Università degli studi di Milano-Bicocca

Data Science Lab for Smart Cities

Final Essay

Smart parking: the case of Brescia between innovation and sustainability.

Authors:
Valentina Stroppa - 819210 - v.stroppa1@campus.unimib.it
Michele Bonera - 890256 - m.bonera1@campus.unimib.it

May 16, 2023

Abstract

Smart Parking represents an intelligent system for the management and control of parking spaces. In the context of the Smart City, it plays a fundamental role in optimizing urban mobility and improving the overall efficiency of the transportation system. The present project aims to study the specific case of the city of Brescia, in order to analyze the strengths and weaknesses of the current situation regarding traffic and parking areas within the municipality. Initially, an overview of Smart Parking will be presented, explaining the theoretical concepts that define a Smart City and illustrating some real-life cases where this system has been successfully implemented. Subsequently, through a theoretical analysis, the topography and urban mobility of Brescia will be further examined to better understand the ethical and social implications that could arise from the potential introduction of the Smart Parking system. Finally, by utilizing analytical data and statistical indicators related to traffic and major parking areas, a comprehensive overview of the current situation will be provided, highlighting possible future implementations that the city of Brescia can undertake in terms of parking management and urban mobility.

Contents

1 Part 1: Problem description and indicators

1.1 Smart parking and its relationship with the city

1.1.1 A brief description of smart parking

Nowadays, the problem of insufficient parking plagues many cities, bringing with it issues related to pollution, road congestion, and wasted time searching for parking spaces. Consider, in fact, that within an urban fabric of a modern Italian city, travel by private transportation covers 62 percent of total travel, and at least 15 percent of inner-city traffic is driven by cars looking for parking. Long-term surveys have also found that a vehicle is on the move an average of 10% of the time and during the remaining 90% remains parked. This leads to major problems as space to build parking lots is limited and people struggle to find free parking spaces near their homes or where they are headed. Increasing the number of parking spaces, however, does not turn out to be an entirely sensible choice because it does not eliminate the root of the problem; on the contrary, it disincentivizes people from using public transportation or adopting equally viable alternatives. Therefore, in addition to changing people's mindsets, efforts are being made to optimize the use of parking spaces in the street network by using smart solutions promoted by new technologies to reduce the environmental impact and increase citizens' well-being.

1.1.2 The goal of this work

According to Durkheim, the city consists of the totality of human contacts and interactions, heterogeneity and division of labor. The more these aspects grow the greater the growth in terms of the city itself and its population. For the author, interdependence, meritocracy and individualism are the keys to having an organic city. Brescia, our hometown, has over the years experimented with new ways to live consciously, converted urban areas into sustainable places, and applied IoT technologies to make life safer and easier and started with what connects people and activities every day: urban mobility. It seems that the various decision-making bodies in Brescia have focused precisely on the connections between all the various areas of the city to promote contacts between all its stakeholders with a conscious eye toward a future of growth and innovation, just as Durkheim theorized. Starting from the concept of urban mobility, we then focused on the analysis of smart parking as a new paradigm of evolution. This project therefore stems from the desire to understand what new technologies are being developed to overcome the problems associated with finding parking by analyzing the reality and hypothesizing solutions. The intent is to first study the context by trying to find descriptive indices that are useful and significant enough for the intended purpose, and then focus on the relationship between parking and traffic, which, thanks to graphical and descriptive analysis, we hope will help us to think of new solutions regarding smart parking and to understand some more aspects of our city.

1.1.3 Some experimental projects

Below we present some experimental projects, both Italian and non-Italian, that help to better frame the solutions that are currently being implemented to solve problems related to poor parking management. In Italy, the "Bosch Smart Parking" system has been developed, which, thanks to hardware, software and artificial intelligence, helps drivers find parking while easing traffic congestion, reducing CO_2 emissions and noise pollution. The first technology developed by Bosch is based on a sensor, with a long-life battery to be mounted on the asphalt, consisting of magnetometer and a radio wave emitter, which is useful to avoid false positives. Each sensor is connected to the network through LoRaWAN connectivity, which uses low-frequency radio waves for low power consumption. Cameras with audio-video analysis systems represent the second technology still under development, which can identify about a hundred cars with 99 percent accuracy. In this case the system is governed by artificial intelligence. These systems for users will be useful because thanks to variable message LED panels, reservation apps, closing full floors or turning on/off lights they will avoid circling in parking lots. Parking lot owners, on the other hand, will be able to monitor entrances, check dwell time, immediately detect irregularities, and more. Another goal for Bosch is to be able to integrate all these systems into an App and open up the system to grid-connected cars with a view to autonomous parking, but this 'last point is still under study.

At the moment, Bosch technologies in Italy are being used for private use, but a pilot project has already been carried out in Mantova, Italy, in 2019, involving the installation of sensors along the main street of the city where there are 66 parking spaces. The results have been satisfactory leading to improved transparency in the use of parking spaces, decreasing pollutant emissions in the historic center, and reducing parking search time by 35 percent. Treviso has seen improvements regarding abuse and non-payment of tickets thanks to a system similar to the one previously described, which has been used for a decade.

Another way that has been thought of to obviate the parking problem is being experimented with in West Moravian, where it has been planned to start sharing parking spaces. This rationale is based on the fact that parking lots often remain unnecessarily empty for the period when a business is closed, but could still be used. Consider, for example, a parking lot reserved for employees of a company that is located near a theater. If such a parking lot could also be used by the show's audience during the company's closed period, it would lead to great benefits in terms of traffic, space, and time.

Systems similar to Bosch's are also beginning to be implemented for tiered parking in which entrances and exits are monitored by means of a barrier and RFID tag and camera systems and through which vehicle characteristics (e.g., length, width, height,...) are identified and then directed to the correct floor. By doing this, parking dimensions can be changed and parking can be even better managed.

1.1.4 Brescia: space, time and scale

To define a smart city usually describes space, time and scale. Brescia has 196640 inhabitants and is the second largest province in Lombardy after Milan, has an area of 90.34 km^2 and a density of 2176.67 inhabitants per km^2. For the purposes of this project, due to time and resource constraints, we focused on a restricted area of the center and some important parking lots in other parts of the city, which will be described in depth in the second part of this paper. For the same reasons described above, we have limited ourselves to collecting data from a single week, thus a fairly short time, in the hope that we can still get a general picture. As far as transportation at the institutional level is concerned, we can mention Brescia Mobilità SpA as the company, which in collaboration with the Municipality of Brescia, Brescia Trasporti SpA and Metro Brescia Srl coordinates mobility services in order to plan, manage and promote an integrated system of urban mobility, guaranteeing an efficient, safe, comfortable service, attentive to users' needs and oriented as much as possible to respect the environment and the territory. The company coordinates more than 13,500 parking spaces in the facility and about 5,000 on-street parking spaces regulated by parking meters. It manages more than 400 rental bicycles for 92 city locations and is also responsible for surveillance, traffic and security. Since the early 2020s, Brescia has also collaborated with A2A Energy Solution and A2A Smartcity to install electric car parking pillars and stalls. This technology relies on the installation of parking sensors and the LoRaWAN network to collect real-time information by encouraging only enabled vehicles to park. The parking lots that will benefit are Vittoria, Arnaldo, Station, North Hospital, Fossa Bagni, and Market Square and count a total of 6 charging stations, 12 charging stalls with related 12 parking sensors. An agreement has currently been signed between the Chinese company Zte and the province of Brescia to launch a smart, effective and sustainable city project. Among the projects is "Smart Roadside parking," the key element of which is an app that shows users, in real time, the status of available parking spaces by showing them the quickest route to the parking areas with a reduction and traffic by 30 percent. In addition, users can extend their dwell time directly from the app, while local governments could triple toll revenues, adjust fare bands based on traffic peaks, and constantly monitor parking areas.

