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SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Executive Summary of the Thesis

The 15 Minutes City: a case study of chrono-urbanism applied to the Lombardy railway stations

Laurea Magistrale in Mobility Engineering

Author: Marco De Donno

Advisor: Prof. Claudio Somaschini

Co-advisor: Ing. Fiorella Sciangula

Academic year: 2020-2021

1. Introduction

The increased awareness towards environmental issues and a greater attention in the rethinking of the structure of our cities is paving the way to a series of actions that aim at the creation of more livable, accessible and sustainable urban environments. The creation of a "15 minutes city" has been put in the plans of major local authorities around the world, with the vision of creating a city in which the citizens are able to access all the services they need to live, learn and thrive within a distance that would not require them more than 15 minutes of walking [1]. The concept, therefore, focuses on the necessity to provide proximity-based services to the inhabitants by reviewing urban policies and establish new development models that grow within this concept of chrono-urbanism. These reshaping of city spaces is believed to positively promote social interaction, citizen participation and to address the private-car dependency by emphasizing the proximity of basic services. The general framework of a "15 minutes city" therefore focuses on the experience of the citizen that is expected to find most of the needed services within a reasonable distance.

This thesis aims at integrating this concept by proposing a shift in the analysis, focusing the attention on the role of the railway stations. The station is now not only seen as a potential mobility hub, where users can find different options of transport and easy exchange between them, but also as a "second door of the house", from which the citizen can start new activities and that therefore expects to find in the near vicinity of the station most of the services that he or she needs. The thesis has been developed through an internship experience at Rete Ferroviaria Italiana (RFI), that provided the essential technical expertise necessary to lay out the work.

The available literature offers a quite extensive exploration on the theme 15 minutes cities [2], describing the theoretical formulation of the concept and providing practical applications on real case studies. The state of the art includes several examples of cities around the world that implemented or are planning to implement some policies following the concept of a 15 minutes quarter, promoting the birth of proximity services and trying to reorganize the urban environment to facilitate pedestrian and cycling mobility, as well as rationalizing some precious public spaces of the city that are today dedicated to private cars. Some remarkable examples are Paris - with

La Ville du quart d'heure project, Barcelona - with the *Superblock* organization, as well as Milano with a plan called *La città a 15 minuti*.
Nevertheless, virtually no literature is available today focusing the concept of the 15 minutes city around the rail station environment. This approach can therefore be considered new and potentially helpful to discover a new dimension of living and using the train station.

2. Objectives and workflow of the work

The objective in which this thesis work is inserted is the study of the role of the rail station today and its potential role in the future, considering what is the field of action of the railway infrastructure manager and of the public administration respectively. Although these two actors are distinct in their functions and responsibilities, a close cooperation between them is required to achieve common goals and plan effective interventions. The thesis therefore aims to show a methodology of collecting, managing, identifying and elaborating data on the Lombardy railway stations and on the cities those stations lie in, with the purpose of understanding the the main opportunities of development within the concept of hyper-proximity. Different reasons have fostered the research in this direction, such as the transformation of the station in a better polyfunctional node, the increase of the value felt by the user in using the spaces of the station and the attraction of more users that today rely on the usage of private cars that, after effective interventions on the accessibility of the station, may find the train option as a viable alternative.
The case study involved the analysis of all the Lombardy railway stations managed by RFI, in order to understand where the main opportunities of development in terms of accessibility and urban regeneration are present. The methodology of the work was articulated into five main different steps. First of all, the collection of data regarding the offering of services around the stations. Secondly, a clustering of the categories of activities present within the 15 minutes walking basin and the development of a quantitative method to rank the different kinds of urban functions. Third, the computation of a synthetic score to translate the attractiveness of each stations into a numerical term. Fourth, an integration of additional data regarding the habits and the mode of access of real users was carried out, to better understand the usage patterns of travellers. Finally, a subset of regional stations was selected to be studied in a deeper way, proposing some analysis of the spatial organization of the stations surroundings through the GIS software. Moreover, a focus on the Lombardy stations that are identified as important poles for the health and educational sector is proposed.

3. Data collection and database construction

The work first relied on the gathering of data from several public and proprietary datasets with information regarding the Lombardy rail stations and the offer of services of each regional city, that allowed to merge all the sources in a unique database, simplifying the management of information and their subsequent elaborations. In particular, this data collection aims at understanding the socioeconomic characteristics of the urban environment in which the stations are included, as well as the number and the typology of services located within a 15 minutes walking distance. Moreover, a complete visualization of the data is provided within the GIS platform.

4. Data classification and analysis of the stations

The created database undertook a first clustering process, merging the different typologies of activities present in the cities into six main categories, to allow an easier and more understandable management of the data.
The following activity saw the proposal for a ranking methodology that would allow to establish an order between the different types of activities present in the urban context. Such a technique falls within the perimeter of Multi-criteria analysis, therefore considering a broad spectrum of inputs to determine a ranking of priorities. The Multi-criteria method that has been used is the Analytical Hierarchical Process (AHP), that allowed to rank in a quantitative and rigorous way the relevance of the different services found around a railway station.

4.1. The AHP method

The AHP method is based on the pairwise comparison between the different variables under study, in order to establish a relation among them [3]. In each pairwise comparison, a preference index is chosen based on the importance of the first variable on the other one. The method proposes a fundamental scale from which the preference indices should be selected from. The decision maker confronts pairs between n alternatives $\{A_1, A_2, \dots, A_n\}$ to obtain a comparison matrix A, where the element a_{ij} shows the preference weight of A_i obtained by comparison with A_j.

$$\mathbf{A} = \begin{pmatrix} 1 & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2j} & \dots & a_{2n} \\ \vdots & & & & & \\ 1/a_{1j} & 1/a_{2j} & \dots & a_{ij} & \dots & a_{in} \\ \vdots & & & & & \\ 1/a_{1n} & 1/a_{2n} & \dots & 1/a_{in} & \dots & 1 \end{pmatrix}$$

In the specific case of this work, the alternatives are represented by the the six macro categories of services that are found around the studied stations and by the two basic variables that describe the urban surroundings, namely number of inhabitants and workers. The AHP method therefore aims at establishing a rank of importance between the categories, assigning in the end a numerical weight to each variable, obtained by further elaboration and normalization of matrix A. The final output of the process yields a final vector of weights, as shown in Table 1.

Service category	Weight
Inhabitants	0,243
Jobs	0,243
Education	0,152
Health	0,152
Tourism	0,103
Culture and Entertainment	0,051
Services to the citizen	0,036
Free Time and Leisure	0,020

Table 1: *Vector of weights from the AHP method*

4.2. Scoring the stations

The following step was the development of a scoring system to assign to each station a numerical value related to its attractivity potential. The computation of the score has been designed as the weighted sum of the number of services present in the 15 minutes walking basin around the station - split into their respective categories - and the weights showed in Table 1, generated through the AHP method. In mathematical formula, the score of each station is obtained as

$$Score_{station} = \mathbf{s} \cdot \mathbf{w} = \sum_{j=1}^{8} s_j \cdot w_j$$

While this numerical value is a good proxy of the attractiveness of the surrounding area in which the station rises, it does not consider the diversification in the offering of services. In other words, a high score does is not necessarily caused by a uniform contribution of all the typologies of services, but can possibly be the result of a really high presence of only certain kinds of activities. To address this issue, two parameters where computed. The first is the *relative standard deviation*

$$\sigma^* = \frac{1}{\overline{x}} \sqrt{\frac{\sum_i^N (x_i - \overline{x})^2}{N-1}}$$

which assesses the irregularity of the partial values that form the overall score of the station. The second parameter is the *skew*,

$$Skew = \frac{\sum_i^N (x_i - \overline{x})^3}{(N-1)\sigma^3}$$

that allows to calculate how skewed or uneven are the partial scores that each station obtains. The skew is an index that yields a measure about the absence of symmetry in a distribution. A skew value close to zero indicates an even spread of values. A value far from zero, instead, is an indicator of a strong asymmetry in the presence of services, where few categories are drastically more relevant than the others.

The score, next to the two steadiness parameters, allows to rank all the stations of Lombardy region by an attractiveness and stability point of view [Table 2].

Station	Score	Skew	σ^*
Milano Centrale	49,6	1,15	1,01
Milano Porta Venezia	49,6	1,41	1,06
Milano Repubblica	46,6	1,15	1,03
Milano Porta Genova	25,4	2,04	1,02
Milano Porta Garibaldi	25,2	1,76	1,05
Milano Dateo	22,8	0,51	0,78
Bergamo	18,5	0,92	0,87
Lecco	16,7	0,82	0,81
Mantova	15,1	0,82	0,90
Varese	13,4	1,78	1,12

Table 2: *TOP 10 stations ordered by score.*

Station
Milano Dateo
Milano Porta Romana
Lodi
Milano Porta Vittoria
Pavia
Milano Lancetti
Cremona
Legnano
Rho
Milano Porta Venezia

Table 3: *Major stations ordered by the percentage of train users that access the place by foot.*

4.3. Integration of ODM data

The preliminary results that were obtained with the scoring method did not consider important elements like the flow of passengers and the typology and habits of the station users. Therefore, the analysis has been complemented by additional data coming from RFI's Osservatorio di Mercato (ODM), a permanent monitoring laboratory with the mission of assessing the perceived quality of the rail service, usage patterns, opinions and preferences from the users. For this thesis, what is relevant is to understand in a deeper way is what are the main features of each Lombardy rail station, as well as rating the main mobility patterns of train users.

The ODM dataset provides information on the number of passengers that cross the station each year, the reason of trip, the percentage of users that access the station by foot as well as the walking access time and the permanence time into the station area. In the context of an analysis that assesses the accessibility and proximity of functions, the datum about the walking access is of particular relevance [4]. The ODM shows that there are at least 43 stations in the region in which more than 50% of the users move by foot. Several Milan stations and provincial nodes register really high walking access values [Table 3].

Another fundamental piece of data when dealing with the concept of walking accessibility is the access time to the station. The elaboration from the ODM data evidenced that there are indeed stations where users take less than 15 minutes of walk to reach their destination, while others still present consistent percentages of people that take between 15 and 30 minutes.

Figure 1 and 2 show the two maps that describe these two categories.

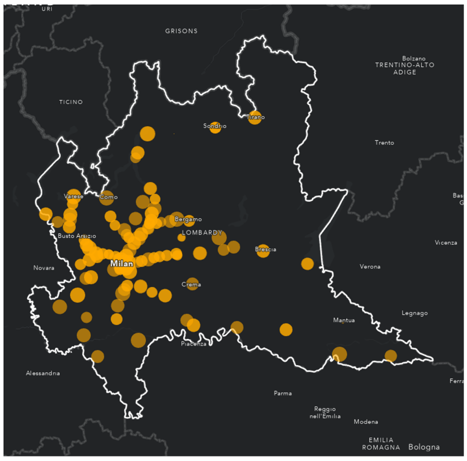

Figure 1: *Map showing the distribution of stations with access time less than 15' (access mode: Walking).*

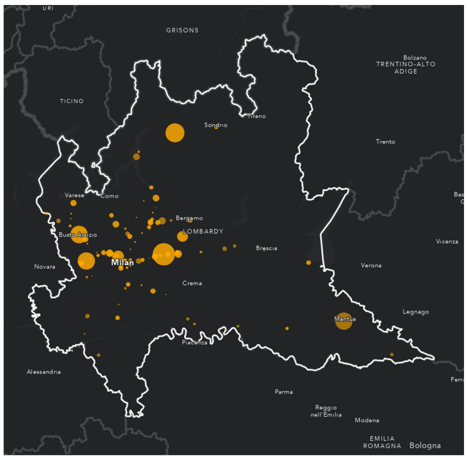

Figure 2: *Map showing the distribution of stations with access time between 15' and 30' (access mode: Walking).*

For instance, Treviglio, Mantova and Milano Villapizzone still present between about a third of users experiencing walking trips longer than 15 minutes. This indicates that there could be some potential space for intervention to improve the accessibility of the station, bringing more people to be included in the 15 minutes walking basin.

4.4. Correlation of variables

Further analysis of the complete dataset evidenced other interesting results on the relationship between the variables. The computation of the correlation coefficient between the different typologies of services [Figure 3] highlighted how *Free time and Leisure* services are strictly correlated to tourist attractions and accommodation facilities, while *Health* related points of interest are positively related to the presence of *Services to the citizen*. Moreover, additional elaborations have demonstrated how the frequency of walking access of users is not correlated to the score the station gets, indicating that an higher percentage of passengers that walk to the station does not relate to a greater presence of proximity services in the quarter.

