di Identità Locale*), has been downloaded from *Milano Open Data* [5]. The shapefile format stores the geometry as primitive geometric shapes like points, lines, and polygons. These shapes, for each NIL, were linked to some other attributes: number of residents, surface area, and population density retrieved from *https://www.comune.milano.it* website [6]. This activity allowed to create the representation of the geographic data.

2.3 Descriptive Analysis

2.3.1 Spatial distribution of the missions

The first step of this work was to analyze the spatial distribution of the registered emergency calls satisfied by each ambulance through *OpenStreetMap* (OSM). To get the latest OSM data, the easiest way was to download an excerpt from a website. There are several web services that provide extracts for an area of interest. In this work, it is used the *Overpass API* which allows querying of specific data from the OSM dataset. It takes some time to get used to, but *Overpass Turbo* has enabled to interactively evaluate the queries made directly in the browser.

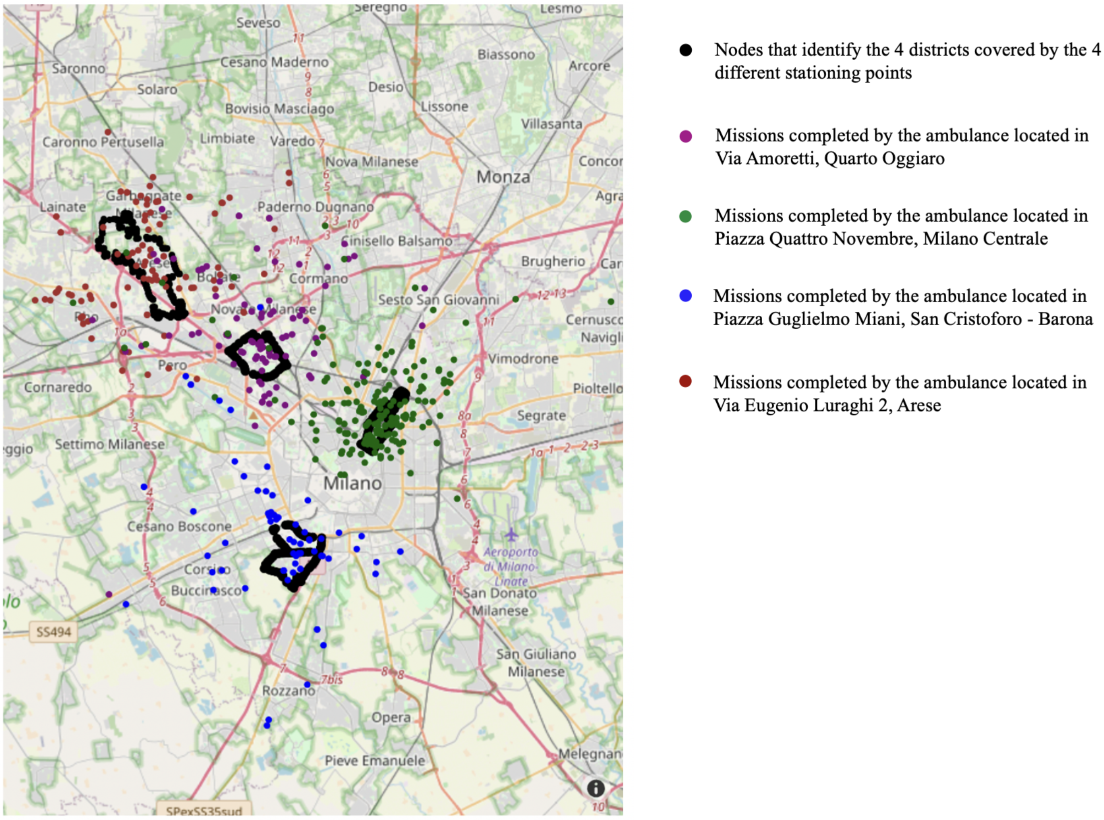

Figure 3: Spatial distribution of the registered missions completed by each ambulance

Figure 3 shows a significant spread in the spatial distribution of the services satisfied by Miani's stationing point with respect to the other 3. This observation suggested an under-dimensioned emergency system in correspondence of Municipio 6 and 7 (San Cristoforo and Barona quarters) of Milan.