1.2 Problems and impacts on the city

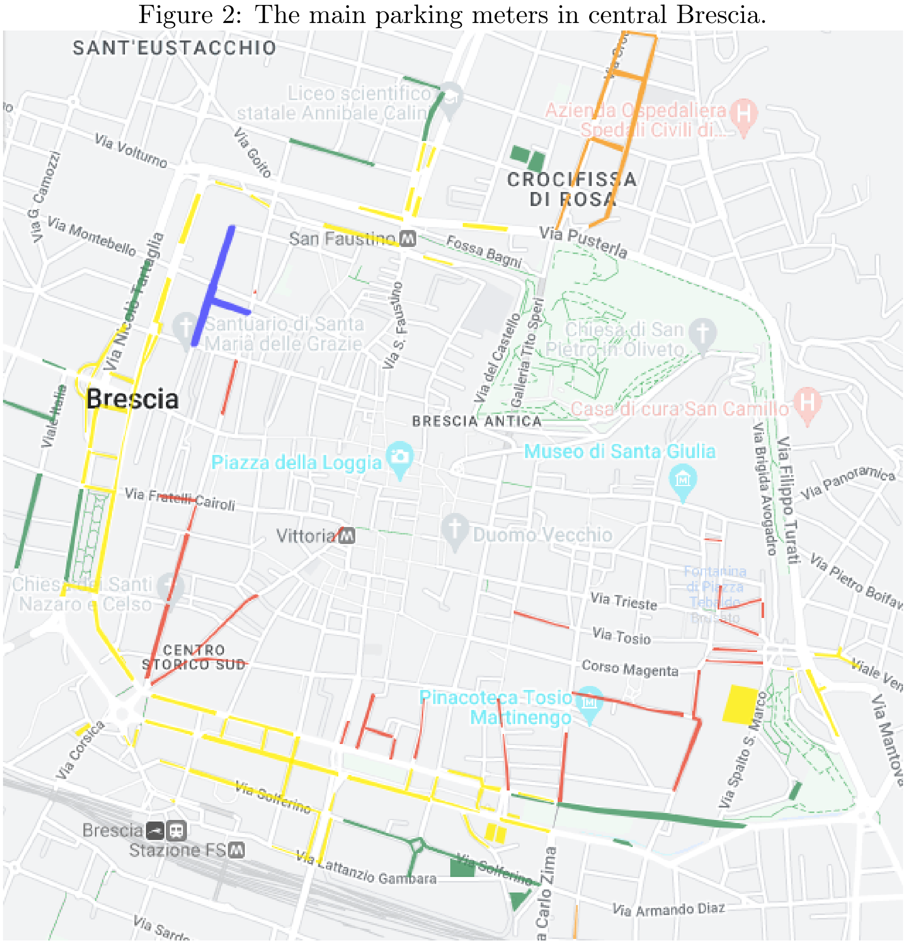
1.2.1 The organization of parking spaces

The city of Brescia has a comprehensive system of structured parking facilities, including 25 underground and surface parking areas with more than 13500 available parking spaces. The entire system enjoys clear regulations and is divided into different tariff zones. There are also four interchange parking lots where users of public transportation services (metro and zone 1 buses) can park their cars for free (Prealpino and Poliambulanza) or at reduced rates (Casazza and Sant'Eufemia-Buffalora). Those who park their cars in the latter two parking lots have two free tickets (one round trip and one return) to use for free on buses and metro. In some parking lots it is possible to pay through Telepass while maintaining the same rate system, or by using the Park City Card, which offers a 50 percent discount on the hourly rate of all parking lots and most of the parking meters in the municipality managed by Brescia mobilità. In addition to the park-and-ride lots, there are the Massimo D'azeglio and Piazza Mercato parking lots, which are reserved only for residents or subscribers. The parking lots in Piazzetta B. Crode and Via San Domenico are located in a fairly central area and differ from the others because they are fully automated. In fact, they have a ramp at surface level, on which the car must be placed, and a structure underneath that is managed totally autonomously and without the need for any intervention by the user. This type of parking allows the citizen to save time spent parking and also saves a lot of surface space by making it possible to exploit the surrounding area for social purposes.

Figure 1: The main parking lots operated by Brescia Mobility.

The parking meters are divided into 3 fare zones as shown by the map below.

Figure 2: The main parking meters in central Brescia.



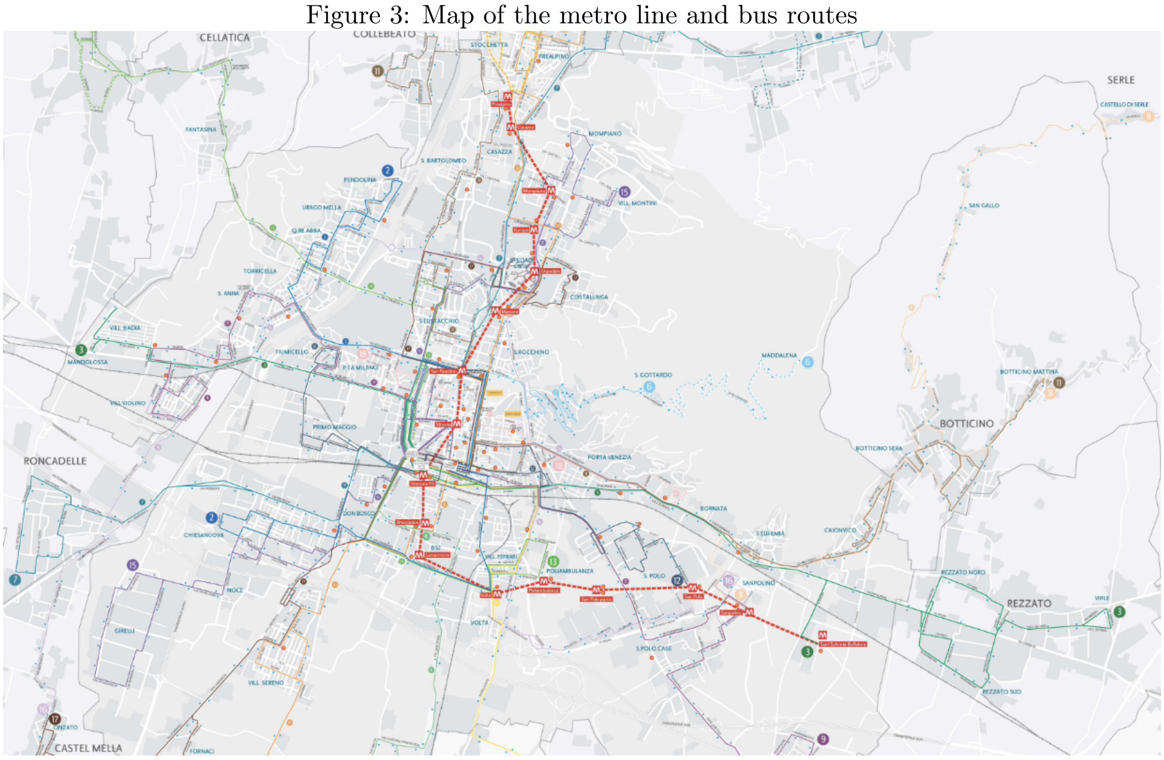
Perfectly replicating the idea of platform city, Brescia makes use of platforms such as Apps and banking circuits to manage payments by accustoming citizens to new and innovative logics that silently shape the city. The payment methods adopted are:

1. ParkMan: a system that allows payment only for actual parking time.
2. Drop Ticket: similar to the previous method but using "Parking Packages" of various amounts.
3. Telepass pay: charging for actual parking minutes by simply using the Telepass App.
4. Easy Park: allows you to control and extend your car's parking time regardless of where you are. It offers a "pay-as-you-go" solution that charges a fixed fee upon use ranging from 0 to 39 cents, or a monthly solution at €2.99.
5. MooneyGo: allows you to define the actual duration of parking and, if necessary, extend it through the App by paying only for the actual minutes of use.
6. PayByPhone: allows to pay the ticket directly from the phone via App.