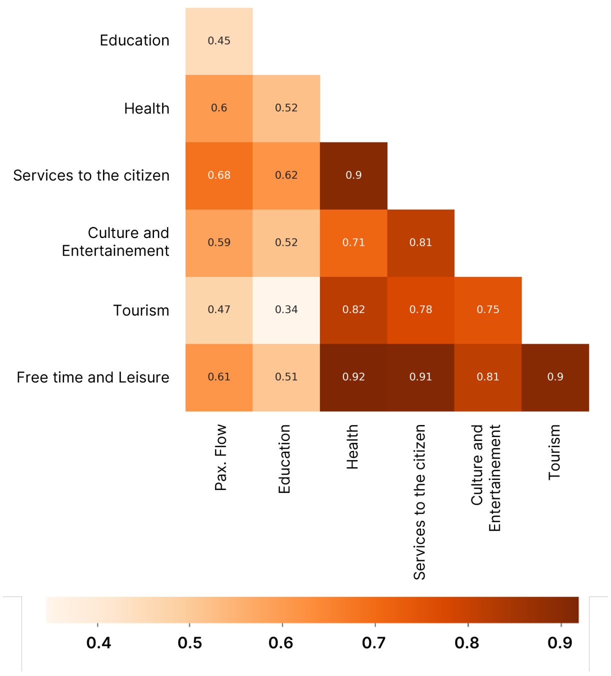

Figure 3: Correlation matrix of the six macrocategories of services analysed and passenger flow. Higher correlations values are highlighted in darker reds.

5. In-depth focus on relevant stations

The subsequent analysis aimed at identifying a subset of stations in the region that would justify the expenditure of resources for better livability, accessibility and integration of services. The initial database of 105 stations has been reduced to only 13, applying a series of filter following some criteria such as *Score*, *Percentage of access by walk*, *Pedestrian access time* and *Passenger flow*.

Among this 13 stations, the case of Lodi and Pavia have been chosen to be further explored. The two stations were picked from the list since they show really consistent values of walking access mode, sustained passenger flows and quite high scores. Lodi and Pavia have therefore been subject to additional spatial analysis via GIS software.

5.1. Spatial GIS analysis

These kind of spatial assessments have the objective of visualizing the distribution of services and activities in the city as well as understanding how the stations spatially relates to the majority of points of interest in the area. These kind of research is to be intended as a complement to the numerical scoring systems previously developed before.

Three analysis were carried out on the GIS software. First, the computation of the service centroid, representing a good proxy for understanding where the majority of services lie in the walking basin and how close to the station this center of mass of the services is.

Secondly, the computation of the directional distribution of the services through the Standard Deviational Ellipse. The method calculates the standard deviation of the x-coordinates and y-coordinates from the centroid to define the axes of the ellipse. The tool shows if the disposition of services around the station follows some peculiar pattern, which may represent a clue on how the city is structurally organised.

Thirdly, the creation of the density heat map of the services. The heat map makes use of a color scale to indicate the intensity of the represented feature: brighter colors stand for the "hottest" zones of the map, while darker colors are synonym of low services density.

The GIS analysis therefore allowed to under-

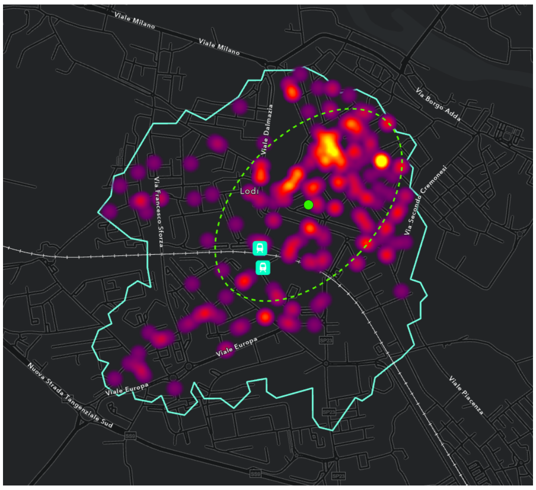

Figure 4: Spatial analysis carried out on Lodi station. The heatmap, the services centroid and the directional ellipse are shown. Example on Lodi station.

stand the urban organization of the two cities and to lay the foundation for additional considerations on their structure.

6. Focus on health and education

As a conclusive step, it was decided to analyse the most important urban poles for health and educational services respectively. This last activity was inserted into a project of collaboration between RFI and the Lombardy Region, to identify and develop new plans for intervention and urban regeneration in key areas of the cities. The first part of the evaluation consisted in the identification of those stations that present particular inclination for health services, offering especially important facilities from the point of view of quality or quantity. The second part of the evaluation consisted in finding a series of stations that particularly excel in the offering of educational services, such as schools and universities. To tackle these two cases, the AHP method has been modified to increase the importance of health and education services respectively, obtaining a new set of weights that could highlight more the best stations in these two service sectors. Moreover, additional data on the user flow of health structures and university departments have been included to perfect the evaluation of the single activities.
As a result, a new ranking of stations has been identified from the point of view of health and educational services. The station of Bergamo resulted as the best health pole of the region, while Lecco emerged as the top railway node for educational purposes.

7. Conclusions

The presented work had the objective of developing the concept of the "15 minutes city" around the railway station. The study started from the existing available literature and it expanded towards the vision of a proximity-based rail station, proposing a real case study as an application.
The integration of different data sources and the creation of a precise methodology allowed to develop an overall assessment of the entire rail network of the region. This work lays the foundation for a broad set of applications, allowing the decision maker in the identification of areas of intervention, where urban regeneration works could be performed to increase walkability, cyclability and to better connect an integrate the station to the services that are present around it. The thesis' main goal is therefore to provide a set of tools of analysis to evaluate the current scenario of an urban environment and its relationship with the transport systems. The developed model proved itself to be flexible and adaptable to different kinds of analysis, two of which are presented in the work, namely a focus towards health and education services.
As future developments, the model may be further improved to include a more detailed study on the weights to be associated to the AHP method, as well as additional simulations on the city networks, in order to have a clearer picture of the traffic flow of the users and more detailed insights on the structure of each city.

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THE 15 MINUTES CITY: A CASE STUDY OF CHRONO-URBANISM APPLIED TO THE LOMBARDY RAILWAY STATIONS

Supervisor: Prof. Claudio Somaschini

Company Supervisor: Ing. Fiorella Sciangula

Thesis of:

Marco De Donno

Student ID 953353

Academic Year 2020-2021

Alla mia famiglia...

Contents

Abstract

In recent years, a particular attention to the rethinking of urban environments in our city has been developed, spurred by a greater sensibility towards environmental protection and by the reclaiming of public spaces for pedestrians, cyclists and soft mobility. Countless initiatives have been proposed all over the world to tackle such challenges and to reshape the organization of urban conglomerates.

In order to assess, plan and execute such projects, a set of analysis is required, focusing on the evaluation of the current as-is scenario and on the implementation of mathematical models that would serve as tools for the final decision-making process.

This thesis focuses of the implementation of the "15 minutes city model" on the railway stations of Lombardy region, thus proposing a paradigm shift with respects to the classical chronourbanism concept of a "15 minutes quarter". The work is inserted in a broader project that sees the participation of both Rete Ferroviaria Italiana (RFI) and Regione Lombardia, with the purpose of promoting the development of the railway stations, with a particular attention towards accessibility, intermodality and new forms of sustainable transportation. Firstly, a data-driven analysis on the current urban organisation around of the regional stations is proposed, focusing on the presence of proximity services. Secondly, a rigorous mathematical method is presented to objectively evaluate and score the different rail nodes from the point of view of attractiveness, also integrating the work with additional on-field data regarding train users' profiles. Finally, a deeper evaluation on some selected stations of the region is illustrated, showing a set of analysis on their urban structure and on their main vocations and characteristics. The aim is therefore to provide a general toolset for the railway company and local authorities to guide the decision making of future interventions, to increase the livability and accessibility of the stations and to promote their interaction with the rest of the city.

Sommario

Negli ultimi anni è stata sviluppata una attenzione particolare verso il ripensamento degli ambienti urbani nelle nostre città, spinta da una più forte sensibilità verso la protezione ambientale e dal recupero degli spazi pubblici da destinare a pedoni, ciclisti e mobilità attiva. Numerose iniziative sono state proposte in tutto il mondo per affrontare queste sfide e rimodellare l'organizzazione dei conglomerati urbani. Al fine di valutare, pianificare ed eseguire questi progetti, una serie di analisi si rivelano necessarie, concentrandosi in particolare sulla valutazione dello scenario attuale e sull'implementazione dei modelli matematici che rappresentino un utile strumento per il processo decisionale finale.

Questa tesi si focalizza sull'implementazione del concetto di "Città a 15 minuti" alle stazioni ferroviarie della regione Lombardia, proponendo perciò un cambio di paradigma rispetto all'idea classica di "quartiere dei 15 minuti". Il lavoro si inserisce in un progetto di più ampio respiro che vede la partecipazione sia di Rete Ferroviaria Italiana (RFI) che di Regione Lombardia, con l'obiettivo di promuovere lo sviluppo delle stazioni ferroviarie, con particolare attenzione all'accessibilità, all'intermodalità e alle nuove forme di trasporto sostenibile.

Viene innanzitutto proposta un'analisi data-driven sull'assetto urbano odierno sviluppatosi attorno alle stazioni lombarde, incentrandosi principalmente sulla presenza di servizi di prossimità. Viene inoltre presentato un modello matematico rigoroso per valutare in modo oggettivo i nodi ferroviari e assegnare loro un punteggio basato sulla loro capacità attrattiva, integrando il lavoro anche con dati reali sul profilo degli utenti ferroviari. È illustrato, infine, un approfondimento su alcune stazioni della regione, mostrando un set di analisi sulla loro struttura urbana e le loro principali vocazioni e caratteristiche. L'obiettivo è dunque quello di fornire uno strumento generale sia per il

gestore ferroviario che per le amministrazioni locali e che guidi queste ultime nelle scelte di intervento future, al fine di incrementare la vivibilità e l'accessibilità delle stazioni e promuovere la loro interazione con il resto della città.

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Introduction

Over the last one hundred years, cities have been largely built around the rapid spread of private vehicles [1], drastically reshaping their spatial organization. Though this development path has undeniably conferred great benefits in terms of enhanced mobility, trade and economic output, the negative consequences have been evident as well. As a result of an excessive reliance on automobiles, large impacts on quality of life, air pollution and inequalities have been clearly identified. Moreover, an extensive usage of cars contributed to an ever growing urban sprawl, resulting in diffused and disordered expansion of cities and an even larger reliance on private vehicle usage.

Only in the recent years, a different perspective that stresses the social, environmental, and aesthetic impacts of transportation facilities and their interactions with land use has emerged. A new way of planning cities that promotes habitable environments and renewed infrastructures that favour user accessibility is being conceived. As a result, some major cities around the world are leading the efforts of revamping urban design and encouraging the use of public transport with the objective of reducing private car ownership and pollutant emissions [2].

Furthermore, the COVID-19 pandemic had the effect of accelerating these processes towards increased sustainability in cities, forcing municipalities and governments to rethink people movement and reorganize the urban living, ensuring proper access to essential services while protecting public health and avoiding major transport issues. Parts of these measures constituted an anticipation of what may be done in the future, as some of the choices that were necessarily introduced during the health crisis are being kept also for the future.

This thesis aims to develop a systematic and data-driven approach on the concept of the "15 minutes city" applied around the railway stations of Lombardy region. A series of steps have been established to identify the potential of a certain city area to fulfil the needs of a typical "15 minutes quarter". Using the railway station as a starting point from which users begin their trips, the developed model tries to quantify the attractiveness and the accessibility of the city within this new framework of *chronourbanism*. As of today, most of the literature focused on the relatively general idea of identifying accessibility and offering of city services without selecting a precise centroid for the analysis [3]. We instead propose an extension of the 15 minutes model by considering the railway station as a "second door of the house", from which user would expect to find all their essential services at a distance that would not require them more than 15 minutes of walking.

This technique of analysis is believed to positively affect the urban fabric in which the railway station is positioned, allowing both the municipality and the rail infrastructure manager to better identify potentialities and flaws of the surrounding city environment. The results of such analysis could lead to a better understanding of the most needed interventions to be implemented, which would favour an improved proximity of services and amenities to the rail station.

The final results obtained show a sub group of stations of Lombardy region, around which further investment on the level of accessibility is believed to be more justified. Moreover, specific evaluations for some of these stations have been proposed as an example, providing the responsible authorities with a proper toolset for a better understanding of the as-is situation and a useful guidance for future infrastructural work.

The document outline will be arranged as follows:

- Chapter 1 introduces in detail the concept of a "15 minutes city", providing an extensive overview of the main features of such a design principle as well as a review of the state of the art. Several examples coming from different parts of the world are presented to contextualize the subject of the work in a meaningful way.

- Chapter 2 deals with a general overview of the thesis work, illustrating the main principles and drivers that pushed the research in this topic and the main achievements that have been set. Moreover, it will assess the methodology and workflow that has been adopted, briefly describing the main passages that characterized the work. Finally, it is presented an explanation about the construction of the initial database - on which the entire analysis is based upon - illustrating the main steps that allowed for the collection of data regarding the case study.