2.3.2 Correlation between reason calls and districts

Milan is a city that holds the record of "capital of inequalities": the distance between rich and poor is the greatest in Italy, in fact, with a range that goes from the average income of 100,000 euros for those who live in Brera to 18,000 euros of those who live in Quarto Oggiaro [7]. The latter is also at the bottom of the list for the incidence of self-employment. It is sadly known for being the most dangerous and infamous neighborhood in the city. In fact, one of the highest crime rates and widespread degradation is recorded here.
Among the most critical areas, there is also the Central Station of Milan, between gangs of drug dealers, the homeless, and the police. It is second place in the ranking of the busiest railway stations in Italy, with around 320 000 passengers per day which consequently increases the demand associated with health care interventions in this area. On the other side, the area of Arese is definitely a city chosen by families, with a low crime rate, on the outskirts of Milan which allows for a greener life.
For the reasons listed above, we searched in our dataset for manifestations of this heterogeneity, which could be translated both into the different types (medical reason of the call) of services performed by ambulances in these neighborhoods, and in the presence or absence of law enforcement on site.

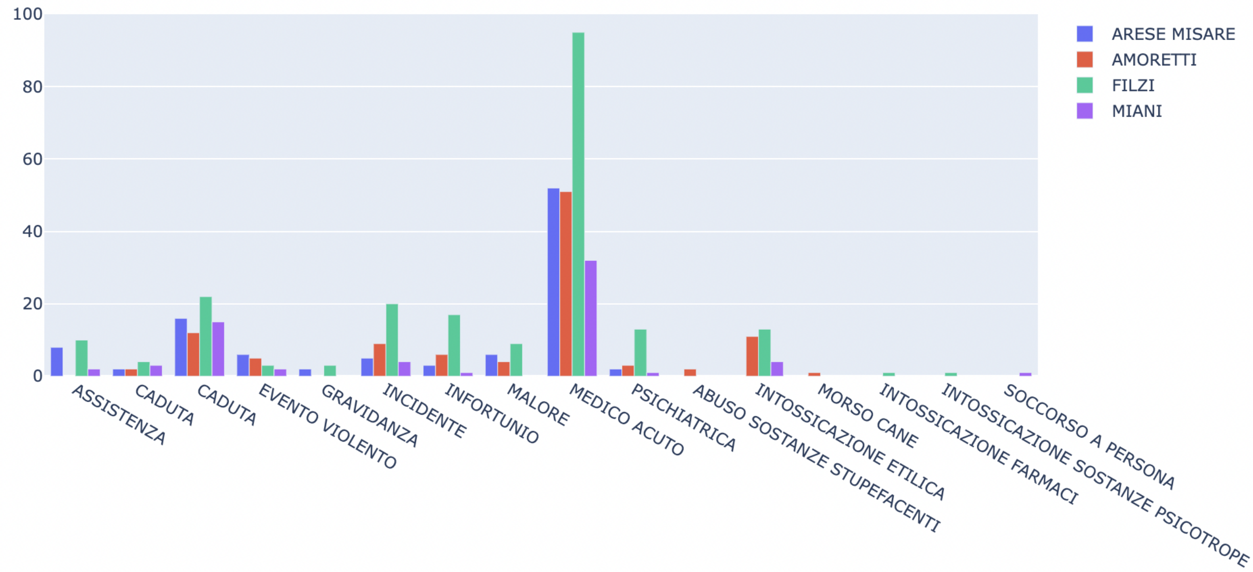

Figure 4: Frequency of services based on motivation and location

From Figure 4 emerges that:

- most of the calls are for reasons related to problematic physical conditions (under the 'Medico Acuto' field fall back calls for cardiovascular, respiratory, neurological, neoplastic, digestive, urogenital, osteo-muscular problems) followed by fall-related events (correlated to elderly patients)
- the missions for alchool abuse are principally faced by the ambulances located in *Quarto Oggiaro* and *Milano Centrale* districts (in the 34% of the cases marked by the presence of Police or Carabinieri)
- psychiatric events are occurring with the highest frequency in the Filzi stationing point
- all the stationings receive on average the identical percentage of calls for violent events (quarrels/aggressions).