1.2.2 The relationship with other transportation services

Still in line with Durkheim's idea of connectedness, the city of Brescia has thought of a rich and well-organized transportation line to allow for an increasingly less problematic road system. The public service covers the city of Brescia and 14 neighboring municipalities and is operated by Brescia Trasporti SpA in coordination with the City of Brescia and the Temporary Association of Enterprises. It provides a bus service operating 365 days a year with a variable service depending on the routes and days of reference covering a time span of about 19 hours on weekdays (5 a.m. to 00.45 a.m.) and about 18 hours on holidays (6 a.m. to 00.45 a.m.). The metro service, last in terms of time, integrates seamlessly with the rest of the city's services. It currently consists of a single line that connects the city from north to southeast and is one of the top alternative mobility services in the entire city's transportation system. The metro runs daily from 5 a.m. to 00 a.m., extending service by an hour on Saturdays. The cars run every 8 to 10 minutes, except at peak times on weekdays, passing every 4 minutes.

Figure 3: Map of the metro line and bus routes

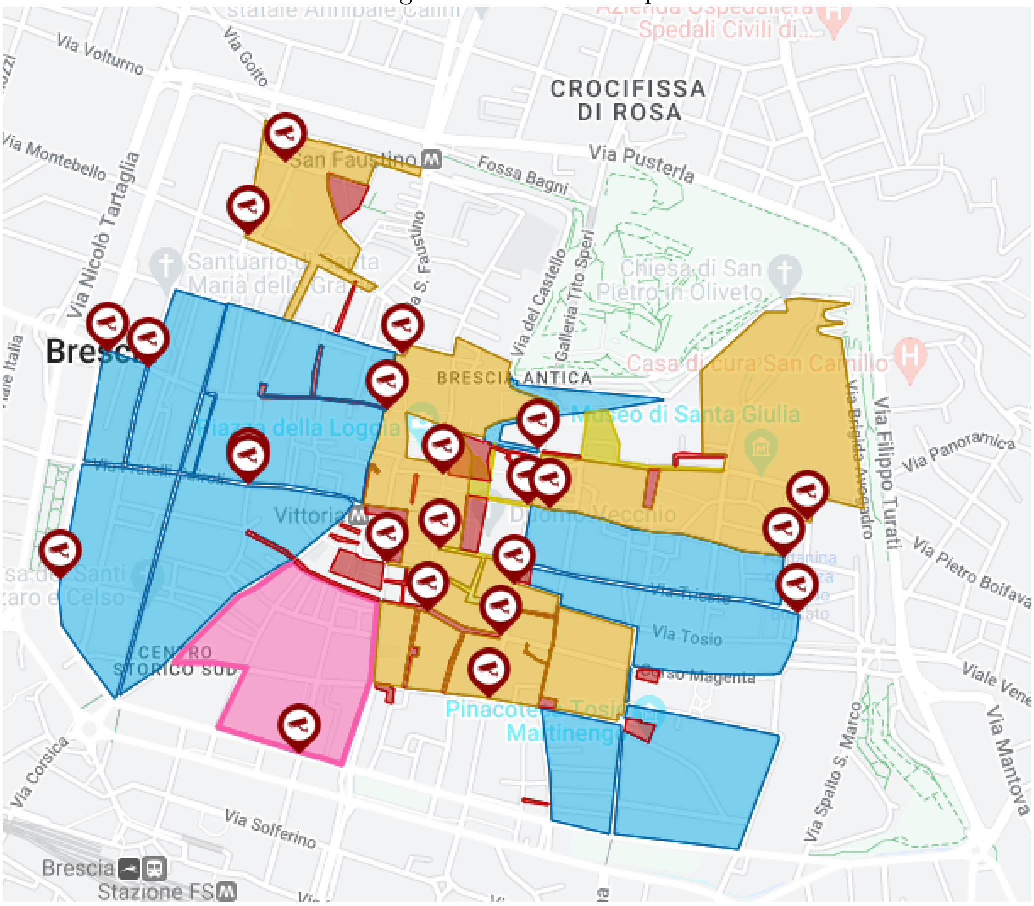


In addition to the bus and metro service Brescia has rental services for bicycles (BiciMia), electric scooters (E-Scooter Sharing) and electric cars (e-Automia) to get around the city.

1.2.3 ZTL area

The Limited Traffic Zone (ZTL) is an area in the historic center where access and circulation are restricted to particular categories of users and vehicles. There is also a pedestrian-privileged ZTL within it, which includes the entire area of museums and the historic center. The entire ZTL area is video monitored by special cameras at each of the 23 access points.

Figure 4: ZTL area map



1.2.4 Main attraction

Most of the larger parking lots monitored by Brescia Mobility are located in the historic center near important buildings and attractions in the city. Among the most frequented places we can include the University of Brescia and the Catholic University, various historic churches, Piazza loggia and Piazza Vittoria usually frequented for shopping and nightlife, museums among which the best known is Santa Giulia, the castle, and much more. The downtown streets also include many businesses and banks that keep the city center alive throughout the week. The others reported are located near the hospital garrisons, the station and the Freccia Rossa shopping center.

1.3 Indicators and possible solutions

1.3.1 The dimensions of the smart city: Lombardi's vision

In 2012 Lombardi argued that smart cities depend on 5 fundamental dimensions that we believe are sufficient to describe Brescia and, in particular, parking management. Intelligence is the first factor that we recognize as foundational relative to the organization of the urban transportation system. The protagonists of this evolution have allowed the city to grow very quickly by integrating services and innovations that have allowed the city to be increasingly competitive. Sustainability has always been the basis of all thinking. Unfortunately, Brescia is one of the most polluted cities in Italy and Europe, but from a transportation point of view many steps are being taken. In addition to the introduction of the metro, which makes travel easier, a sharing service of bicycles, mopeds and electric cars has been introduced, which aim to further reduce pollution. Plans are also beginning to be made for a streetcar service that will also benefit the city system. Innovations in urban planning have been equipped with all the amenities available to date to improve and facilitate the lives of citizens and users. All this was carried out not forgetting the neighboring towns while also centering the last dimension, urbanization, defined by the author.

1.3.2 Smart city indicators: Deloitte City Mobility Index

In 2020, Deloitte, a major consulting firm operating in a wide range of sectors, redefined indices on mobility because they claim that in recent years many aspects regarding the mobility of cities have changed and there have been various problems with the data. For this reason, we decided to try to define the condition regarding parking and traffic in Brescia by taking a cue from the indicators they proposed. The research topics covered were divided into three main categories:

1. Performance and resilience. Cities must have efficient and reliable mobility systems, they must offer integrated transportation modes making the system safe by minimizing congestion or malfunction. Brescia from this point of view is a state-of-the-art city in that, as described above, in addition to cars there are metro, various bus routes and various sharing systems that work in perfect harmony. From TomTom data we also know that on average it takes 10 minutes to travel 10 km by car with an annual expenditure of 88 hours per year, a fuel expenditure of 654€ spent and an emission of 802 kg of carbon dioxide. With these figures, Brescia ranks 350th nationwide, winning a good position.
2. Vision and leadership. Every innovation must be deeply thought out, must have well-defined goals with ad hoc investments and involving collaboration among various actors. Environmental problems must become increasingly central, not only to be minimized but to be able to define new paradigms.
3. Service and inclusion. City mobility must be within everyone's reach and be a pleasant and safe environment for all users.