- Chapter 3 introduces a set of analysis that have been carried out about the classification of features of the railway stations; the proposal for a ranking technique on the relevance of the different categories of city services; the creation of a scoring method for assessing the attractivity of the Lombardy railway stations and further integration of additional data sources that complement the evaluation of the case study.

- Chapter 4 proposes a deeper focus on some selected stations of the region, showing a set of tools that help in the exploration of the city structure that surrounds the station, complemented with easy-to-understand visualization techniques. Moreover, an additional focus on health and educational services is presented, supported by pertinent real-case examples.

- Finally, Chapter 5 summarizes and discusses the results of the thesis work, highlighting the key achievements and providing directions of research for future work.

Chapter 1

State of the Art

The case of a "15 minutes city" has been presented in the academic literature in a quite extensive way, with different contributions coming from several experts in the architecture, urban planning and transport management field.

1.1 The neighbourhood city structure

The search of an optimal arrangement for the development of the urban environment has been a research topic since the beginning of the modern era. The neighbourhood has been often marked as a fundamental element for the organization of a city. Early findings date back to the late 1920s, when city planner Clarence Perry outlined the neighbourhood as the critical structural unit for the development of cities [4]. Perry proposed a hierarchical system of urban services and amenities starting from the neighbourhood unit, completed with a set of quantitative measures for assessment and evaluation. During the last century, the neighbourhood concept has been extensively adopted in urban planning studies and commonly used in city development practices [5]. Nevertheless, Perry's rigorous design approach was not free of criticism since its initial conceptualization. Numerous studied expressed the inadequacy of this framework as beneficial for cities, remarking its disregard for the original and natural organization of the urban environment [6]. The development of cities in the modern era has been, in any case, characterized by a strong spatial separation of urban functions, that deepened socioeconomic divisions and encouraged a strong dependence on cars and other private vehicles. These widely adopted practices led, since the second half of XX century, to a progressive revisiting of Perry's neighbourhood concept, integrating the traditional practices with a new approach that includes a more sustainable and human-centered urban organization. This new movement, often named "New Urbanism" [7], advocates for the restructuring of public policies and development practices towards a more diverse use of neighbourhoods as well as more accessible city environments, designed not only for private vehicles but also for pedestrians and public transit [8]. The original neighbourhood structure imagined by Perry would now be seen as a more mixed-use urban environment, in which residents could meet their daily basic needs and experience higher quality living.

In the last decades, an increased level of awareness and sensibility of the public opinion with respect to climate change related issues and poor urban planning practices, enabled an even greater attention to new concepts and ideas regarding the spatial arrangement of cities.

1.2 Moreno's 15 minutes city concept

In light of a new urban organization concepts, in recent years, a new design principle emerged. The “15-minute city” concept has been firstly introduced by Professor Carlos Moreno in 2016 [9], offering an innovative perspective of *chronourbanism* and aiming at building more humane urban fabrics and safer, sustainable and inclusive cities. The basic principle of a 15 minutes city is the idea that all citizens should be able to meet most or all of their basics needs within a distance that would not require them more than 15 minutes of walking or cycling. This approach focuses on the fundamental principle of proximity rather than on the idea of mobility. Cities would be therefore designed to bring activities to the users and not users towards the activities. Increased levels of proximity should translate in a more extensive decentralization of activities, amenities and services, letting users access them without effort and in a manageable amount of time.

It is worth noting than this model build around a precise number of minutes may appear quite arbitrary in its choice. Similar chronourbanism models have been proposed or introduced around the world focusing on slightly different time scales, such as 20 or

30 minutes [10] [11]. The choice for an appropriate time model is therefore dependent on the morphology of the city, on the socioeconomic characteristics of the area as well as the cultural features of its inhabitants. Regardless of the specific features, what remains important to highlight is the underlying concept of spatial and temporal proximity, that remains common among all these new urban regeneration projects. Moreno vision of a 15 minutes city is mainly justified by the fact that, within this time frame, many modern city can accommodate for the essential needs for most of the people's everyday life.

Moreno's new development framework has the main objective of decreasing the biggest issues of modern urban organization by enhancing the level of accessibility of all the inhabitants to all the services they need everyday. Such a principle is believed to partially improve most of the greatest challenges of modern urban organization, such as excessive traffic congestion, pollution, social exclusion and segregation and overall quality of life [12] [13].

With his "15-minute concept", Moreno suggests that resident will be able to enjoy a higher standards of life if they will be able to fulfil six essential urban social functions. Those include (a) living, (b) working, (c) commerce, (d) healthcare, (e) education and (f) entertainment [9]. A 15 minutes neighbourhood ought to properly offer all these kind of activities to its citizens by complying with the design principles of vicinity, reachability and diversity.

Moreno therefore envisioned four main pillars upon which a 15 minutes city should be built, alternatively called the 4Ds [9] [Figure 1.1].

Density - In a 15 minutes city, density is viewed as number of people per squared kilometer. There is in fact an optimal density value for a given area that can easily accommodate all the citizens and all the services they need, while respecting the design notions of proximity and accessibility. This dimension, where properly implemented, also allows for the growth of soft-mobility infrastructures such as walking paths and bicycle lanes, while it reduces the need for private cars trips. Dempsey et al. identified the density factor as a key aspect for achieving sustainability in urban development. Really high-density neighbourhoods are in fact found to be less likely to support socially sustainable urban behaviours [14].

Figure 1.1: *The four Ds of a 15 minutes city*

Diversity - Moreno divides this point into two: (1) diversity intended as a healthy mix of residential, entertainment and commercial services and (2) diversity in people and culture. A blend of activities of various nature is considered of particular importance to achieve an economically vivid urban environment [15]. The concept of diversity translates also into the objective of reducing travel time for users, that would be able to access most of their basic services in their immediate vicinity.

Design - A fundamental notion of the 15 minute city is the possibility to easily access services within a 15 minute walking distance. This requires well-designed and organized radial nodes that not only promote short travel times but are arranged in a way that favours social interactions [12] [13].

Digitalization - This last dimension is of paramount importance, especially with the aim of ensuring the effectiveness of the other three dimensions. The presence of well-though digital platform allows for a better and easier exploitation of the city services, such as shared mobility services, online shopping and delivery, interaction platforms or information services [16]. An increased and smart use of the digital instruments may also enable a reduced need for commuting, as some services could be delivered digitally. This last aspect was especially evident during the COVID-19 pandemic, as a forced stay-at-home situation left no choice for citizens.

1.2.1 The COVID-19 experience

The COVID-19 outbreak in 2020 pushed public administrations to contain the spread of the virus with a vast spectrum of measures. Among those, many cities adopted some extraordinary anti-pandemic solutions that pushed for to rethink the urban organization of quarters and the mobility sector as a whole. Even though many modern cities have been originally built under the development models of urban sprawl, function separation and private vehicle reliance, there have been major examples of renewed urban planning measures that favoured walking, cycling and other form of shared mobility - such as [17] and [18] [Figure 1.2]. This shift in mobility habits has been encouraged by the infrequent use of public transit for health reasons, that pushed people to rely more on alternative means of transport.

Figure 1.2: *Example of temporary cycling infrastructure in Milan during the pandemic*

The COVID pandemic accelerated many already existing urban plans towards more sustainable and human-sized cities and what has been initially foreseen as a temporary measure could potentially become a new long-term structural approach. The 15 minutes concept gained therefore increased popularity among public authorities and urban planners during the pandemic, despite this model was originally introduced back in 2016. A progressive rethinking of cities could in fact lead to increased levels of walkability, cyclability and better consideration of public spaces.

1.3 Case study cities

Over the last decade, several new plans for urban revitalization following a chrono-urbanism concept have been proposed around the world. Example of strategies built around a 15 or 20 minutes concept have captured the interest of public administrations in Europe, United States, Asia and Australia. These include the development of better pedestrian accessibility, improved proximity of services and amenities for the citizens, measures aimed at increasing safety in the streets by limiting the usage of private cars or by lowering speed limits and initiatives promoted at improving multifunctionality and livability of quarters.

Hereafter, a description of some of these projects is presented, highlighting their main features and peculiarity, as well as their potential criticalities and weaknesses.

1.3.1 Barcelona's superblock

The Barcelona Superblock model is an innovative urban organization strategy aimed at creating additional public spaces for citizens while reclaiming part of the motorized vehicle infrastructure from the city. The Catalan city, like most modern European towns in the last century, mainly developed around a preponderant focus on private vehicles. This inevitably impacted on pollution, traffic, noise production and put less care for pedestrian, livability and micro-mobility.

The fundamental idea of this development plan envisions a complete overhaul of the structure of Barcelona's streets into an innovative structure named Superblock [19]. Following the characteristic urban fabric of Barcelona - which features a peculiar orthogonal grid pattern - the idea of outlining a quarter of larger dimensions within the already existing city structure was envisioned. The first attempts to re-imagine such a urban organization dates back to the mid-1980s, with the former head of the Urban Ecology Agency of Barcelona Salvador Rueda, who initially studied a possible plan to improve the noise pollution problems of the city.

A Superblock is generally designed as a 400x400m conglomerate, inside which only active mobility and local residents vehicles are allowed to circulate on the street. The outer boundary of the Superblock is instead delimited by a primary road network that connects the city and allows for the usual circulation of private vehicles and public transit at a maximum speed of 50 km/h [Figure 1.3]. The interior part of the Superblock is therefore designed to provide high level of accessibility for pedestrians, bicycles, and other forms of active transport and thus promoting healthier lifestyles for its citizens, the creation of additional green and public spaces and the potential relocation of activities inside this new more attractive urban environment. The development plan for Barcelona sees the potential of implementing 503 Superblocks, creating a network of sustainable and polyfunctional blocks that would remarkably change the urban structure of the city.

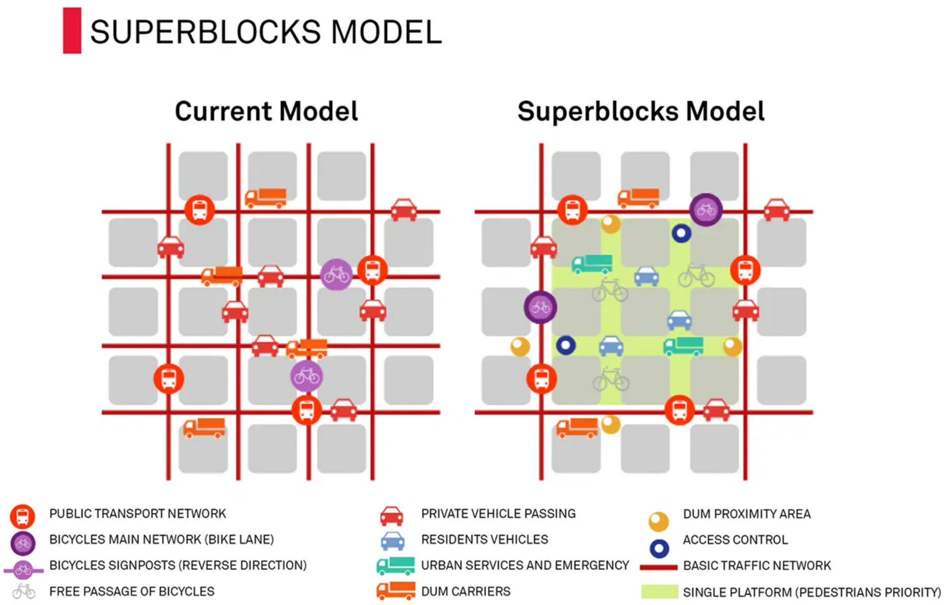

Figure 1.3: *A comparison between the current design and the Superblock model. (Source: Plan de Movilidad Urbana en Barcelona)*

Studies have shown how such a project, when finally completed, could avoid an average of 667 premature deaths, attributable to reduction in NO_2 emissions, road accidents, excessive noise and greater green spaces availability. The positive economic impact has also been estimated to be at around 1.7 billion EUR [19].

While the original Superblock idea was initially outlined in the late 80s, a first real attempt of creating a Superblock is to be found in the 2015 Urban Mobility Plan, that proposed the final goal of creating about 500 Superblocks. In 2016, a first pilot project started in the Poblenou quarter and five new Superblocks are underway to be completed in the next few years [20]. Overall, the initial attempt of Poblenou area has been considered an overall success, even though the development plans for this kind of city model inevitably confronted socio-political barriers and discussions. As stated in [21], the confrontation on whether and how the Superblock initiative should be implemented has been the ground of not always easy political debate in the municipality.

1.3.2 The Portland Plan

The city of Portland (Oregon, USA) began developing its own city plan with contribution coming both from the public and the private sector. The Portland Plan [22] outlines a series of policies aimed at improving different aspects of the urban life, with an achievement target set in 2035. Three main strategies have been identified by the administration, namely "Thriving Educated Youth", which focuses on the support and creation of opportunities for younger generation; "Economic Prosperity and Affordability" aiming at boosting innovation, employment and growth throughout the city and, most remarkably, the "Healthy Connected Cities" program that manages urban revitalization, accessibility and better connections among communities. The development of a proximity-based city planning built around a 20 minutes neighborhood is part of the "Healthy Connected Cities" strategy.