2.3.3 Timetables of the missions

At this point, it is analyzed the daily time interval covered by each ambulance guaranteed by Misericordia Arese association.
This activity is based on the free activity of about 200 volunteers and 6 employees: the volunteers, after a first aid course, can choose to cover night shifts (from 19 PM to 7 AM) or can lend their time on Saturday day (divided into 2 turns: 7 AM - 13 PM, 13 PM - 19 PM) satisfying principally the Misare stationing point with a GET_3_NE convention ambulance and external services devoted to the community such as assistance to the Arese shopping center (just in front of the Misericordia Arese site), to sporting events in the area, to private transports, to the San Siro stadium during matches and to the Assago Forum for concerts attendance; the 6 employees, instead, cover completely the H8 conventions in Miani and Amoretti -Lessona stationing points and the H12 convention (from 8.30 AM to 8.30 PM) of Filzi excluded the weekends, satisfied by the volunteers. For this reason, as volunteers, we studied the time slot covered by Miani and Amoretti - Lessona. The first one (Miani) is active from Monday to Friday from 8 AM to 4 PM showing regularity in the time of the first and last missions, while the second one is from Monday to Saturday in the time slot 4 PM - 12 PM (Figure 5).

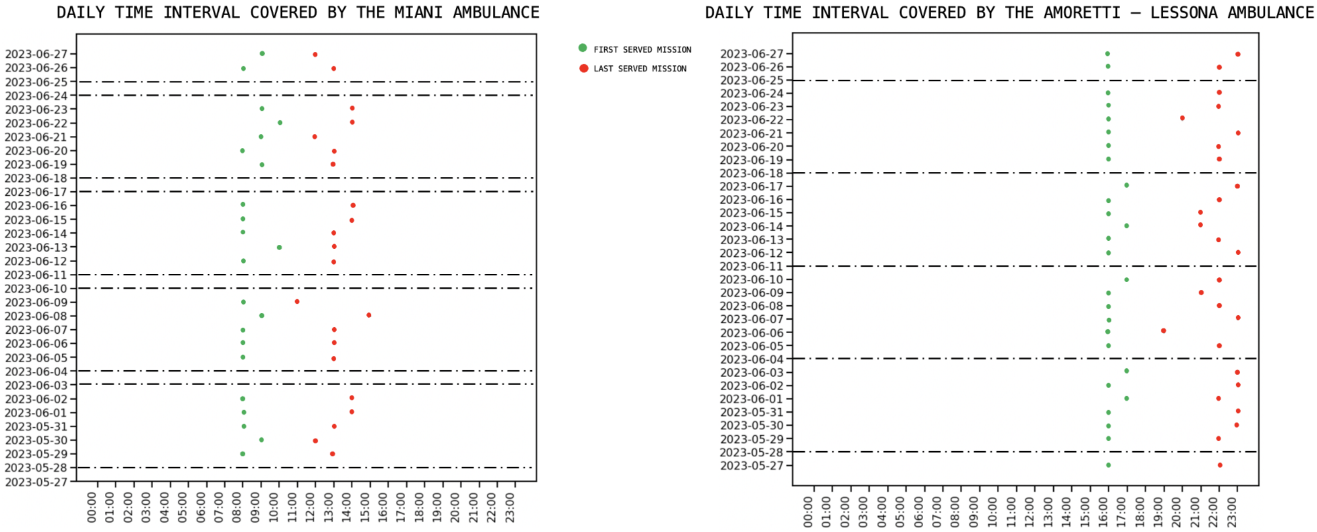

Figure 5: Daily time interval covered by 2 ambulances guaranteed by Misericordia Arese in Milan urban area

The timetables of services are collected thanks to the communication between the driver and the control unit through the use of a tablet placed on the emergency vehicle by which communicates every single travel time: the departure time towards the patient, the arrival time at the scene, the departure time towards the hospital of destination, the time of arrival at the hospital, the time of departure from the hospital to the stationing point and finally the time of the end of the mission. In particular, through the analysis of this information, it was possible to study if the time requirements are satisfied.