Brescia in terms of performance and resilience is a city at the forefront in that, as described above, in addition to cars there are the metro, various bus routes, and various sharing systems that work in perfect harmony. We also know from TomTom data that on average it takes 10 minutes to travel 10 km by car with an annual expenditure of 88 hours per year, a fuel expenditure of €654 spent and an emission of 802 kg of carbon dioxide. With these figures Brescia ranks 350th nationwide, winning a good position. There seems to be a clear vision with respect to next steps. Air pollution is high with a moderate PM_{10} level of 34 so environmentally there is still work to be done but there are initiatives in this regard. City mobility is quite accessible and safe for users especially during daylight hours.

1.4 Ethical and social implications

1.4.1 Characteristics of the population and access to the platforms

The majority of the population in Brescia is adults (62.6%) between the ages of 15 and 64, which makes them the target audience for our analysis. The most commonly used means of transportation in the city is still the car, used by 67.7% of the population, with equal usage of other modes of transportation such as walking, cycling, buses, and trains at 8.1%. The motorization rate seems to confirm these figures, as there are approximately 61 cars per 100 residents. Of course, not all users of parking lots or public transportation are residents; in fact, many of them come from nearby provinces and are commuters. Very often, these commuters drive to the nearest parking lot or take the train to reach the city and then rely on public transportation to move around. Referring to the cost of transportation, there don't seem to be significant price differences for single tickets, but there are large differences in annual subscriptions: a daily ticket for the metro or bus costs around €3, while an annual pass covering the entire city costs approximately €480. On the other hand, parking costs range from €2 to €5 for a daily ticket, and can go up to €1500 for a reserved parking spot on an annual basis. Access to payment methods is quite varied and allows people from all income groups to use them without any problems. However, in recent years, there has been an increasing emphasis on the use of digital or automated payment systems.

1.4.2 Increasing control

All the smart parking systems seen so far have many positive aspects but also bring along issues, one of which is control. As mentioned earlier, these systems allow the installing authorities to constantly monitor the data they receive through sensors and camera systems, further threatening privacy and increasing control. In fact, not only could they decide where to park the user, but they could also understand their habits, monitor the parking duration, promptly enforce rules in case of violations, and much more. One can expect an improvement in parking management, traffic flow, and reduced parking time, but an increase in control. Therefore, institutions should address these issues as soon as possible to prevent abuse. Currently, Brescia is experiencing a high number of cybercrimes that could seriously undermine the safety of its citizens and users.

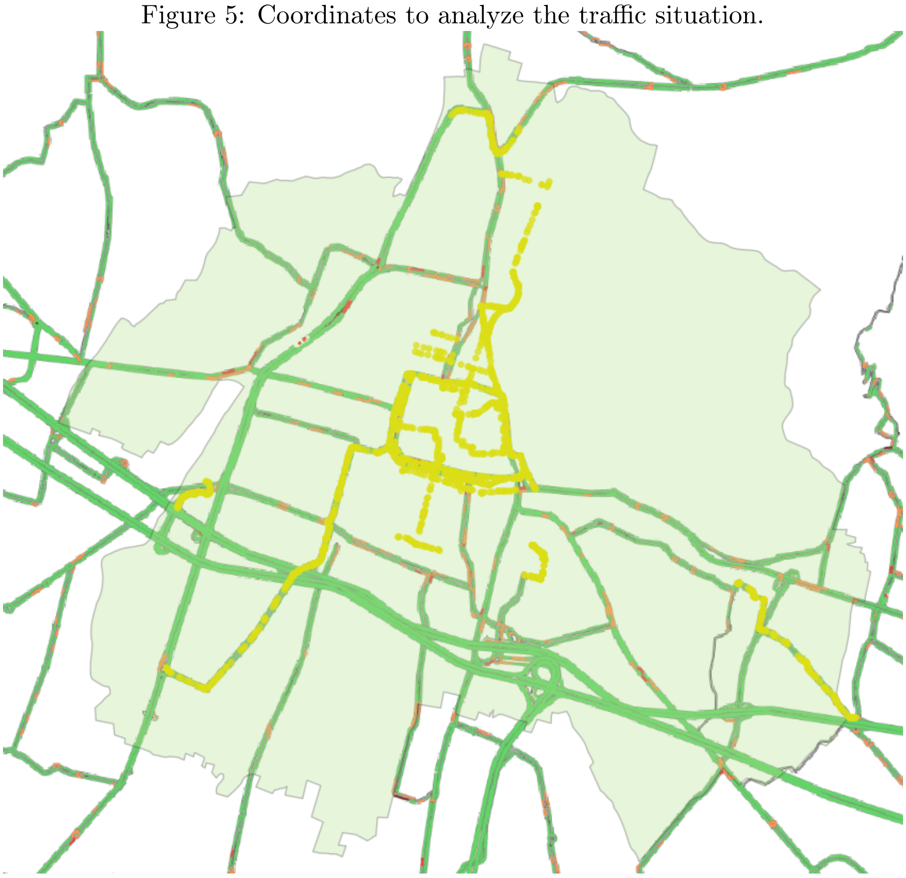
2 Data Analytics, Optimization and Policy Suggestions

2.1 Selection and cleaning of datasets

2.1.1 A brief description of datasets

The first phase in creating the datasets involved selecting the parking lots to be considered for analysis. Unfortunately, this process was somewhat obligatory, as the only available source for accessing analytical data on parking lots in the Brescia area was Brescia Mobilità. Within the "parcheggi in struttura" section, there is a table containing data on total parking capacity and the number of available spaces for each facility located in the municipality of Brescia, which is updated in real-time. It was decided to utilize this data, which was obtained through a scraping function activated every 6 minutes using Raspberry. At the conclusion of this process, 25 parking lots were selected, namely: *Piazza Vittoria, Goito, Ospedale Nord, Ospedale Sud, D'azeglio, Fossa Bagni, Randaccio, Piazza Mercato, Freccia Rossa, San Domenico, Benedetto Croce, Stazione, Palagiustizia, Crystal, Arnaldo Park, Casazza, Sant'Eufemia Buffalora, Autosilo 1, Prealpino, Poliambulanza, Palaleonessa, Stadio, Ospedale Poliambulanza, Castellini, Apollonio, Crystal Superficie*. The data obtained through scraping was then concatenated into a unified dataset in order to perform aggregated analysis over time. In addition to parking data, the analysis work also required traffic information to verify any potential correlation between road congestion and congestion within the parking area. The selected data source for traffic was TomTom Developer, which provides real-time data on speed and travel time for specific roads through its API, as well as additional descriptive information about the routes. The roads analyzed were those adjacent to the parking areas, in order to have an overview of the traffic that influences the surrounding area of the parking lot. Since access to past data was not possible, it was necessary to create a Raspberry instance to proceed. In this case as well, requests were forwarded every 6 minutes to obtain real-time values. Once the responses to the requests were obtained, they were added to a dataset to collect all the information and make it available for aggregated analysis as well. Furthermore, the request provided a list of coordinates pertaining to the roads where traffic-related fields were calculated. To identify these specific roads, a file was initially created, containing all the coordinates obtained from the initial requests for each parking area. Subsequently, this data was plotted within QGIS, generating the results shown in the figure below.

Figure 5: Coordinates to analyze the traffic situation.