The first phase of such an application was the computation of an index to measure the accessibility of each neighborhood of the city with respect to amenities and services. The score is based on a 0 to 100 scale and a with a value above 70 the quarter is considered relatively complete in terms of attractivity and functions. The connectivity among the different neighborhoods has been redesign to accommodate a greater number of walking and cycling paths and greenways. Such measure are believed to positively transform the urban structure, to grow the economic output of the city and promote the creation of more local businesses while at the same time avoiding unwanted outcomes such as gentrification phenomena and increased income inequalities. To prevent those risks, the plan prioritizes the development of low-income neighborhoods and tries to minimize the impact of rising value of homes by facilitating access of housing for the most disadvantaged communities [3]. Figure 1.4, posted in the 2017 Portland Plan Progress Report [23], shows the percentage of neighborhoods that are considered complete. The value has slightly increase with respect to the baseline and it is projected to increase more in the the coming years.

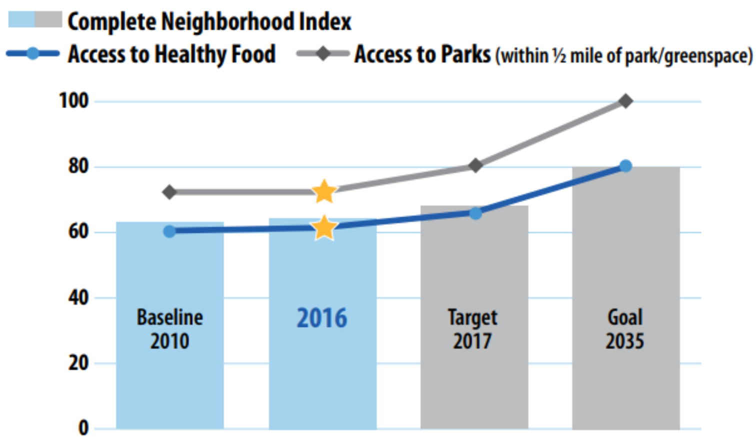

Figure 1.4: *The percentage of "complete neighborhoods" in Portland (recorded and projected values). (Source: The Portland Plan Progress Report, 2017)*

Overall, the plan is a complex set of strategies, visions and projects that aim at solving main issues in the urban development and in the accessibility to job, resources and opportunities. Interventions on a medium-sized conglomerate like Portland, characterized by a substantial amount of urban sprawl, is believed to require major planning and design efforts [3].

1.3.3 Paris - La ville du quart d'heure

Since the first entering in power of Mayor Anne Hidalgo in 2014, plans for a new process of urban renovation started in Paris. In a way similar to the aforementioned examples, the project of a 15 minutes city (*La ville du quart d'heure*) gained relevance in the municipality's plans and quickly became one of the most iconic and probably well done initiative of its category. The French capital joined the C40 Cities Climate Leadership Group, a conference of 40 cities around the world that aim at implementing measures to fight climate change and guaranteeing opportunities and well-being for all their citizens [24].

The strategy includes four axes spanning from solidarity transformation, ecological measures, citizen commitment and hyper-proximity. This last concept represents the fundamental key idea of Paris future development path, whose administration found direct advice from prof. Moreno itself, the father of the concept of the "15 minutes city" [25]. Translated into actual policies, Hidalgo administration aims at improving diversity and distribution of services and facilities in the different city districts of the inner ring area. The project thus involves the redefinition of structure and function of major parts of the neighborhoods to improve accessibility to pedestrians and bicycles, reduce the impact of private cars traffic and promote a more healthy way of living Paris based on proper localization and proximity of functions [26]. The plan also sees the potential of giving facilities different uses during the day, such as utilizing schoolyards as sport centers during the evening hours. Moreover, the program considers a massive extension of the urban bike network, to better connect the city center with the surrounding suburbs [Figure 1.5]. The financing of such a policy is backed by a total of 300 million EUR investment on bike friendly roads and larger sidewalks [27].

Figure 1.5: *The complete Paris bike network planned by 2024, including roads with dedicated bike lanes and bike-friendly streets. (Source: Paris Municipality)*

Despite the long term vision for a more livable and sustainable city and the overall good results, some important challenges remain for a proper success of the initiative. Focusing the greatest part of investments on the inner an most central area of Paris resulted, alongside better accessibility, also in increasing prices of housing. The affordability of properties and gentrification have become a serious problem for the city center, forcing out lower-income people and making the cost of living unsustainable for most of the population. To mitigate this negative outcomes, Hidalgo's plan also aims at expanding the city's network of public housing into wealthier areas, reaching about 30% of the total by 2030.

Overall, the Paris en Commun plan is considered a success [26]. The assessment on the main evaluation attributes concluded that the project shows credible plans for a complete renovation of the city and a remarkable contribution from citizens thanks to public participation in the planning and decision making processes. The strategy, however, seems to lack proper measures aimed at fighting gentrification and limiting excessive rent and housing prices.

1.3.4 Milano 2020

Following the most critical phase endured during the COVID-19 pandemic, the city of Milan developed a new set of proposals to update the urban mobility and organization in light of the new health measures of the so called "Phase 2". The strategy follows the objective of achieving greater adaptation capabilities for any future critical situation that may require a sudden shift in mobility and living behaviour for the citizens of Milan. The plan is subdivided into five main pillars - inclusion and governance, economy and values, work, time and space, and sustainability. These policy choices aim both at mitigating the potential future impact of other waves of the pandemic and at redesigning a city with new concepts in mind, among which the plan for a "15 minutes Milan" finds ample margin of development [28].

An innovative model for the "new normal" sees the opportunities of a proximity-based city as the foundation of an overall upgrade of the urban environment. The introduction of additional space for safe and fast transport by bicycle or foot (such as 35km of new bike lanes), the push to avoid unnecessary movement when not strictly needed (such as promoting working-from-home when possible) and the lowering of the speed limit for vehicles in the city center are all part of an extensive strategy that aims to transform Milan in a more sustainable and livable city [Figure 1.6].

Milano 2020 shares major element with Hidalgo's *Paris en Commun* plan. Both cities are trying to implement measures that foster diversity in functions, social cohesion, the importance of rediscovering the size of the neighborhood and the underlying concepts of urban connectivity and permeability [29].

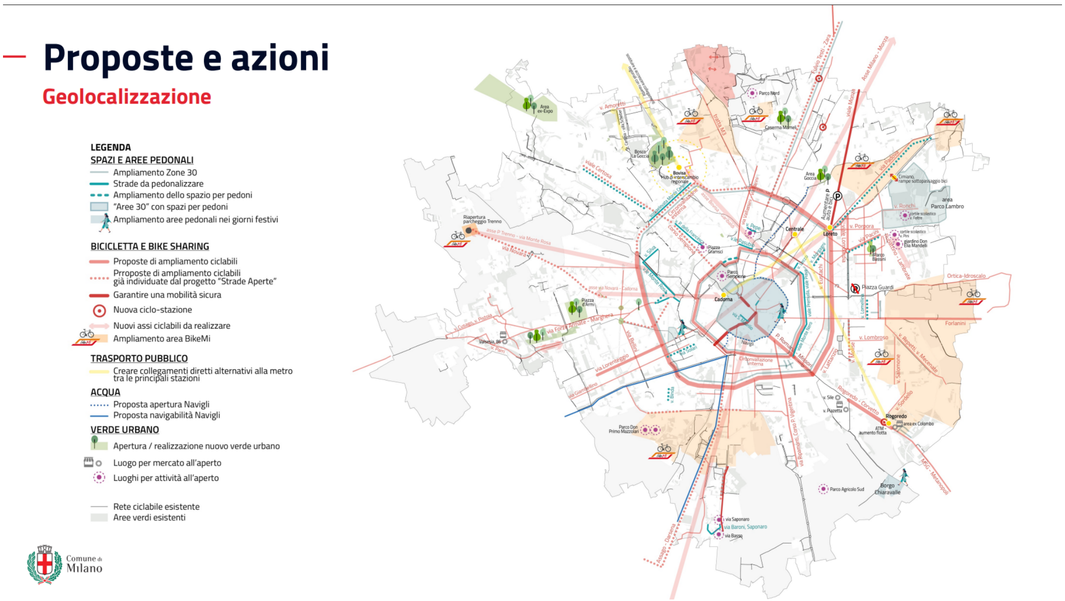

Figure 1.6: *A summary map showing the complete set of interventions planned for the vision of Milano 2020. (Source: Milan Municipality)*

Chapter 2

General overview and methodology

The concept of the 15 minutes city has been extensively introduced in Chapter 1, highlighting its origins and initial conceptualization as well as presenting some major examples of its application in cities around the world. The contribution that this thesis wants to give is to propose a paradigm shift to the 15 minutes station notion by focusing the start of the analysis on the railway station.

As the hyper-proximity conception gained popularity in the literature and frequently translated into actual practices, this work aims at exploring a new model of chronourbanism that considers the railway station as "a second home door", from which the rail users start new activities, expecting to find around the station all the services and functions they may need. Therefore, if the classical 15 minutes originally considered the promotion of a proximity-based development throughout the city, this concept, when applied to the rail domain, puts a greater attention on the environment that surrounds the station. The 15 minutes walking basin is now believed to accommodate most of the activities a rail user might use for her everyday life, creating a more livable place and, overall, generating value for the citizen.

The transition from the idea of moving the citizens towards the services to moving the services closer to the citizens is a radical transformation on how the surrounding urban environment of a station is conceived. This puts grater attention on the importance of accessibility when planning and redeveloping quarters, considering a better integration of the functions that the city can offer with the ones that the rail station presents.

The work that is here presented has been carried out during an internship experience at Rete Ferroviaria Italiana (RFI) - the Italian railway infrastructure manager - in which this new approach has been applied to the rail stations of Lombardy region.

2.1 The reasons and the objectives of the work

The development of such a project has been carried out with several objectives in mind. The original conceptualization comes from previous works of RFI itself on the theme of proximity and interaction between the railway node and the urban context, on which this thesis is based upon. The company tried to identify what is the role of the rail station today and what should become its role in the future, considering what is the field of action of the railway infrastructure manager and of the public administration respectively. Even though these two actors are distinct in their functions and responsibilities, a close cooperation between them is required to achieve common goals and effective interventions. The main key ideas that spur the elaboration of this topic are multiple and different in nature, and they are here reported:

The creation of a polyfunctional node - The rail station should be seen more and more as a place that is meant not only to collect and leave passengers, but as a useful center where users could find additional services and a strong interlinkage with the city.

Letting demand and offer meet - The passenger flow in a station is, other than a mere number of users, a valuable source of income for many additional activities. The station is a crossroad where demand of goods and services and the offer could easily meet, creating additional opportunities for many citizens.

Increase felt value - Nowadays, living nearby a station is generally felt as a disvalue for different reasons, like degraded environment, poor urban development, unsafe or dirty ambient and lack of livable public places. The enrichment of the station area with new services and an increased walking accessibility factor is a promoter of increased value perceived by the users and the citizens. The potential contribution of such interventions may positively affect the way the station is considered.

Attraction of more train users - The increased attractiveness of the station may represent a reason for people that do not use the train to shift their mobility habits, embracing the rail as a valid alternative of transport.

The work that is therefore proposed aims to show a methodology of collecting, managing, identifying and elaborating data on the Lombardy railway stations and on the cities those stations lie in, with the purpose of understanding the main opportunities of development within the concept of hyper-proximity.

This thesis, conducted with the support of RFI, wants to put into highlight what are the stations that are to be prioritized from the point of view of civil works, considering both the demand side - represented by the demand of rail trips - and the offer side - represented by today's supply of services and function around or inside the station itself. In fact, the particular vocation of a certain railway node has to be considered when planning possible interventions to improve the quality and the accessibility of the services in the area.

2.2 Case study

The entire work has been carried out considering the Lombardy region. It extends for 32.844 km^2 and counts more than 10 millions inhabitants in total, located in 11 provinces and 1 metropolitan city, Milan. Lombardy is one of the most dense regions in Italy and one of the largest.

The regional rail network is the most extensive in the country and features 302 railway stations against a total of 1523 towns and cities [Figure 2.1]. The electrification of the lines is present for the 84% of the total, of which 59% is double track. The Lombardy network presents one of the highest degree of utilization in Italy, averaging at 12'732 trains*km/km of track, making it a really critical node for passenger and freight transport as well as an often congested transport infrastructure [30].
RFI operates most of the total rail network of the region, managing 1927 trains/day and about 33.2 millions trains*km/year [30].