Stationing Point	Transport Color Code	Average mission time duration (min)
Amoretti - Lessona	-	56.22
	G	115.56
	R	127.00
	V	104.01
Arese Misare	-	52.45
	G	86.03
	R	70.0
	V	76.19
Miani	-	43.75
	G	122.58
	R	143.62
	V	164
Filzi	-	36.10
	G	103.76
	R	108.50
	V	103.75

Table 1: Average mission time duration depending on the stationing point and transport color code of the calls

From Table 1, obviously can be seen that the missions where the patient refuses transport to the hospital, are the shortest ones in terms of time duration and represents the 25% of the total number of completed missions. Furthermore, all the services managed in Arese are completed on average in less time than the other stationing points: an explanation for this observation may also be due, in addition to the peripheral geographical location of Arese, to the fact that they are served mainly at night. This total time also includes the time spent waiting in hospital emergency departments.
In Figure 6 it is possible to analyze the average time spent in each hospital by the ambulance.

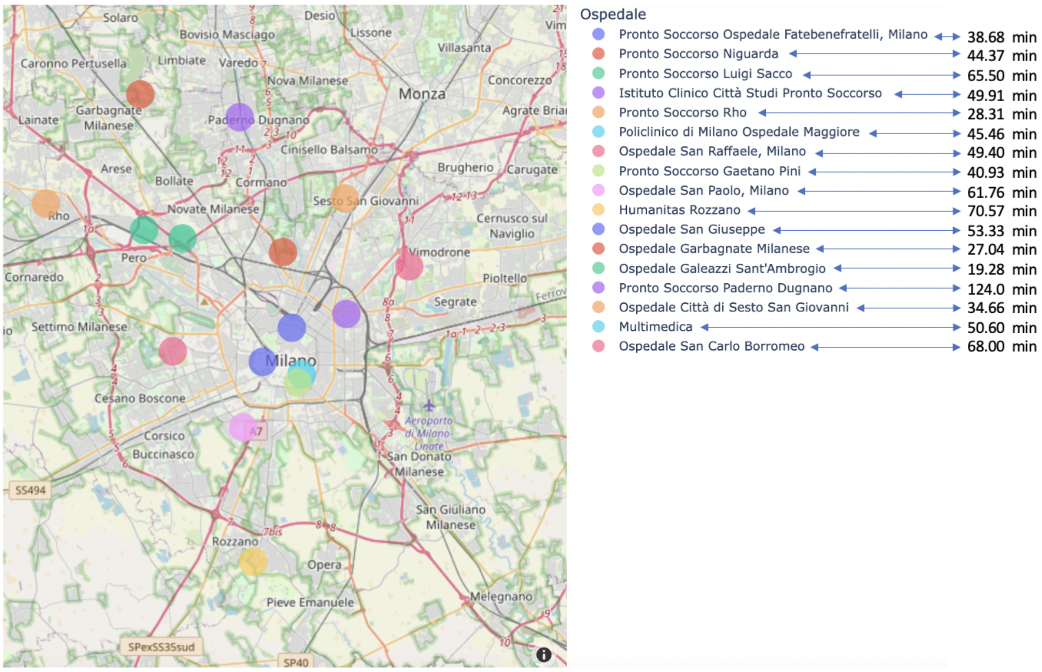

Figure 6: Average time spent in each hospital by the ambulance

Stationing Point	Send Color Code	Average mission time arrival to patient location (min)
Amoretti - Lessona	G	10.30
	R	6.66
	V	13.93
Arese Misare	G	11.31
	R	10.00
	V	14.21
Miani	G	11.34
	R	12.33
	V	14.75
Filzi	G	8.50
	R	6.57
	V	10.75

Table 2: Average mission time arrival to the patient location depending on the stationing point and send color code of the calls

Instead, in Table 2, for each stationing point, the average time interval between the receipt of the mission by the ambulance and its arrival at the scene is reported, depending on the color code of the calls.
As can be seen, only the ambulance located in Filzi satisfies all the time constraints: indeed, both yellow and red emergency calls are covered in around 8 minutes and, instead, the green calls have a reasonable time of around 11 minutes, but anyhow within the 15 minutes of a smart city. In general, this is valid for all the green calls at any stationing point.
Regarding Miani, instead, it registers the longest time employed to reach the patient location, both for yellow and red calls. So, the previous hypothesis of under dimensioned emergency system in correspondence with Municipio 6 and 7 (San Cristoforo and Barona quarters) of Milan was confirmed by this analysis.