2.1.2 Main variables

The following variables are contained within the traffic dataset:

1. *date*, refers to the full date;
2. *coordinate*, longitude and latitude of the selected point;
3. *frc*,type of road;
4. *currentSpeed*, the current average speed at the selected point;
5. *freeFlowSpeed*, the free flow speed expected under ideal conditions;
6. *currentTravelTime*, current travel time in seconds based on fused real-time measurements between the defined locations in the specified direction;
7. *freeFlowTravelTime*, the travel time in seconds which would be expected under ideal free flow conditions;
8. *Street-Name*, name of the parking lot

Instead the dataset with parking data has such variables:

1. *Parcheggio*, name of the parking lot;
2. *Indirizzo*, address of the parking lot;
3. *Posti-totali*, number of total parking spaces;
4. *Posti-disponibili*, number of available parking spaces;
5. *Data-e-ora*, refers to the date of extraction

Following the construction of the datasets, it was necessary to define some indicators that would allow us to understand the development of traffic conditions and parking over time. Regarding traffic, the following variables were introduced:

1. *traffic-index-speed*:
$$\frac{FreeFlowSpeed - CurrentSpeed}{FreeFlowSpeed}$$
This variable takes a value between 0 and 1. The higher the value, the greater the congestion on the specific road at the given moment. The free-flow speed is indicated first to obtain positive values.

2. *traffic-index-time*:
$$\frac{CurrentTravelTime - FreeFlowTravelTime}{CurrentTravelTime}$$
This variable also ranges from 0 to 1. The higher the value, the longer the time spent on the road due to traffic. The terms in this index are inverted compared to the previous one to obtain only positive values, as the current time increases in the case of traffic.

3. *state-traffic-speed*:
$$\frac{CurrentTravelTime_t - CurrentTravelTime_{t-1}}{CurrentTravelTime_t}$$
This variable describes the congestion state of traffic over time. It can take both positive and negative values. If the index is less than 0, it means that the traffic has increased between the two time points as the speed has decreased. If the index is equal to 0, the traffic remains constant. If the index is greater than 0, the traffic has decreased between the two time points as the speed has increased.

4. *state-traffic-time*:
$$\frac{CurrentTravelTime_t - CurrentTravelTime_{t-1}}{CurrentTravelTime_t}$$
This variable provides information about the congestion state of traffic in terms of time. It accepts both positive and negative values. This index has a positive correlation with the CurrentTravelTime variable. As the CurrentTravelTime increases, the index value also increases, and as the CurrentTravelTime decreases, the index value decreases.

Regarding the parking dataset, the following indicators were created:

5. *congestion rate*:

$$\frac{Postitotali - Postidisponibili}{Postitotali}$$

This index describes the percentage of parking occupancy at the given moment. It ranges from 0 to 1. A higher value indicates fewer available spaces and a full parking lot, while a value close to 0 indicates a high availability of parking spaces.

6. *turnover index*:

$$\frac{Postidisponibili_t - Postidisponibili_{t-1}}{Postidisponibili_{t+1}}$$

This variable helps understand the congestion state of a specific parking lot. It can take positive and negative values. If it has values greater than 0, the parking lot is emptying at the given time. If the index has a negative value, the parking lot is filling up. Adding 1 to the denominator prevents null values when the available spaces are 0.

As for the indices *stato-traffico-vel*, *stato-traffico-time*, and *indice-ricambio*, they were calculated using the portions of the datasets related to specific parking lots, ensuring that the values assumed by the variables were sequenced accordingly.

2.1.3 Preliminary operations

Once the relevant indicators were introduced, further operations were performed on each dataset. In both the parking dataset and the traffic dataset, a column containing date and time information when the data was obtained was added. These values were formatted in the same way, excluding the seconds, to ensure identical values between the two datasets. Additionally, two columns were included, containing only the hour and day values, which are useful for aggregated data analysis. Within the traffic dataset, road names were modified to include the name of the corresponding parking area, following the same format as indicated in the parking dataset. This was necessary to maintain naming consistency and because the road name was used as an index in creating an additional dataset resulting from the merge of the two original datasets (explained later). Furthermore, some columns that did not provide useful information for analysis were eliminated. Finally, certain parking areas were also excluded since they were extensions of others or located in close proximity to others (e.g., Crystal and Crystal superficie), which resulted in redundant data.

Regarding the parking dataset, the main modification concerned the values contained in the columns related to total parking spaces and available parking spaces: they were initially converted to integers (as they were previously text strings) and, in order to carry out some analyses, some parking lots that contained null values in the aforementioned columns were excluded. Unfortunately, the lack of values was directly derived from the Brescia Mobilità website, as they were already absent in the table from which the scraping was performed. The last operation involved creating a unique dataset that aggregated the information contained in the parking and traffic datasets. A left join was opted for starting from the traffic dataset, using the parking lot name field and the field containing the date on which the data was obtained as indices. Through this method, only the parking lots contained in the first dataset were selected. Subsequently, the parking lots that contained null values in the Posti Disponibili and Posti totali columns were eliminated.

2.1.4 Main problems

During the course of the project, we encountered several issues that partially hindered us from conducting more detailed analyses related to the topic at hand. The main problem concerned data collection. Specifically, TomTom's API limits the number of daily requests and does not provide historical traffic data. Additionally, the parking data from Brescia Mobilità excludes non-structured parking lots, whose data could have been collected through sensors inside the parking meters. For these reasons, our research focused on the data we obtained over a one-week period, limiting our understanding of any finer-grained temporal trends below an hourly level. Consequently, the results obtained from the analyses may be characterized by bias. A more comprehensive information-gathering process conducted over a longer period of time could be carried out by the public entity in order to comprehend the actual improvements to implement and the potential benefits that Smart Parking offers.

2.2 Analysis of the results

The results are presented through two modes: initially as an aggregate, to understand the dynamics of urban mobility and parking; subsequently, by considering specific parking areas, in order to visualize the behavior of variables over time. The parking areas selected for detailed analysis were chosen based on specific characteristics that allow capturing different patterns of parking area utilization. They are:

1. Piazza Vittoria parking: Located in the heart of the municipality of Brescia, this parking area accommodates a variety of user types, including workers, tourists, residents, and students.

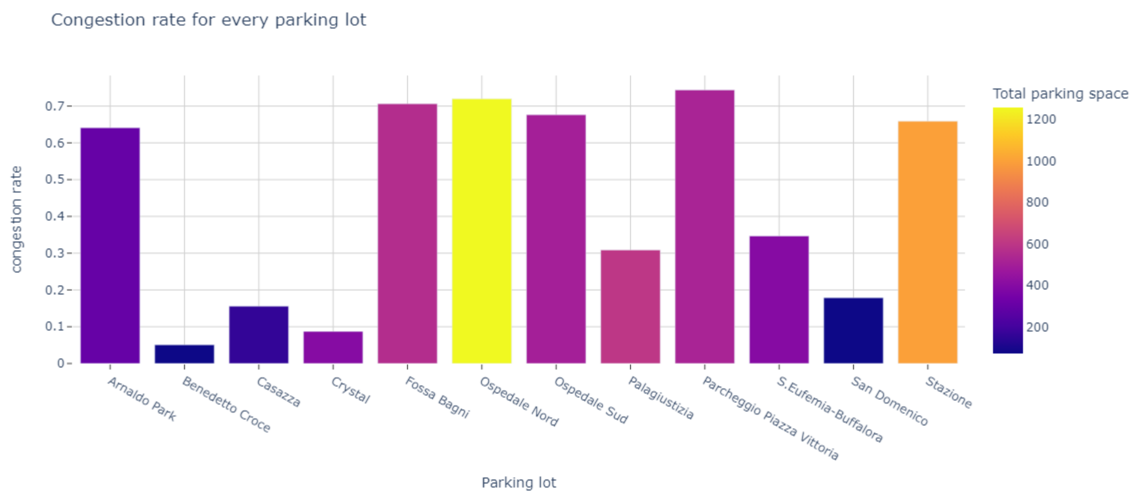
2. San Domenico parking: An automated parking facility in downtown Brescia. Studying this area helps understand how users approach a system that falls under the category of Smart Parking.