Moreover, Ferrovie dello Stato Group's rail network can subdivided into three main categories that allow to distinguish, in general terms, the size and the vocation of the different stations. Those are represented by the *Grandi Stazioni*, *ex-Centostazioni* and

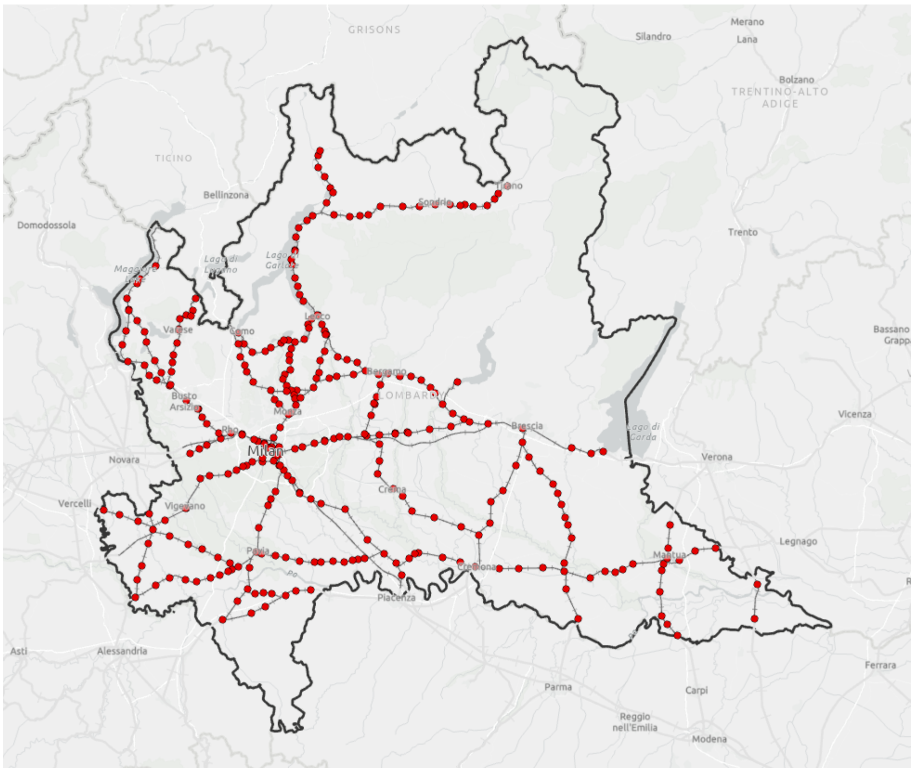

Figure 2.1: *A view of the entire Lombardy rail network. Stations are shown as red dots.*

500 Stazioni networks. Grandi Stazioni (GS) - of which, in Lombardy, only Milano Centrale station belongs to - is the company assigned to the management and requalification of the biggest rail mobility hubs in Italy. Centostazioni was instead a company dedicated to the valorization of 103 medium to large stations across the country, that has been merged into RFI in 2018. Lastly, the "Progetto 500 Stazioni" is a project meant to manage 500 medium and small stations to promote the growth and development of commercial services as well as client satisfaction. This subdivision is of particular interest since it allows to better categorize the regional network, in light of further analysis that will we carried out in the thesis.

2.3 Methodology and workflow

In order to present the general framework of the work, the fundamental steps of the project are introduced. The thesis workflow is the result of six main passages, starting from the collection and first elaboration of the raw data to the final evaluation of the results and evidences emerged. All the procedures and activity involved in the thesis are essentially carried out with a data-driven approach, always maintaining a strong quantitative and scientific attitude towards data elaboration and interpretation.

The first passage is represented by the collection of data regarding the stations and the urban context in which they are inserted. The starting point of all the following analysis is represented by the gathering of information from trusted data sources, without which a reliable analysis would not be possible. A first categorization and visualization of georeferenced data is then performed.

The second step regards the clustering and classification of the services within the 15 minutes walking basin, using a quantitative method to develop a hierarchy among the different kinds of urban functions.

The third step is the computation of a score to evaluate the attractiveness of the Lombardy stations and to understand the stability and validity of such a method to rank them.

The fourth passage consists in integrating into the station database additional data regarding the habits and the mode of access of real users, to better understand the utilization patterns of the travellers and to further explore the correlation between the different variables.

The fifth section of the work is about the selection of a subset of stations to be further and more deeply studied, to figure out their main spatial characteristics and the surrounding interaction with the external urban environment. Moreover, a deeper focus on the health and educational sector is proposed, with opportune real case examples.

Finally, the last part shows the main results and evidences of the thesis work, completing the study with additional visualizations.

2.4 Data gathering and database construction

In order to create any further analysis, model or consideration, a strong data foundation is necessary. The work that has been carried out has, as its starting point, the previous collection of information regarding the Lombardy rail stations and the offer of services of the host cities performed by RFI. This activity had the objective of preparing a unique database that could accommodate all the necessary and useful information about the railway stations, representing a common starting point for a vast spectrum of future projects. The data gathering required extensive research and selection of different sources, belonging to both public and proprietary datasets.

The data collection aims at understanding the socioeconomic characteristics of the urban environment in which the stations are included as well as the number and the typology of services located within a 15 minutes walking distance. The sources RFI used to obtain such elements span from the ISTAT census databases [31] to private entities specialized in data supply like HERE [32], a leading provider in geolocalized mapping. All the retrieved information are presented in the geo-referenced form, in which each single piece of data is incorporated with its geographical coordinate.

Once the collection of the POIs has completed, the 15 minutes walking isochrone has been calculated around each stations, taking as input the road network and considering a typical walking speed of an adult person. The obtained isochrone is very dependent on the features of the streets that connect the station to the rest of the city, as well as the potential natural barriers that can impose clear limits to the extension and shape of the polygon. For example, the railway itself can represent a first obstacle to the reachability of some areas, limiting the access of passenger from only one side of the rail. Moreover, the presence of watersides, rivers, lakes or particular terrain morphology can play a significant role in the determination of the 15 minutes basin.

Additional work on this data has then been carried out on the ArcGIS software, in order to filter out all the points of interest located outside of the 15 minuted walking basin. Furthermore, an appropriate labelling of the collected services has been implemented to create a clear and appealing visualization on the GIS platform.

The final result of this process is a double output. The first is a complete GIS mapping of the POIs around each Lombardy station while the second is a unique database containing, for each railway node, the number and typology of services within the 15 minutes isochrone combined with the number of people living and working in the area. Figure 2.2 and Table 2.1 are shown as an example.

This first passage is an important achievement, since it allows to have a complete dataset of all the services offering nearby the station, as well as a first general indication of the potential demand of train passengers, represented by the number of inhabitants

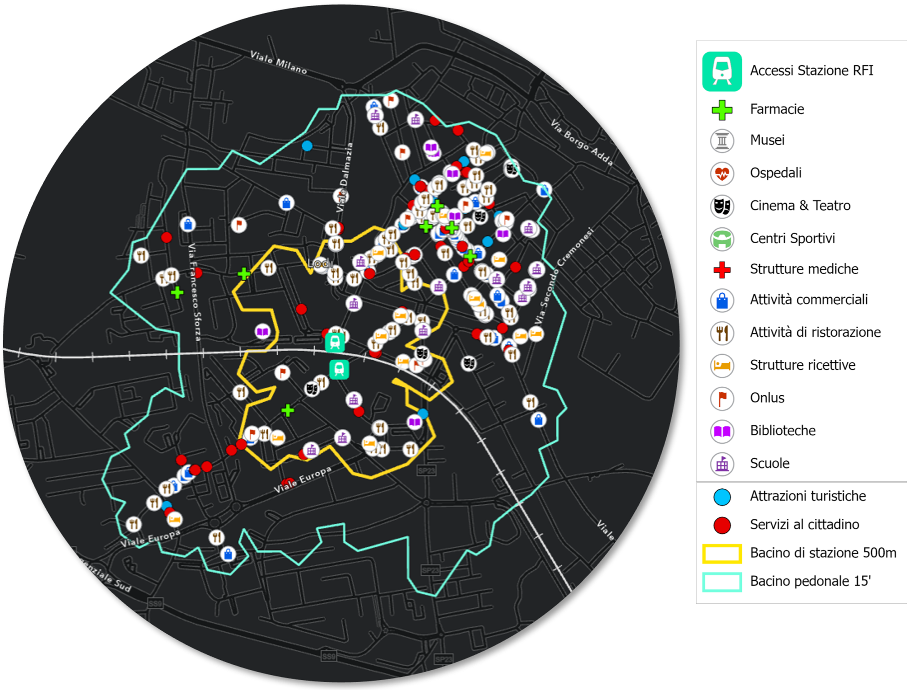

Figure 2.2: *Localization of the POIs in the 15 minutes basin (example on Lodi Station).*

and workers. The following chapter will illustrate how this database has been managed, extended and elaborated to perform additional analysis on the attractivity of the different stations of the region.

Stazione	Milano Centrale	Milano Porta Venezia	Milano Repubblica	Milano Porta Genova	Milano Porta Garibaldi	Milano Dateo	...
Province	MI	MI	MI	MI	MI	MI	...
Network	GS	500RFI	500RFI	500RFI	ex CS	500RFI	...
Inhabitants 15 min. basin	44.362	49.147	18.393	51.506	35.083	54.128	...
Workers 15 min. basin	65.875	45.939	64.380	20.040	34.408	22.327	...
Universities	0	0	0	0	0	0	...
High Schools	21	12	13	9	2	11	...
Hospitals	0	0	1	1	1	1	...
Services to the citizen	171	147	166	93	97	120	...
Pharmacies	33	35	24	17	20	21	...
Culture and Tourism	13	43	45	18	26	4	...
Food services	457	469	478	382	357	187	...
Shopping	370	444	264	119	141	124	...
Leisure	21	23	16	21	15	15	...
Hotels	140	129	144	42	45	45	...
Museums	0	0	0	1	0	0	...
Cinema and Arts	4	4	5	4	1	1	...
Theatre	1	3	1	3	3	3	...
Gym	16	16	10	14	11	11	...
ONLUS	58	61	51	36	29	31	...

Table 2.1: *Fragment of table showing the complete database of socioeconomic variables and services around the stations.*

Chapter 3

Data classification and analysis of the stations

This chapter focuses on the central steps of the work. The following paragraphs describe the elaboration of the original dataset, proposing a first classification of the services collected, the development of a methodology to rank and score the stations assets and a further integration of data, to propose a selection of the stations with the greatest potential for future interventions on accessibility.

3.1 Clustering of services

The process shown in Chapter 2 resulted in the creation of a unique dataset containing the complete offer of services within the 15 minutes walking isochrone of the Lombardy rail stations and information about the number of inhabitants and workforce of the area.

The next step has been the categorization of the different kinds of services into some macro categories, to allow a better management of data and an easier evaluation process. The merge of the services has been performed considering the function they play into the urban context and the public at which they are targeted. The subdivision into these classes aims to resemble the typical activities that a person would do in her everyday life, such as working, studying, getting healthcare, shopping or spending free time. Figure 3.1 shows the final clustering that was adopted. A total of six categories were chosen, namely Education, Health, Services to the citizen, Free time and leisure, Tourism and Culture and entertainment.

Service	Marco Category
Universities	Education
High Schools	
Hospitals	Health
Pharmacies	
Services to the citizen	Services to the citizen
ONLUS	
Food services	Free time and leisure
Shopping	
Leisure	
Gyms	
Hotels	Tourism
Culture and Tourism	Culture and Entertainment
Museums	
Cinema and Arts	
Theatre	

Table 3.1: *Macro categories in which the different services have been clustered in.*

3.2 Ranking the clusters: a proposed methodology

The urban environment is various in its characteristics, functions and opportunities. A town - or a city - generally accommodates different kinds of services that aim at intercepting the various needs of the population. A urban fabric that is rich and able to offer all the necessities of the citizens' everyday life can promote economic development and well-being [9].

However, the different roles associated with the different activities may not be considered equally important in the city context. The following paragraphs will show an analytical approach with the purpose of creating a ranking of the services that have been identified in Chapter 2. The technique that has been adopted is the Analytical Hierarchical Process (AHP), a quantitative method that allows to associate a numerical weight to each category that is taken into account, using a pairwise comparison of the alternatives.

3.2.1 Multi-Criteria Analysis Techniques

Over the last decades, a number of methods have been developed that use pairwise comparisons of the alternatives and criteria for solving multi-criteria decision-making (MCDM) between finite sets of alternatives. MCDM methods have been developed to help decision-makers solve MCDM problems. They are widely used in different types of real-life situations where some decision alternatives may be considered to be conflicting criteria [33]. Numerous multi-criteria decision-making methods have been developed to support decision-makers during the judgement process. The literature generally identifies three main types of methods [34].

- **Reference level methods**, that identify how far each alternative is from the ideal goal. An example of this is the TOPSIS technique.
- **Outranking methods**, where each pair of alternatives is compared for each criterion to rank the alternatives. One of the techniques that uses this approach is called PROMETHEE.
- **Full aggregation methods**, where to every criterion is assigned a weight, which indicates its importance. Then, a numerical score for each alternative is computed and the one with the highest score prevails. The AHP exploits this method.