Consequently, to find a solution to this problem, in the second part of this work, we implemented an optimization model aimed at identifying the best parking points where to place new ambulances, in such a way as to face the average daily request for medical assistance in the geographical area in question and being able to satisfy it within the pre-established times. In this way, a relationship of extreme trust can also be created with citizens who can therefore feel safe in the event of highly critical emergencies for which every minute delay in response times reduces the chances of survival.

2.4 Optimization model

There is widespread literature on the problem of optimally locating ambulance posts (more in general on vehicle location). A recent survey is provided in [8], where static models and dynamic models are discussed in which static ones differ from dynamic ones in that they do not describe the transfer of ambulances after the end of a service. Furthermore, both deterministic and probabilistic descriptions of the phenomenon have been studied. Indeed, there are many random parameters involved, such as the instant of a new call occurring at the emergency service, the time of response, and the waiting time in a hospital. etc. This randomness influences the availability of an ambulance, which becomes a random variable itself. In deterministic models, in which this randomness is neglected, the optimization of post-distribution imposes constraints on the coverage.
In this work, we have focused only on the definition and development of a static deterministic model called the facility location model with the aim of determining the minimum number of ambulances and their optimal location in order to satisfy, first of all, the question and at the same time reduce the time of arrival on site. This optimization task can be distinguished into capacitated and uncapacitated. Although the model is a static one and does not represent the dynamic behavior of the system, we wanted to take into account somehow the availability of the ambulances. Indeed, an ambulance can afford a limited number of missions in a given time interval and this value depends on both the time needed for the rescue and the time spent at the hospital; on the basis of the collected data, an average value was computed that we decided to use as an ambulance capacity index in the optimization model.
More in detail, with the aim to place new ambulances with an H12 convention, inferior and superior ambulance capacity was considered to be the average minimum and maximum number of daily services of the Filzi'ambulance (since it is an H12 convention too).

We posed the problem as the minimization of the following objective function:

$$\sum_{j=1}^{M} y_j + \sum_{i=1}^{N} \sum_{j=1}^{M} t_{ij} \cdot x_{ij} \tag{1}$$

where:

- N is the set of points where we located the demand. In particular, for simplicity, we have assigned the estimated demand for each quarter to its centroid. In total, the number of selected districts is 24 (Figure 7);

- M is the set of points identified as potential sites for new ambulances. In particular, the choice of potential points where a new ambulance can be placed followed this procedure: first of all, we selected the districts of Milan that cover the affected area (Figure 7), then, for those with a number of residents higher than 3000, we have downloaded their road network through the *graph_from_place* function of the *osmnx* library. This function takes in input the district name and the network type, set to *drive* in order to load road accessible to cars, and return a graph object, an instance of *MultiDiGraph* which is a directed graph type from *NetworkX* package. Subsequently, for each road network, we extracted a specific number (depending on the visual road network density) of random points belonging to them, through the function *utils_geo.sample_points(G, n)* of *osmnx* library. It takes in input the previous graph and the number (n) of random points we want to select. These points represent the possible sites where to locate a new ambulance since, from our knowledge, they usually station in roadside parking lots, waiting for emergency calls. The total number of identified potential sites is 64

- t_{ij} represents the arrival time from site j to quarter centroid i. In order to extrapolate this information, we exploited the osmnx graph of Milan. Since it is described by nodes and edges, it is possible to calculate the shortest route to be traveled by ambulance between two points. Considering the maximum speed and lenght of edges in meters we can calculate how long it would take to drive along this road segment (edge) in seconds. In this way we were able to build a dictionary containing, for each potential ambulance site, the travel time needed to reach each centroid

- x_{ij} is the number of missions (and so, demand) of the quarter i covered by the facility (ambulance) in site j

- y_J is a binary variable (0 or 1) indicating whether the ambulance should be located in j ($y_j = 1$) or not ($y_J = 0$)

The following constraints have been added to the objective function:

1. Since we are modeling a capacitated problem, each ambulance j can supply a daily maximum capacity C_j and a minimum capacity c_j, set respectively to 9 and 6. Therefore, the number of demand supplied to a quarter, x_{ij}, cannot be greater than C_j and less than c_j:

$$c_j \cdot y_j \leq \sum_{i=1}^{N} x_{ij} \leq C_j \cdot y_j \tag{2}$$

2. The daily missions carried out by the potential ambulance j to the district i must range between zero and d_i, the daily demand from quarter i:

$$0 \leq x_{ij} \leq d_i \cdot y_j \tag{3}$$

3. we must meet districts demand. We impose that the ambulances serving a district must fully meet its demand:

$$\sum_{j=1}^{M} x_{ij} = d_i \tag{4}$$

Since we have no information about the daily average number of calls in the critical area we considered (Municipio 6 and 7 of Milan, indicated in Figure 7), we estimated it using the additional dataset from the AREU website regarding the total number of daily services performed by 118 in the province of Milan. The average daily number of missions over 30 days turned out to be 954. In the mild hypothesis that Milan consisted of only 9 Municipalities, the total demand associated with Municipalities 6 and 7 would have been equal to the $\frac{2}{9}$ (202) but, since the province is larger than the 9 Municipalities, we arbitrarily limited this value to 150.
Thus, this number of requests, in turn, has been divided into districts based on the population density of each quarter.

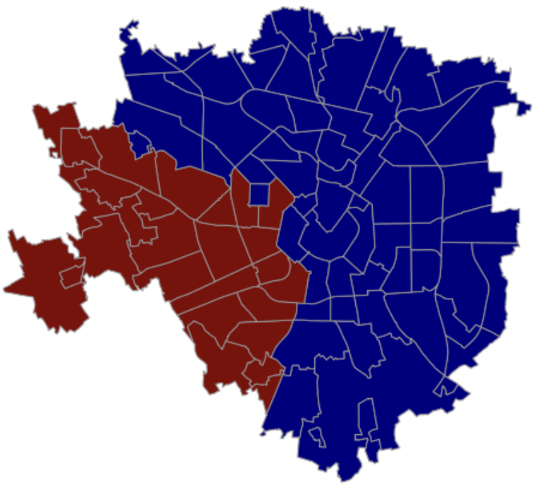
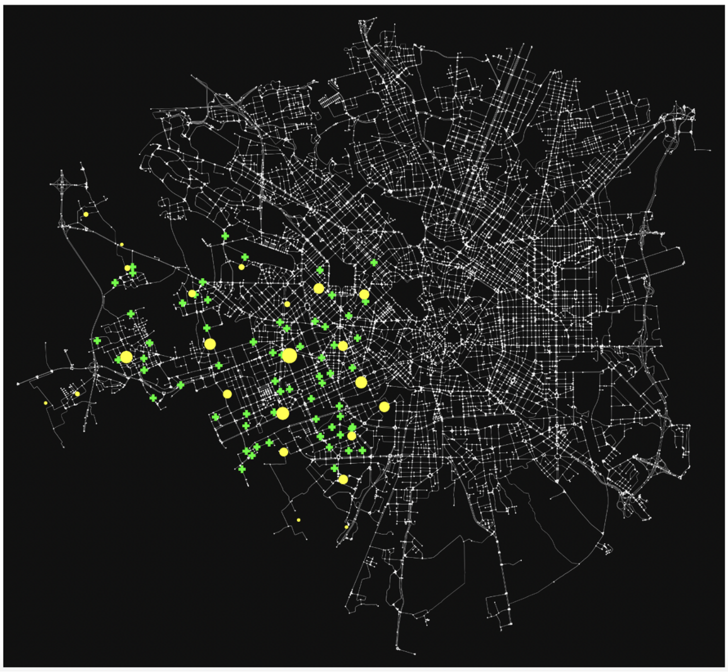

Figure 7: **Left**: the brown area corresponds to Municipio 6 and 7. The districts belonging to them are: *Ronchetto sul Naviglio - Q.re Lodovico il Moro, Figino, Quarto Cagnino, Stadio - Ippodromi, Quinto Romano, San Siro, De Angeli - Monte Rosa, Cantalupa, Barona, Parco Bosco in Città, Assiano, Muggiano, Porta Ticinese - Conchetta, Porta Magenta, Forze Armate, Bande Nere, Baggio - Q.re degli Olmi - Q.re Valsesia, Moncucco - San Cristoforo, Giambellino, Porta Genova, Parco dei Navigli, Pagano, Lorenteggio*
Right: the road network of Milan, potential sites for new ambulances are indicated by green dots, yellow points indicate the centroids to which we assigned the demand (represented throughout the size of the circle)