3. Sant'Eufemia Buffalora parking: Paid interchange parking located at the southern terminus of the subway line that runs through Brescia. It serves as a support facility for all users who wish to utilize the metro as a means of transportation towards the city center from the southern side of the province. Additionally, it provides a concession to the user (2 tickets for public transportation) each time it is used.

2.2.1 Aggregated analyzes and results

From the aggregated analysis of the parking dataset, it was possible to understand some trends regarding parking utilization. Firstly, Friday is the day of the week when parking lots are most congested (congestion rate = 0.439), followed by Thursday and Monday. In fact, on Fridays, the congestion rate distribution peaks between 10:00 and 11:00 (assuming a value of 0.615). However, even in the evening hours, the congestion rate remains higher than the overall global average for that time period (in fact, the average congestion rate globally at 21:00 is 0.403, while on Fridays, the average rate is 0.443). On the contrary, Sunday is the day of the week with the lowest congestion value in the parking lots (0.318), with the congestion peak occurring at midnight (0.375), close to Saturday. In the remaining hours of the day, there are no values above 0.36. In this case, however, it is plausible to assume that the data may not fully conform to the trend that would occur if a larger time frame were analyzed, as Sunday, May 14th, was a very rainy day. Regarding individual parking lots, Piazza Vittoria has the highest congestion rate (average congestion rate = 0.744), followed by Ospedale Nord (0.719) and Fossa Bagni (0.706). The lowest rates were observed at the Benedetto Croce (0.051) and Crystal (0.087) parking lots. These results are shown in the following graph.

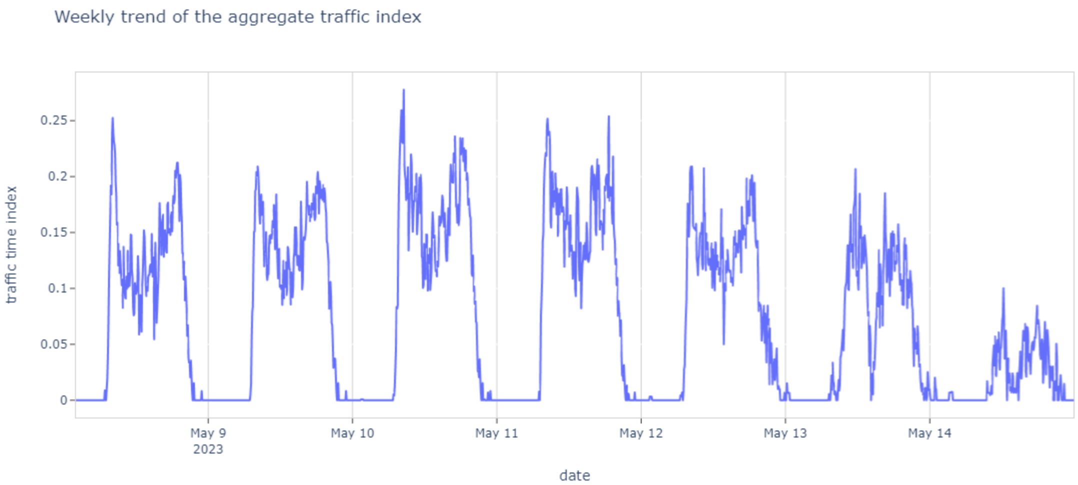
Figure 6:



It is also worth noting that the graph shows a slight positive correlation between congestion rate and parking size, indicating that the latter has been designed to accommodate the influx of vehicles, given its strategic location. The results obtained from the turnover index data are only significant when analyzed based on the time of day (see the underlying graph). The most critical hours are in the morning between 08:00 and 09:00 (with relatively low indices of -0.024 and -0.052), during which the parking lots tend to fill up the most. Conversely, a reverse trend occurs after 11:00 for the majority of the remaining duration of the day, with positive turnover index values. During this time frame, the parking lots gradually empty out. It is worth mentioning that at 14:00, the index assumes a negative value again (specifically, -0.001).

During the analyzed time period, the traffic trend (represented by the *traffic-time-index*) remains fairly consistent on weekdays, with heightened peak values at two points during the day: at 8:00 (with a global average index value of 0.397) and at 18:00 (0.496). Presumably, these values occur due to commuter traffic as workers travel to their workplaces. On holidays, however, the average traffic decreases, especially on Sundays (with an average index value throughout the day of 0.018, lower than the overall global index value of 0.072). Saturdays are characterized by a minimum peak around 14:00 (*traffic-time-index* = 0.031), surrounded by two maximum peaks (at 12:00 and 16:00). These observations become clearer when considering that a football match involving Brescia took place during this time frame.

Figure 7:



As for individual parking lots, those with high traffic on surrounding roads are Prealpino parking (0.171), Ospedale Sud (0.167), Autosilo 1 (0.153), Randaccio (0.153), and Stazione parking (0.149). It is reasonable to consider that part of the street traffic surrounding these parking lots is also composed of cars searching for parking spaces, given the functions some of them serve (Prealpino parking is designated as an interchange, Ospedale parking accommodates not only hospital staff but also patients and visitors). On the other hand, there are several parking lots with low turnover index values: Arnaldo Park (0.005), S.Eufemia Buffalora (0.001), Poliambulanza (0.001), Palaleonessa (0.006), and D'Azeglio (0.008). The reasons behind these values can be manifold: the examined roads generally experience low traffic, the parking lots are restricted to residents only and not open to the public (D'Azeglio), or the parking lots are used only on specific days of the week, resulting in less overall street congestion (Palaleonessa).

Figure 8:

Finally, thanks to figure 9, it is possible to verify the relationship between traffic indices and parking-related indices. The correlation between the *velocity-traffic-index* and the time-traffic-index is evident, as expected. However, the correlation between the congestion rate and the two traffic indices is less clear. In fact, there are outliers that are worth noting:

1. Sant'Eufemia and Arnaldo Park parking: these two parking lots show a significantly lower traffic rate compared to the congestion rate. This could imply either a regular and smooth flow of vehicles towards the parking lots or a tendency for the parking lots to fill up only at certain times of the day.

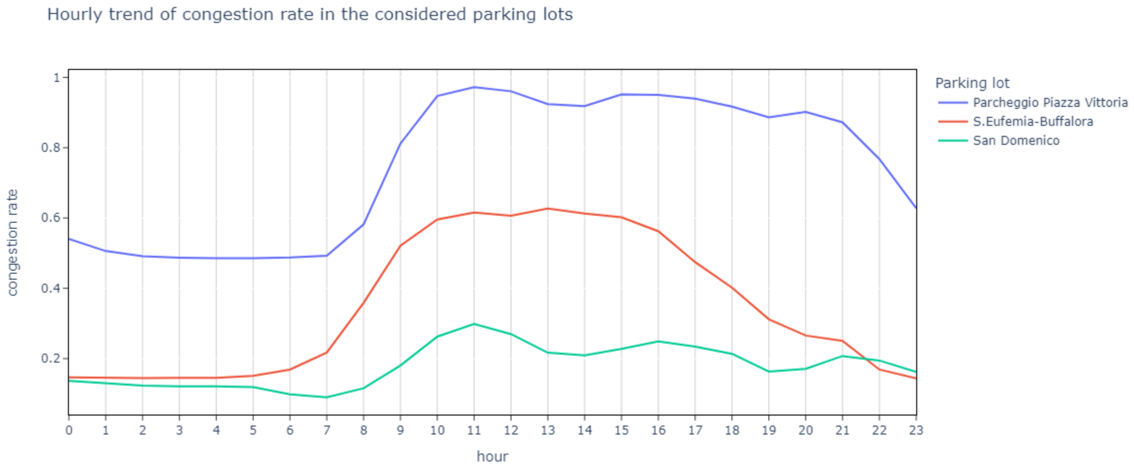
2. Casazza parking: on the other hand, this parking lot exhibits a high traffic index related to the surrounding roads but a low congestion rate. It may be located near a heavily utilized road but may not be useful as a stopping point since it is far from the users' point of interest.