3.3 The AHP method applied to the case study

Among the possible alternatives of MCA, the Analytical Hierarchical Process has been chosen. The Analytic Hierarchy Process (AHP) was originally conceptualized by Saaty in 1980 [35] and it is often referred to as Saaty's method. It is a commonly used and widely accepted method in decision making processes and in a wide range of other applications, such as planning and resource allocation. This technique has been utilized in the context of the analysis of the urban services, to rank in a quantitative and rigorous way the relevance of the different services found around a railway station. For this particular work, the choice of the AHP method justified by the good compromise of effectiveness and easiness of implementation of the model.

3.3.1 The Analytical Hierarchical Process

A commonly open problem in decision making process is the measurement of physical and psychological events, where the former refers at something that is tangible and real, the latter which refers instead to the realm of the intangible. As Saaty suggests, the AHP method can be an answer to the problem of establishing a measure for both physical and social issues. The AHP method is based on the pairwise comparison between the different variables, in order to establish a relation among them.

Each pairwise comparison considers a single couple of variables and assigns a preference index based on the importance or relevance of the first variable on the other. To weight a criterion more than another, Saaty originally identified a fundamental scale the preference index should be chosen from [Table 3.2]. The larger the index is, the greater preference is given to the first variable of the pairwise comparison to the other. The evaluation is then repeated for all the possible couples of attributes considered, therefore creating a matrix expressing all the relative values.

Weight Index	**Comparative Importance of Parameters**
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Overwhelmingly more important
2,4,6,8	In-between weights can be used in pairwise comparisons

Table 3.2: *Analytic hierarchy process (AHP) based on Saaty's work.*

Assigning preference values

The matrix of pairwise comparisons A = $[a_{ij}]$ represents the intensities of the preference between individual pairs of alternatives. The decision maker confronts pairs between n

alternatives $\{A_1, A_2, \ldots, A_n\}$ to obtain a comparison matrix A, where the element a_{ij} shows the preference weight of A_i obtained by comparison with A_j.

$$\mathbf{A} = [a_{ij}] = \begin{pmatrix} 1 & a_{12} & \ldots & a_{1j} & \ldots & a_{1n} \\ 1/a_{12} & 1 & \ldots & a_{2j} & \ldots & a_{2n} \\ \vdots & & & & & \\ 1/a_{1j} & 1/a_{2j} & \ldots & a_{ij} & \ldots & a_{in} \\ \vdots & & & & & \\ 1/a_{1n} & 1/a_{2n} & \ldots & 1/a_{in} & \ldots & 1 \end{pmatrix}$$

What is obtained is a square matrix of order n where the diagonal must equal to 1, as it represents the comparison of each criterion against itself, while the values above the diagonal are the inverse of those below it ($a_{ij} = 1/a_{ji}$ for $i \neq j$ and $a_{ii} = 1$, $\forall i$). Such a matrix is called *reciprocal matrix.* The assigned weights are said to be *consistent* if they are transitive, meaning that $a_{ik} = a_{ij}a_{jk}$ for all i, j and k. A perfectly consistent matrix, therefore, is not obtainable if the chosen preference indices are not exactly measured data.

The actual matrix filled with the values associated to the typologies of services that have been previously analyzed is shown Table 3.3. For the sake of compactness and clarity, the six services are identified with some acronyms: Inhabitants (IN), Jobs (JO), Education (ED), Health (HE), Tourism (TO), Culture and Entertainment (CU), Services to the citizen (SE) and Free Time and Leisure (FT).

Computing the weight for each category

In order to assign a final weight to each category of service, thereby creating a hierarchical order among them, it is necessary to compute a vector of weights $\{w_1, w_2, \ldots, w_n\}$ associated with the matrix A. According to the Perron-Frobenius Theorem [36], if A is an $n \times n$, non-negative, primitive matrix, the eigenvalue of maximum modulus λ_{max} of A is real positive and the corresponding eigenvector $\mathbf{w}$ has all positive components and it is the only non-negative eigenvector of A. Moreover, the eigenvalue is a simple root (matrix Frobenius root) of the characteristic equation

CRITERIA	IN	JO	ED	HE	TO	CU	SE	FT
IN	1	1	2	2	3	5	6	8
JO	1	1	2	2	3	5	6	8
ED	0,500	0,500	1	1	2	4	5	7
HE	0,500	0,500	1	1	2	4	5	7
TO	0,333	0,333	0,500	0,500	1	3	4	7
CU	0,200	0,200	0,250	0,250	0,333	1	2	4
SE	0,167	0,167	0,200	0,200	0,250	0,500	1	3
FT	0,125	0,125	0,143	0,143	0,143	0,250	0,333	1
Sum	3,8	3,8	7,1	7,1	11,7	22,8	29,3	45,0

Table 3.3: *AHP values for each category considered.*

$$Aw = \lambda_{max} w$$

Where the **w** is the actual vector containing all the weights. The correspondent eigenvector can be easily computed by determining the matrix of the percentages of preferences, namely a matrix A' where each values is divided by the total sum of its column.

$$a'_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{ik}}$$

The result is presented in Table 3.4. Saaty [35] suggest that a good approximation of the eigenvector of the matrix A can be calculated by averaging each row of the matrix A'. Therefore, the final output would be the vector shown in Table 3.5.

Checking the consistency of the result

Since the AHP method relies on human judgment when assigning the preference indices to the different categories, the consistency between all the values of the matrix A is not guaranteed. Because of this, Saaty defined a consistency index (CI) as

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

CRITERIA	IN	JO	ED	HE	TO	CU	SE	FT
IN	0,261	0,261	0,282	0,282	0,256	0,220	0,205	0,178
JO	0,261	0,261	0,282	0,282	0,256	0,220	0,205	0,178
ED	0,131	0,131	0,141	0,141	0,171	0,176	0,170	0,156
HE	0,131	0,131	0,141	0,141	0,171	0,176	0,170	0,156
TO	0,087	0,087	0,070	0,070	0,085	0,132	0,136	0,156
CU	0,052	0,052	0,035	0,035	0,028	0,044	0,068	0,089
SE	0,044	0,044	0,028	0,028	0,021	0,022	0,034	0,067
FT	0,033	0,033	0,020	0,020	0,012	0,011	0,011	0,022
Sum	1	1	1	1	1	1	1	1

Table 3.4: *AHP computed percentage of preference.*

Service category	Weight
Inhabitants	0,243
Jobs	0,243
Education	0,152
Health	0,152
Tourism	0,103
Culture and Entertainment	0,051
Services to the citizen	0,036
Free Time and Leisure	0,020

Table 3.5: *Vector of weights from the AHP method.*

where CI is a numerical value that tells how inconsistent the AHP preference indices are. A set of perfectly consistent values (so that $a_{ik} = a_{ij}a_{jk}$ for all i, j and k) would yield $CI = 0$ and $\lambda_{max} = n$. It can be also proven that $\lambda_{max} \geq n$ is always true. This suggest using $\lambda_{max} - n$ as a index of departure from complete consistency, therefore considering the CI as it is above formulated. The implemented model gives a CI = 0.047. Moreover, Saaty suggests an additional value called consistency ratio (CR) defined as

$$CR = \frac{CI}{RI}$$

where RI is the average random consistency index, obtained from a sample of size 500 of randomly generated reciprocal matrices using the scale 1/9, 1/8, ..., 1, ..., 8, 9. The different RIs are reported in Table 3.6 for each individual size of n.

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.52	0.89	1.11	1.25	1.3	1.4	1.45	1.49

Table 3.6: *AHP random consistency indices.*

A CR < 0.1 is considered acceptable. A CR > 0.1 would require a revision of the judgments assigned in the first step. The model here implemented yields a $CR = \frac{CI}{1.4} = 0.034$.

3.4 Scoring the stations

The passages illustrated in the previous paragraphs showed how the collection of geo-referenced data about the surrounding environment of a station was performed and proposed a quantitative method to put the features and services into a hierarchy order. These two steps will allow for the development of a scoring system to assign to each station a numerical value related to its attractivity potential. The computation of the score has been designed to take as input the number of services present in the 15 minutes walking basin - subdivided into their respective categories - and the weights obtained in 3.3.1. The score is therefore calculated performing the scalar product between the vector with the number of services ($\mathbf{s}$) and the weight vector ($\mathbf{w}$) previously calculated. In other words, a weighted sum of the components of the services vector is performed.

$$Score_{station} = \mathbf{s} \cdot \mathbf{w} = \sum_{j=1}^{8} s_j \cdot w_j$$

Therefore, this method allows to score a station according both to the quantitative presence of services but also to the importance of each service with respect to the others. Hence, an higher score could represent not only a sign of the presence of a great number of activities but also of the presence of valuable services. For instance, a station surrounded by a large number of leisure points of interest could obtain a similar score of a station that offers fewer but more relevant attractions, like schools or hospitals.

Features like the number of inhabitants and workers are also taken into account for the final score generation. Figure 3.7 shows some of the Lombardy stations with the highest scores. Both partial and total values are reported.

	NUMBER OF SERVICES								PARTIAL SCORES								
Station	Basin inhabitants (thousands)	Basin Workers (thousands)	Education	Health	Services to the citizen	Culture and Entertainment	Tourism	Free time and leisure	Inhabitants/ 10000	Jobs/ 10000	Education	Health	Services to the citizen	Culture and Entertainment	Tourism	Free time and leisure	SCORE (Σ)
Milano Centrale	44.3	65.8	21	33	171	18	140	848	1,08	1,60	3,19	5,02	6,15	0,91	14,43	17,21	**49,6**
Milano Porta Venezia	49.1	45.9	12	35	147	50	129	936	1,19	1,12	1,82	5,32	5,28	2,53	13,29	19,00	**49,6**
Milano Repubblica	18.3	64.3	13	25	166	51	144	758	0,45	1,57	1,98	3,80	5,97	2,58	14,84	15,39	**46,6**
Milano Porta Genova	51.5	20.0	9	18	93	26	42	522	1,25	0,49	1,37	2,74	3,34	1,31	4,33	10,60	**25,4**
Milano Porta Garibaldi	35.0	34.4	2	21	97	30	45	513	0,85	0,84	0,30	3,19	3,49	1,52	4,64	10,41	**25,2**
Milano Dateo	54.1	22.3	11	22	120	8	45	326	1,32	0,54	1,67	3,34	4,31	0,40	4,64	6,62	**22,8**
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Table 3.7: *Portion of table showing the partial and final scores of different regional stations.*

The score, as it is conceived, aims at expressing in numerical terms what is the the availability of services around the station and, therefore, its attractiveness to train users and local citizens. The ordering of the different results by magnitude allows to rank all the stations of Lombardy region by their capability of creating value to the users through their offering of activities. Figure 3.8 lists the scores of the first 40 stations in descending order. As predictable, the stations located in Milan get the best values, as they are inserted in a rich and lively urban environment that ensures a consistent and diversified number of attractions and functions. Secondly, the provincial chief towns obtain high scores as well, being main reference points for the different provinces. On the other hand, smaller stations do not reach high values as they do not serve enough passengers to justify complex sets of services.

n°	STATION	SCORE	n°	STATION	SCORE
1	Milano Centrale	49,6	21	Vigevano	9,6
2	Milano Porta Venezia	49,6	22	Cremona	9,5
3	Milano Repubblica	46,6	23	Gallarate	8,6
4	Milano Porta Genova	25,4	24	Milano Lancetti	8,5
5	Milano Porta Garibaldi	25,2	25	Legnano	8,0
6	Milano Dateo	22,8	26	Rho	7,3
7	Bergamo	18,5	27	Milano Romolo	7,2
8	Lecco	16,7	28	Sesto S.Giovanni	7,2
9	Mantova	15,1	29	Desenzano del Garda	6,9
10	Varese	13,4	30	Voghera	6,8
11	Brescia	13,2	31	Milano Forlanini	6,3
12	Monza	13,0	32	Crema	6,1
13	Milano Porta Romana	12,6	33	Seregno	5,3
14	Milano Lambrate	11,9	34	Abbiategrasso	5,2
15	Como S.Giovanni	11,7	35	Treviglio	5,2
16	Sondrio	11,5	36	Tirano	5,0
17	Milano Porta Vittoria	11,4	37	Busto Arsizio	5,0
18	Lodi	10,9	38	Lissone-Muggiò	4,9
19	Monza Sobborghi	10,8	39	Magenta	4,8
20	Pavia	10,7	40	Melegnano	4,8

Table 3.8: *List of the first 40 station ordered by score. Milan stations are in the top positions.*

3.4.1 Evaluating consistency and stability of the scores

The score that has been computed is a good proxy of the attractiveness of the surrounding area in which the station rises. This value, however, cannot consider the diversification in the offering of services. As a matter of fact, the single score value only tells how many points the station gets starting from its availability of activities. It does not tell what are the main typologies of services that contribute to the final score, meaning that the information about the entity of the original partial scores gets lost once those are summed together. Moreover, there is no clue about the variability that the partial scores assume. Hence, two new indicators could be introduced to describe how uniform and stable are the contributions of partial scores to the definition of the final score.