Once we defined the problem, it has been solved in *PulP* and, this allowed us to identify 21 points of the 64 potentials, where to place new ambulances in order to satisfy the demand (Figure 8). Therefore, this solution made it possible to find the points through which both the number of new emergency stations and the time necessary for the ambulances to reach the patients could be minimized. Since in the optimization problem, we did not consider any time coverage constraint (i.e., the 8 minutes requirement), we build isochrone maps to verify if a given ambulance, among the identified 21, can serve patients within this recommended time. Indeed, an ambulance covers an area if the mean time needed to reach the area starting from the stationing point is less than a threshold time.
Thus, three isochrone maps were constructed and an example of them is shown in Figure 8: the first identified by the yellow area indicates the areas that the ambulance can travel in a maximum of 5 minutes, the second identified by the pink region, indicates instead those that the ambulance can serve in 8 minutes and, finally, the third in blue defines the area where patients can be reached within 15 minutes.
From this analysis, we could observe that all the identified 21 new ambulances would be able to fulfill this condition, which is of crucial importance in the context of smart cities.

2.5 Policy Suggestion

Our solution demonstrated to be capable of properly satisfying the requests within the recommended time. Clearly, given the fact that the analysis focuses on a small region of Milan only, this solution would represent an extremely over-dimensioning of the emergency system. In this regard, it should be stressed that half of the daily calls are on average classified as 'green' missions, characterized by a low level of criticality with vital parameters in a normal range and no developmental risks. Such situations do not even represent emergencies but may keep the ambulance crew occupied for hours, causing more serious emergencies to be assigned to distant ambulances that need more time to reach the patient.
However, the green codes could be handled by the family doctor or the 'Guardia Medica' service, if the former is not available, as they are specialized figures in the area with the purpose of assisting, both physically and by telephone, patients with minor problems.
This situation, if not improved, undermines the entire emergency management system and results in the occupation of resources that would be allocated to more serious cases. However, this happens for several reasons: (i) the misinformation of citizens who, although not in extreme conditions, use the emergency service to receive personal medical assistance which in reality should be provided directly by the general practitioner himself, (ii) the inefficiency of the 'Guardia Medica' service which very often redirects patients to the emergency number 118 even though it is not necessary and (iii) the increasingly reduced availability of family doctors which leads citizens to turn to emergency facilities and emergency rooms in case of need, consequently causing an overload of hospitals, which, as can be seen from the average time observed by ambulances in hospitals, (Figure 6), are experiencing increasingly long waiting times.
At the cultural level, changes occur in the long term step by step, but in the short term, one could start to act by changing political and administrative choices.It could be useful to undertake actions similar to the *walk-in services* of the United Kingdom, which consists of the installation in the territory of intermediate services, which are placed between primary care and family medicine, and the emergency rooms, to which citizens could turn in case of a series of problems for which it is not necessary to access the emergency departments.
Another element that could be useful in safeguarding the overloading of hospitals could be the introduction of a nursing continuity service precisely because nurses very often find themselves assisting patients in emergency rooms who could also receive the same care at home.

Some many other measures and actions can be taken to primarily safeguard the well-being of citizens within the city, however, one element is certain: if we continue to consider the emergency room as a hospital entity with the function of "filter and sorting" with respect to operating units, the problem will persist indefinitely. We must try to create a valid alternative network at the local level that citizens can use for minor problems and that can establish a sense of confident well-being in them, allowing the citizens to feel safe.
Indeed, to solve the problem of the super influx of emergency rooms, it is necessary to ensure that the population does not have to access them except for real urgency. This requires that the filtering action with respect to the emergency departments also start from an integrated action with the territorial medical emergency management system, which to date only takes a small part of patients to the hospital, as most of the user goes independently to the emergency room, but if reorganized into a network with the territory and integrated into its action with the primary care departments, it could have an important role in stemming the arrival of inappropriate cases in the emergency room.