Figure 9:

2.2.2 Specific parking space: analysis and results

Based on the data obtained from aggregate analyses, it is evident that the most congested parking lot globally is Piazza Vittoria (congestion rate = 0.744), followed by Sant'Eufemia Buffalora (0.347), and finally, San Domenico (0.17). Analyzing the specific days when the parking lots experience high congestion rates, it is observed that both Piazza Vittoria (0.81) and San Domenico (0.235) reach their maximum rates on Saturdays, while for Sant'Eufemia, it is on Mondays. Examining the hourly trend of the congestion rate, as shown in the graph, it is noticeable that Piazza Vittoria exhibits the most consistent trend, maintaining a high value between 10:00 and 20:00. On the other hand, Sant'Eufemia experiences a congestion rate above 0.45 during the timeframe of 09:00 to 17:00, which is typical working hours. Lastly, San Domenico peaks at 11:00 and remains relatively constant during the remaining hours.

Figure 10:



These values seemingly reflect the function performed by the parking lots (fig x). Sant'Eufemia, in fact, serves as an intermodal parking lot primarily used by workers who can leave their cars there during working hours and utilize public transportation. Piazza Vittoria is the most central parking lot, typically full, especially on weekends when people want to explore downtown Brescia. San Domenico is also centrally located but appears to be less frequently used, except on holidays when there is potentially higher influx of citizens towards the city center. It is also interesting to note that in all three parking lots, especially Piazza Vittoria, there is a positive congestion rate even during nighttime hours. This implies that they are also utilized as areas where residents or external workers from Brescia leave their cars overnight. To analyze the turnover index trend, a specific day was chosen (Monday, May 8th). By examining this single day, it is possible to utilize data with maximum time granularity, capturing the actual trend of the index.

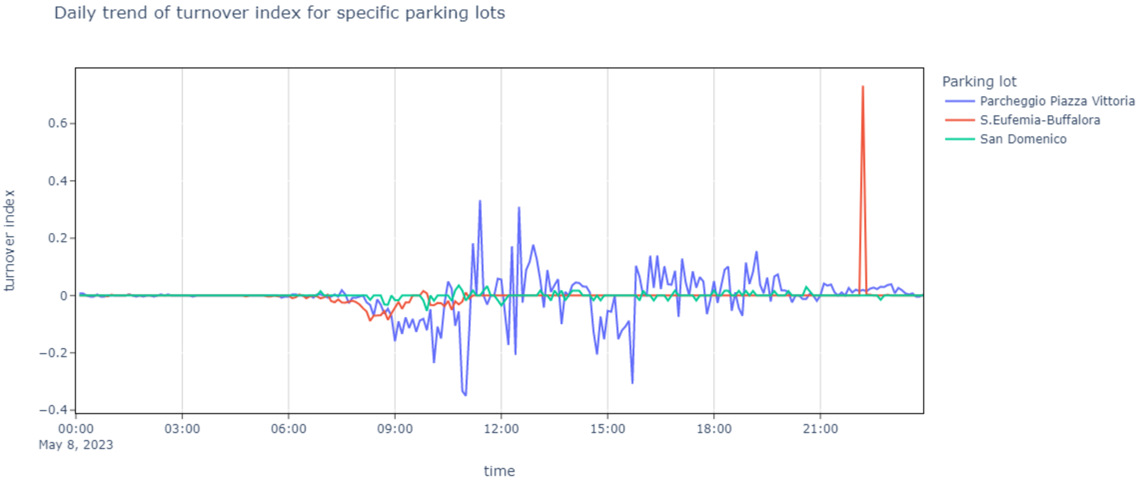
The results are as follows:

1. The trend for San Domenico remains relatively constant around 0 throughout the day, indicating low utilization with few car turnovers inside.

2. Similarly, for Sant'Eufemia, the trend is consistent over time, with the peculiarity that at 08:00, the index takes a negative value (-0.08) and remains negative until 11:00. It then stays neutral until 22:00, when it reaches a peak with an extremely high value (0.73).

3. On the other hand, for Piazza Vittoria, the trend is highly irregular, with significant fluctuations and changes in direction, indicating a constant turnover of cars in the parking lot throughout the day.

Figure 11:



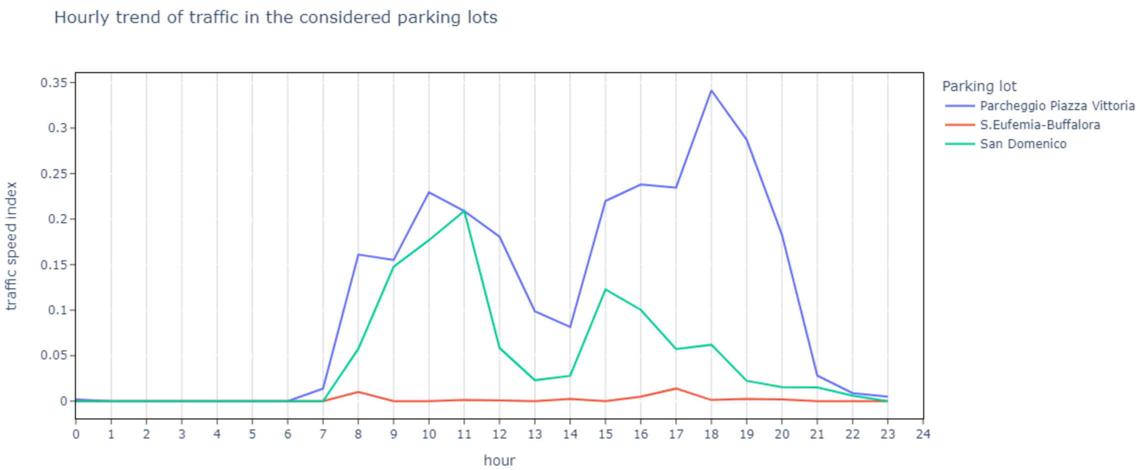
Regarding traffic, the parking lot surrounded by the busiest road is Piazza Vittoria (*traffic-index-time* = 0.113), followed by San Domenico (0.046), and finally, the parking lot with a lower average traffic index is Sant'Eufemia (0.001). These values are somewhat confirmed by the hourly trends of the traffic indices:

1. Piazza Vittoria exhibits a trend with three critical points, where there is a change in direction: at 10:00 and 18:00, two peak maxima are identified, while at 14:00, there is a minimum peak (0.081). This partially reflects the previously analyzed congestion rate trend of the parking lot.

2. San Domenico partly follows the trend shown by Piazza Vittoria but with lower values. The peak maximum in this case occurs at 11:00 (with a value of 0.20).