Firstly, the *relative standard deviation* can easily measure the variability of the partial scores and relate them to the average of the distribution. A low values signals a quite constant distribution while higher values stand for greater levels of irregularity.

In mathematical terms,

$$\sigma^* = \frac{1}{\overline{x}}\sqrt{\frac{\sum_i^N (x_i - \overline{x})^2}{N-1}}$$

where x_i is the i-th element of the distribution, $\overline{x}$ is the mean value and N is the number of samples.

Secondly, the *skew* parameter allows to calculate how skewed or uneven are the partial scores that each station obtains. Generally speaking, the skew is an index that yields a measure about the absence of symmetry in a distribution, and in the discrete domain it is computed as follows

$$Skew = \frac{\sum_i^N (x_i - \overline{x})^3}{(N-1)\sigma^3}$$

When applied to the case study, the skew parameter is calculated on the set of partial scores of each station. A value close to zero translates into a good even spread of values, indicating that the different services, scaled by their respective weight, are equally important. A value far from zero, on the other hand, is an indicator of a strong asymmetry in the presence of services, where few categories are drastically more relevant than the others. The skew can assume both positive and negative values depending on the direction of the skewness of the distribution. This, however, is not relevant from the point of view of the analysis and can be neglected by imposing the absolute value of the skew. Figure 3.1 shows two remarkable examples that well illustrate the concept of variability: Varese station presents consistent levels of unevenness than Rho, whose partial scores instead appear much more stable. Therefore, such a parameter could represent an important criteria to distinguish the stations, marking them as either well distributed in services or with evident imbalances in the offering of activities. Table 3.9 lists the skew parameter and the relative standard deviation of some important stations in the region, next to their score.

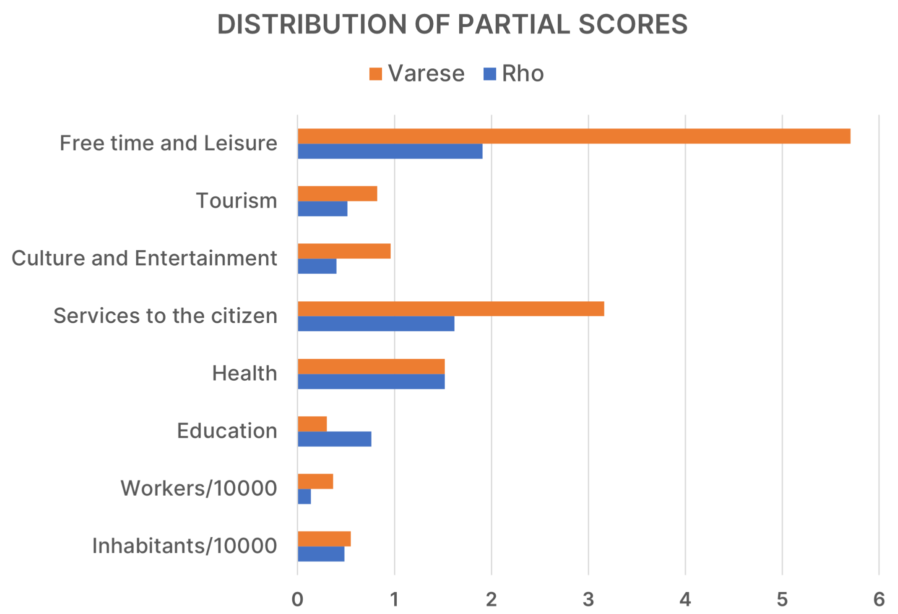

Figure 3.1: *Example of different distributions of scores in two different stations. Varese ($\sigma^* = 1.12$, Skew = 1.78) shows more irregularities than Rho ($\sigma^* = 0.72$, Skew = 0.50).*

3.5 Integration of ODM data and further analysis

The previous paragraphs highlighted a methodology that allowed to gather the necessary data, categorize the different services and develop a scoring technique in order to classify and rank the different stations under and attractivity point of view. This series of processes, while they allowed a synthetic evaluation of the offering in proximity of the stations, they had no ability in assessing the demand side of the analysis. As a matter of fact, the preliminary results that were obtained did not consider important elements like the flow of passengers and the typology and habits of the station users. For this reason, the analysis has been complemented by additional data coming from RFI's Osservatorio di Mercato (ODM), a permanent research, analysis and monitoring laboratory with the mission of assessing the perceived quality of the rail service, usage patterns, opinions, preferences and needs from the users. This instrument has been activated since 2004 and futher extended in 2013 to include also the rail freight transport.

The ODM data collection process takes place through surveys taken from actual train users of over 760 RFI stations, that manage in total almost 94% of the total traffic. About 183.000 interviews are made each year to travellers above 14 years old

Station	PARTIAL SCORES								SCORE (Σ)	SKEW	Relative ST.DEV
	Inhabitants/ 10000	Jobs/ 10000	Education	Health	Services to the citizen	Culture and Entertainment	Tourism	Free time and leisure			
Milano Centrale	1,08	1,60	3,19	5,02	6,15	0,91	14,43	17,21	49,6	1,15	1,01
Milano Porta Venezia	1,19	1,12	1,82	5,32	5,28	2,53	13,29	19,00	49,6	1,41	1,06
Milano Repubblica	0,45	1,57	1,98	3,80	5,97	2,58	14,84	15,39	46,6	1,15	1,03
Milano Porta Genova	1,25	0,49	1,37	2,74	3,34	1,31	4,33	10,60	25,4	2,04	1,02
Milano Porta Garibaldi	0,85	0,84	0,30	3,19	3,49	1,52	4,64	10,41	25,2	1,76	1,05
Milano Dateo	1,32	0,54	1,67	3,34	4,31	0,40	4,64	6,62	22,8	0,51	0,78
...	...	...	...	...	...	...	...	...	...	...	...

Table 3.9: *List of the some major Lombardy station ordered by score, completed by the skew parameter.*

regarding the evaluation of the perceived quality. Moreover, about 9.900 measurement are carried out each year by the so called "mystery clients", specific personnel that, under full anonymity, lives in first person the experience of the station to understand strengths and weaknesses of the offered service in the most objective way [30]. The gathered data coming from the on-field sampling are then grouped together and fully analyzed to model the user's behaviour and generate a series of performance indices to assess the overall quality of the rail service. What is of particular interest for this thesis work is to understand in a deeper way what are the main features of each Lombardy rail station, as well as rating the main usage patterns of the train users. Therefore, the focus of this paragraph is to present and explain relevant data coming from the ODM dataset and integrate them into the initial analysis. Starting from 2018, RFI monthly monitors user's mobility in the last mile from/to the station. Through the customer satisfaction survey procedure, the company is able to understand the the typology of mean of transport used to arrive and depart from the station, the reason and the duration of the journey, the permanence time into the area and other samplings that allow for a statistically significant overview of the inflow/outflow of the rail system. An example of the collected ODM data is presented in Table 3.10.

Station name	Pax/year	% Walk access	Work	Study	Vacation/ Leisure	Other	% Walk egress	Access time < 15'	Access time 15' - 30'	Access time > 30'	Perm. time < 15'	Perm. time 15' - 30'	Perm. time > 30'

Table 3.10: *Data fields provided by the ODM surveys.*

3.5.1 Important premise on the management of confidential data

The work that is described in the following paragraphs heavily relied on the availability of precise numerical data coming from the ODM and other public sources provided by administrations and government entities. Due to strict policies put in place by RFI and additional regulations outlined by central authorities, several numerical values could not be reported in this thesis work as they are confidential. These data are considered private by the Italian Transport Regulatory Authority (ART) and sensible for the overall market equilibrium. RFI guarantees the integrity and the security of this datasets and considers them for internal use only. Therefore, the following paragraphs, although they will deal extensively with the analysis based on these sensible information, will not explicitly report the data on which the study is based upon.

3.5.2 ODM: access mode to the station and trip purpose

In recent years, the mobility industry has experienced an increased attention toward the concept of intermodality. The push for finding better organizational models to create a more sustainable and intelligent transportation environments led to greater than ever efforts in the integration of mobility systems. It is widely believed that additional levels of intermodality cause significant contribution to urban accessibility and help in resolving major congestion issues in cities [37].

The ODM surveys data present information about the mode of access of the users of a certain station. The potential alternatives that a person could have to reach the train may be multiple, thus a more precise understanding of the main mobility habits represent a valuable source for the railway company to better organize the station systems. The ODM data that are cited in Table 3.10 show the percentage of users that reach and exit the station by foot, as the entire analysis is focused on the concept of hyperproximity and accessibility.

The results obtained from the survey at the national level remark how, in more than 40% of the cases, people that reach the 760 RFI stations move by foot only. Another 31% uses public transport options, 41% goes by bike while about 27% takes a private vehicle. These values are fundamentally different from the ones elaborated for the entire urban Italian population: here more than 62% of the people uses the car or bike for their daily trips while only 22% relies only on walking [Figure 3.2].

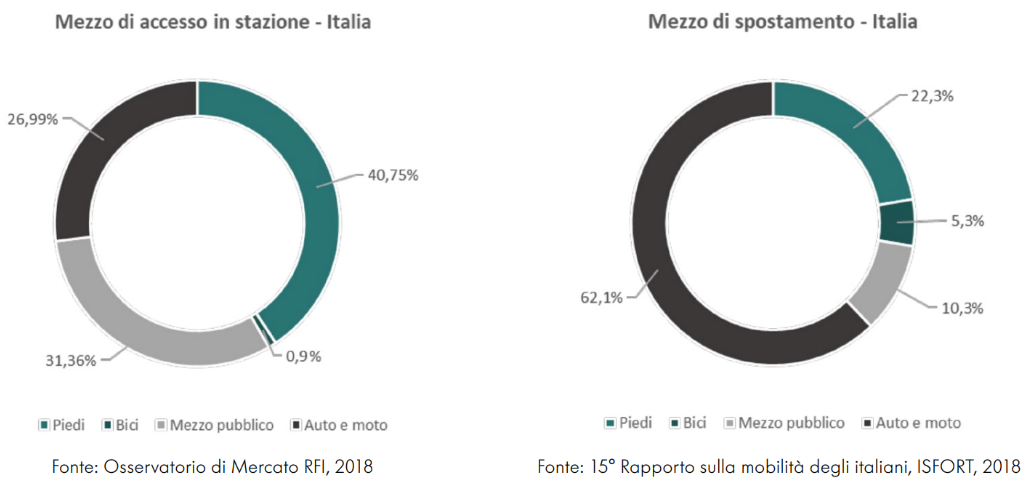

Figure 3.2: *Modal share for habitual train users and for the total of Italian urban citizens. Station users are confirmed to rely much less on private vehicles than the rest of their compatriots.*

Considering instead the perimeter of the work - the Lombardy region - the ODM shows the presence of a large number of stations that are reached mainly by walking users. The ODM shows that there are at least 43 stations in the region in which more than 50% of the users move by foot. Some remarkable examples on this evidence are below reported [Table 3.11]. Several Milan stations and provincial nodes register really high walking access values.

Furthermore, the ODM data [see Table 3.10] also points out the trip purpose of walking users. The surveys answers have been subdivided into three main categories - namely *Work*, *Study*, *Vacation and Leisure* - that well represent most of people's intentions. The *Other* category is added too in order include all the additional reasons.

Station
Milano Dateo
Milano Porta Romana
Lodi
Milano Porta Vittoria
Pavia
Milano Lancetti
Cremona
Legnano
Rho
Milano Porta Venezia

Table 3.11: *Major stations ordered by the percentage of train users that access by foot.*

These values are or remarkable importance since they allow to understand the main usage of the station, providing useful guidance for future intervention and development of services in the area. Table 3.12 shows the rankings of walk access percentage for work-oriented and study-oriented stations respectively. There are indeed stations in the region with almost the totality of walking users that use the train for working purposes, while other nodes have a distinct vocation for student travelling. Numerical values could not be reported in the tables, being them for internal use only. The table, however, can give insights of the usage pattern of some important stations.