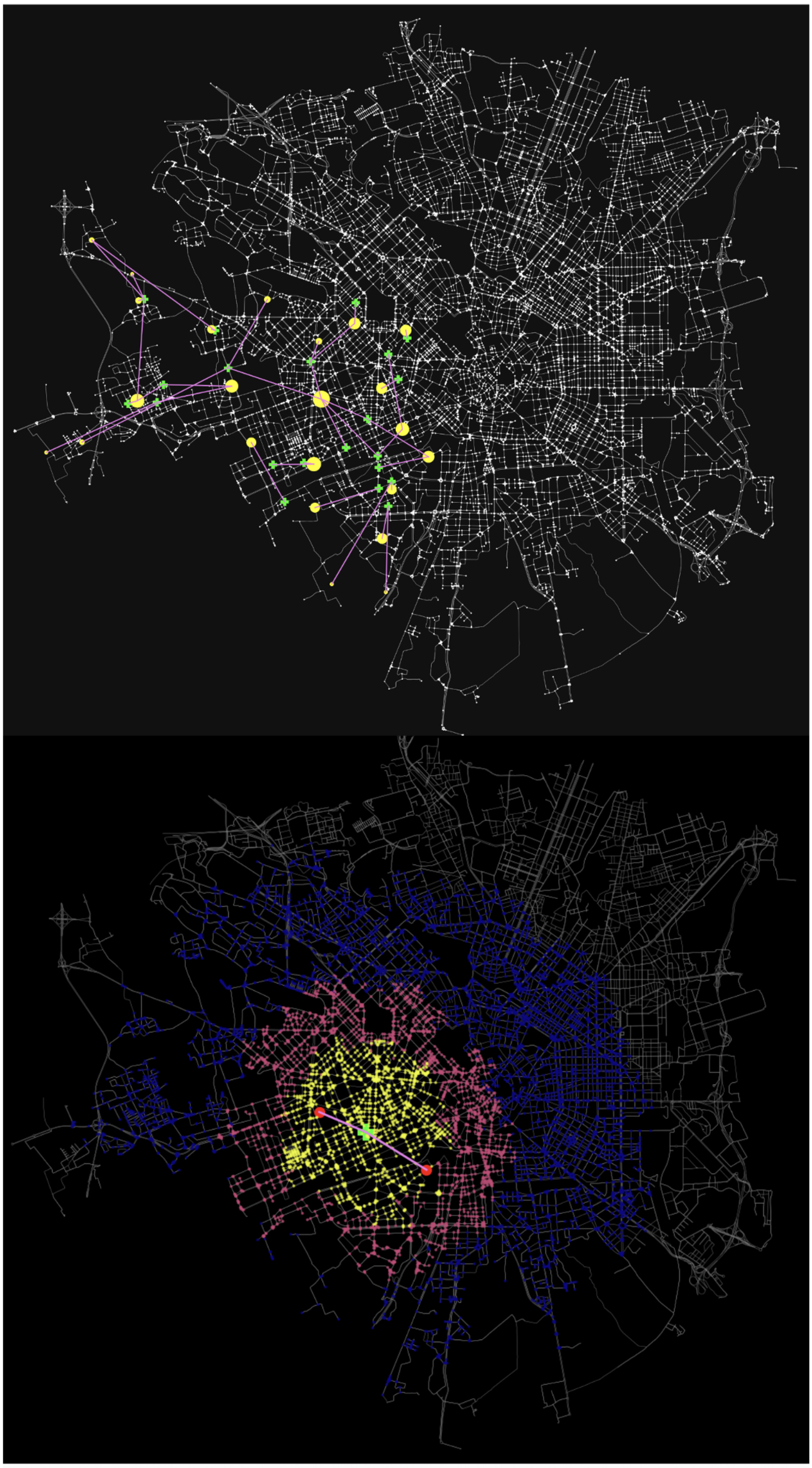

Figure 8: **Top**: Optimized Ambulance sites. Which districts are served by which chosen ambulances in the optimized solution are shown
Bottom: Isochrone map for a selected ambulance site that satisfies 2 districts' demand. In yellow the urban area served by the ambulance in 5 minutes, in pink served in 8 minutes and in blue the one served in 15 minutes.

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