3. Sant'Eufemia, on the other hand, demonstrates a constant trend consistently close to 0. This indicates, as previously highlighted, the absence of traffic on the surrounding roads of the parking lot.

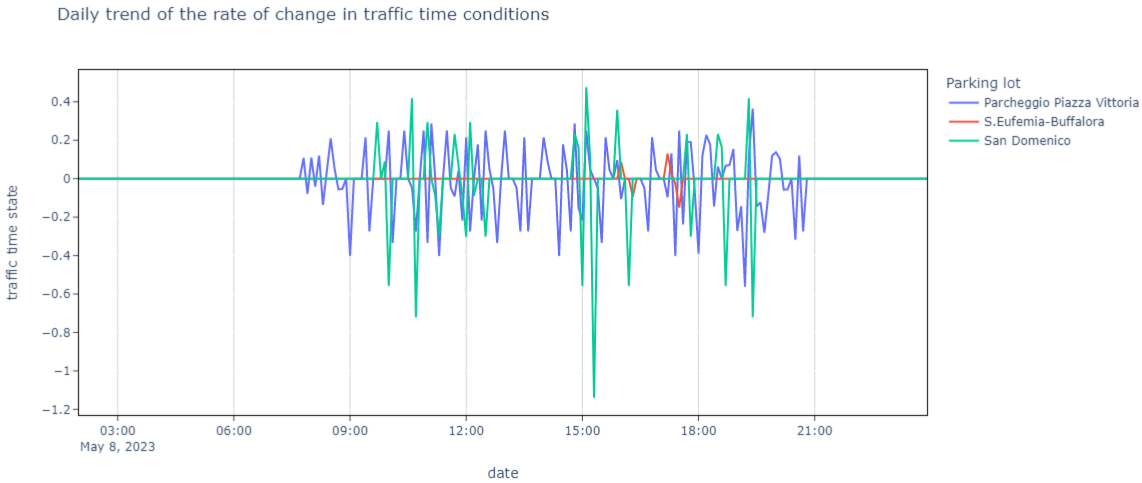
Figure 12:



To analyze the data related to traffic conditions (considering the *traffic-state-time indicator*), only the data recorded on May 8th are taken into account to capture the real trend with maximum granularity. In the analyzed instance, the most irregular behavior, with significant fluctuations, is observed in the trend of the San Domenico parking lot. It reaches the absolute minimum point between 15:00 and 16:00 (-1.14), indicating a significant decrease in traffic levels compared to the previous measurement. Similarly, the Piazza Vittoria parking lot exhibits an irregular trend, but with less pronounced fluctuations compared to the previous case.

Instead, it shows more frequent fluctuations, indicating a state of continuous alternation in the flow of cars on the road. The trend of the index for the Sant'Eufemia parking lot, on the other hand, remains consistently around 0, with slight dips between 16:00 and 18:00. Therefore, on the selected day, the parking lot does not experience traffic situations.

Figure 13:



2.2.3 Impacts on the city

Considering the overall results obtained from the analyses, it is possible to understand the impact that parking structures have within the city. Firstly, the distribution of the congestion rate among parking lots is not uniform. Some parking lots are more heavily used while others are less utilized. This is certainly influenced by the strategic location of the parking lot, determined by the surrounding activities and places. Another factor that may influence this phenomenon is the parking fees and the ease of access (for example, the San Domenico parking lot is automated, requiring precise positioning of the car on the carriage, which is more complex compared to simply driving into the structure).

Furthermore, it is evident that there are specific hours during which there is high influx and turnover within the parking lots, leading to congestion. These hours correspond to working hours and also the lunchtime period when the parking lots tend to empty out. Work is a significant influencing factor, as indicated by the presence of a consistently higher average congestion rate on weekdays compared to weekends. These results are further accentuated by the data calculated on the traffic of the surrounding roads, with peak congestion occurring during working hours. Some parking lots exhibit trends consistent with the congestion data observed within their premises. However, in some cases, there is no such correlation, indicating that certain parking lots are located near roads that serve as transit routes to workplaces (thus experiencing high traffic during peak hours) but are not in close proximity to them. For example, the Casazza parking lot, despite being located next to a metro station, exhibits a significantly lower congestion rate compared to the traffic rate.

By analyzing the statistics of individual parking lots, further information can be understood, as seen from the results of the three parking lots under analysis. The Piazza Vittoria parking lot is likely the most utilized parking facility in the center of Brescia, as indicated by the calculated indicators. It is also a clear example of how traffic can be caused by the search for parking spaces. In fact, the traffic rate increases exponentially only after the congestion rate of the parking lot rises. This is further accentuated by the morphology of the road, which has the parking lot as the only stopping point. Regarding the Sant'Eufemia parking lot, it follows the behavior of a transit parking lot primarily used during working and school hours. However, the utilization of this parking lot should be further encouraged since it never reaches high congestion levels and is located on a road with low traffic. Focusing on the San Domenico parking lot, it is evident that despite being designed as a Smart Parking system, it is poorly utilized by users. The data shows that the parking lot is surrounded by roads with low traffic levels and never experiences congestion. There could be multiple reasons associated with this phenomenon, such as inconvenience in usage, issues with payment methods, or excessively high tariffs. Despite this, its location is convenient for quickly reaching the city center. Therefore, considering the perspective of diverting a portion of traffic from a nearby parking lot, it should be more valued by the municipality of Brescia. Bringing forward the analysis for each parking lot would provide insights into details and specificities that cannot be captured by aggregated data.

3 Conclusions and future developments

The situation outlined by the conducted study has demonstrated how Brescia remains a significantly underdeveloped city in terms of the Smart Parking system. However, it presents excellent potential for progress in this direction (as seen in the initiative undertaken by A2A). This process can also rely on the support of the public mobility network, which extensively covers the entire municipality, thus providing an excellent complementary service.

Given the industrialized nature that characterizes the city, it will be crucial to conduct a study on the main routes and roads used by workers. They partially influence the traffic, especially during peak hours, in the vicinity of parking areas, thus affecting access for other user categories as well. Finally, one of the most profitable projects to consider in managing parking congestion is the development of a study to understand how to divert traffic that arises in parking circumstances through its redistribution to neighboring parking areas. The future implementations that we deem essential involve the creation of an app capable of displaying real-time traffic and parking congestion status, including relevant indicators to determine the turnover rate over recent time intervals. This would enable recommending nearby parking areas with more available spaces. Furthermore, the integration of a detection system for metered parking would contribute to greater control over the congestion rate, allowing for cross-referencing studies with data from "structure" parking lots to redefine the management system for these spaces.

References

@articleIEEE, abstract = Insufficient parking capacities trouble almost every city today. The demand for parking space is considerably higher than the supply and since creating new parking facilities is economically very challenging, it is important to look for ways to make the most of the existing parking space, especially as on-street parking is regarded. The aim is therefore to apply systems for efficient use of existing parking space, focusing in particular on monitoring the occupancy of parking space and providing the information to drivers. A large-scale pilot project was implemented in Uherské Hradiste in the second half of the year 2017. It involved testing of features and subsystems for parking management as well as monitoring the turnover and occupancy of parking spaces in the city. This article describes the course of the pilot project, the employed detection and action elements of the system and also deals with the evaluation and the outcomes of the pilot testing., author = Jan Šilar, Jirí Růžička, Zuzana Bělinovà, Martin Langr, Kristýna Hlubučková, title = Smart parking in the smart city application, year = 2018

- https://www.bresciamobilita.it/
- https://www.qgis.org/it/site/
- https://www.autoappassionati.it/bosch-smart-parking-sistema-parcheggio-intelligente-come-funziona-cose/
- https://www.gruppoa2a.it/it/cosa-facciamo/smart-city