3.5.3 ODM: access time to the station

The ODM provides useful insights on the user mobility dynamics and daily habits. One fundamental piece of data when dealing with the concept of walking accessibility and urban proximity is the access time to the station. The on-field surveys asked people to indicate how much time they took to reach the station by walking, and split the results into three main categories, namely *Less than 15 minutes*, *Between 15 and 30 minutes* and *More than 30 minutes.* This time indication can give a clear idea of the present situation about station accessibility and reachability: an high percentages of users that reach their destination in less than 15 minutes can be related to good levels

Ranking	**Work trip purpose (Walking)**	**Study trip purpose (Walking)**
1	Airuno	Milano Greco Pirelli
2	Camnago-Lentate	Ponte S.Pietro
3	Varenna-Esino	Sesto Calende
4	Calusco	Treviglio
5	Rho Fiera	Palazzolo sull'Oglio
6	Cantù-Cermenate	Bergamo
7	Albairate-Vermezzo	Albizzate-Solbiate Arno
8	Milano Porta Romana	Poggio Rusco
9	Milano Forlanini	Cernusco-Merate
10	Milano Lancetti	Vanzago-Pogliano

Table 3.12: *Top-10 stations ordered by the percentage of users reaching the station by foot, with work ans study trip purposes respectively.*

of infrastructure development and urban organization. On the other hand, a large number of users that fall into the other two categories are a synonym of a situation that can be potentially improved. The portion of people that takes between 15 and 30 minutes to reach the station are of particular interest for the analysis as those users, with proper infrastructure upgrade, could arrive at their destination in less than 15 minutes, therefore allowing to be included into the concept of a 15' station. The purpose of building a rich and livable quarter should not, in fact, be limited to the creation and the restructuring of service already in proximity but should also aim at the expansion of the 15 minutes isochrone in poorly reachable ares. Figure 3.3 displays two maps: the one on the left represents the percentage of users that take less than 15' to get to the stations, the one on the right shows instead the portion of people in the region taking between 15' and 30'. This last image visualizes how there are still important Lombardy cities than do not allow passengers to move from their starting point to the station in short amounts of time. For instance, Treviglio, Mantova, Busto Arsizio and Milano Villapizzone still present between about a third of users experiencing walking trips longer than 15 minutes.

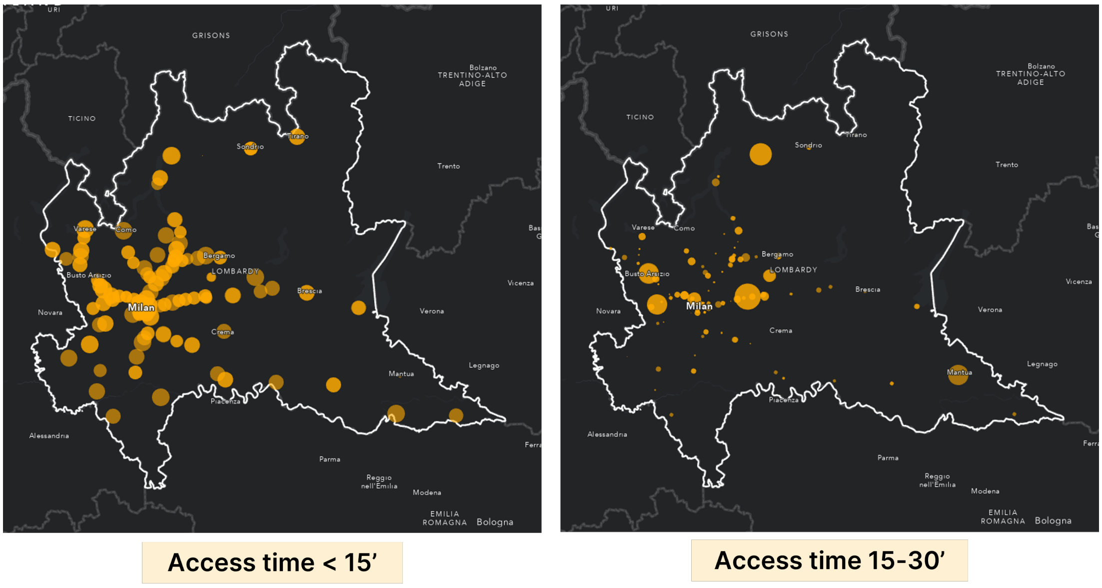

Figure 3.3: *Maps showing the distribution of stations with two different access times (access mode: Walking).*

3.5.4 ODM: passenger-score ratio

Section 3.4 illustrated a methodology for computing and assigning a score to each station of the Lombardy region while section 3.5.2 and 3.5.3 presented a series of considerations on the habits of train users. Another relevant piece of information featured in the ODM is the annual passenger flow of the stations, a numerical count that reports how much the station is frequented by people. Therefore, the previously calculated attractivity score of the stations has been put in relation to the total traffic flow, computing the ratio between the passenger flow and the score.

$$(Passenger \div Score)_{station} = \frac{PassengerFlow_{station}}{Score_{station}}$$

This ratio shows the number of yearly passengers flowing into the stations for each point of attractivity scored. In other words, the passenger-score ratio indicates how much the station is congested with respect to the services it offers. An high value therefore represents a situation in which the number of users that frequents the station is significantly higher than its score, describing a case where the offer of proximity services is not keeping up with the passenger flow. On the other hand, a low passenger-score ratio is synonym of a situation in which the availability of services is positively comparable to the amount of traffic. Therefore, a ratio that is low is preferable. Figure 3.13 lists the worst 10 stations of the region in terms of passenger-score ratio, ordered therefore from the the biggest value to the smallest. Rho Fiera results by far in the highest number of passenger for each point of score it received. The first large intermodal hub that features high values of the ratio is instead Milano Rogoredo.

Worst 10 stations in terms of passenger-score ratio
Rho Fiera
Villamaggiore
Albairate-Vermezzo
Milano Rogoredo
Certosa di Pavia
Cassano d'Adda
Pieve Emanuele
Segrate
Milano Greco Pirelli
Pioltello-Limito

Table 3.13: *Worst 10 stations from the point of view of Passenger-Score ratio. Rho Fiera presents indeed really few services but a really high passenger flow.*

Such high values reported in Table 3.13 suggest that these stations could potentially be improved from the point of view of livability and richness of activities and opportunities. In any case, each of these stations would present unique peculiarities and characteristics, therefore requiring more specific analysis for a deeper understanding of the reasons of such a low attractiveness. A methodology for a more in depth analysis of the station surroundings will be proposed in the next chapter.

3.6 Additional exploration of data

A further step towards a deeper understanding of the data has been made by a new set of analysis aimed at producing valuable outputs and models. The construction of the complete station database required the collection of data from different sources, starting from the initial database of services and demographic data with 276 stations, to the ODM dataset containing user surveys on the usage of the stations and traffic flow figures (105 stations analyzed). Therefore, the merging of all the different blocks of data resulted in a final database of over 100 stations, of which much information on both the demand and offer side are known.

The following performed analysis had the objective of finding possible correlations between the variables and to visualize particular patterns that could emerge from the data points distribution. This activity may in fact result in valuable insights on the relationship of the different data entries.

3.6.1 Correlation of services categories

A powerful tool that could be exploited is the so called Correlation Matrix [Figure 3.4]. It is a visualization structured in a matrix form that shows the Pearson correlation coefficient (ρ) of the different variables that are chosen as input. The matrix is squared with dimension $n \times n$ and symmetric since $\rho_{ij} = \rho_{ji}$. In this case, the six categories of services plus the passenger flow are analyzed and the values of the ρ coefficients are displayed through a color scale that emphasizes higher scores. For the sake of clarity, only half of the matrix is showed thanks to its symmetrical structure. The correlation matrix highlights particularly high correlations among Services to the citizen and Health activities as well as Free time and Leisure against Health, Services to the citizen, Culture and Entertainment and Tourism attractions. This behaviour can confirm that there is a tendency for many cities of the region to promote the birth of activities where others are already present. For example, the presence of cultural facilities and touristic POIs favours the birth of other leisure activities in the area, or that health services are a promoting factor for additional services to the citizen. This positive correlation between the variables emphasises how the services development can potentially generate a virtuous circle, further promoting the development of the city and accelerating its attractivity.

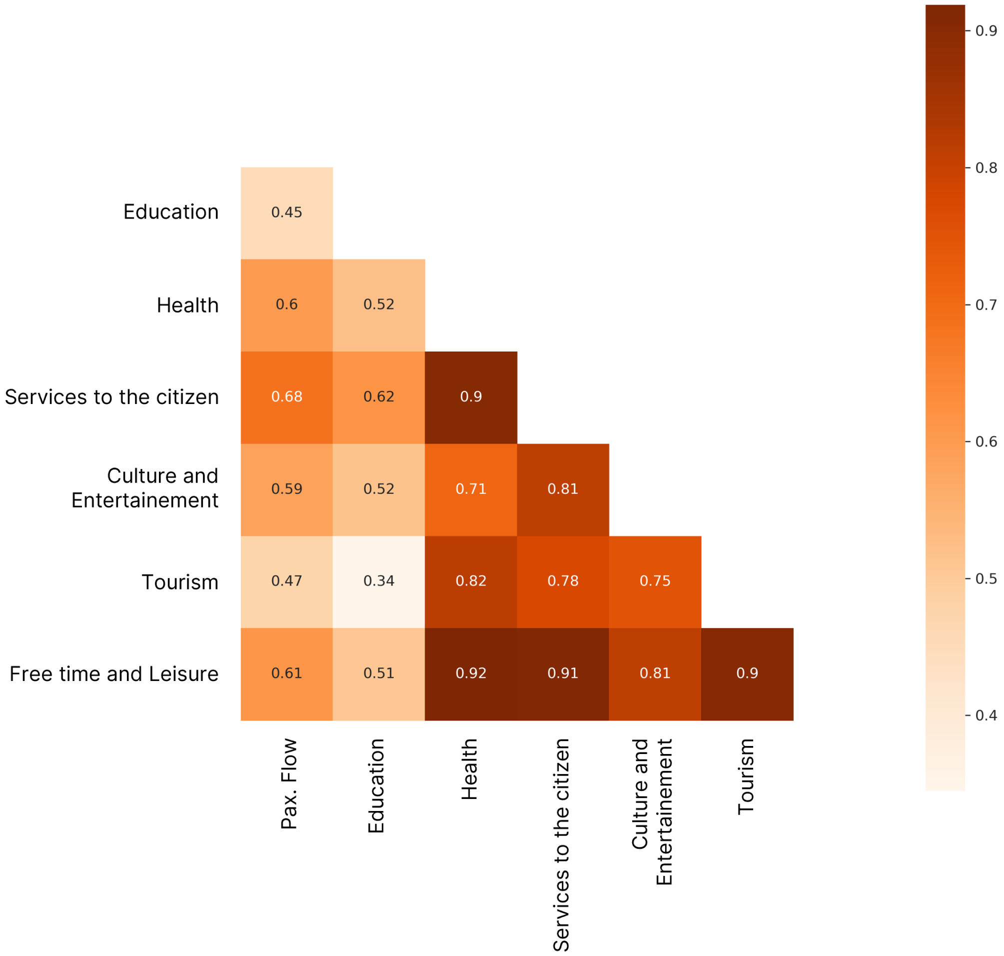

Figure 3.4: *Correlation matrix of the six macrocategories of services analysed and passenger flow. Higher correlations values are highlighted in darker reds.*

3.6.2 Scatter plots from database variables

Further analysis tried to observe the relation between different variables of interest with the usage of scatter plots [Figure 3.5 and 3.6]. A scatter plot is a Cartesian representation of data points that can evidence the presence of particular data patterns and help in the explanation of such distributions. Hereafter, four results of particular interest are reported.

The first graph [3.5] plots the relation between the number of inhabitants living in the 15 minutes basin around the station with the number of train that arrive and depart from that station each day (values are normalized). The ODM in facts provides, in the form of aggregate data, also the daily offering of rail service. The data points are rather scattered in the plane and the coefficient of determination (R^2) is quite low. It is however possible to identify a certain trend in the distribution: an high number of residents generally corresponds to an higher number of trains per day. There are in any case some exceptions - highlighted in light yellow. There is in fact an evident horizontal distribution of points at different values of inhabitants, caused by the service offered by the Passante Ferroviario under the city of Milan. The number of trains is in fact constant on the entire underground line while the number of people living in the basins still depends on the part of the city in which the station is built. Moreover, two stations present a really high number of residents while not being offered with much rail traffic - namely Milano Porta Genova and Milano Porta Romana.

The second graph [3.6] shows instead the relation of the number of workers in the walking basin against the daily train flow. The correlation between the two measures is again quite low and no trend can be easily identified among the points. In light yellow are highlighted the stations of the Passante Ferroviario. The data point with the highest train count represents Milano Centrale.

Figure 3.7 compares the percentage of passengers reaching the station by foot with the attractivity score calculated in paragraph 3.4. This scatter plot is of primary importance since it relates the walking habits of the users with the capability of the city to offer services and activities. Two evidences arise from the exploration of this graph. The first is the recognition that the two variables are not in any way correlated ($R^2 = 0.003$), meaning that an increased level of walking access does not relate to higher density of services and vice versa. The dots distribution generally lies in bottom of the graph, indicating the presence of many stations with relatively low score but very different percentages of walking access. Another evidence concerns the position of some stations in the plot, with three zones that are highlighted in green - labelled A, B and C respectively - that represent three particularly interesting areas of analysis.

Ellipses A represent stations that do get a really high score thanks to the outstanding density of services of various kind but that users only marginally reach by foot (Milano Centrale, Milano Porta Porta Venezia and Milano Repubblica). Such a discovery remarks that these hubs rely much on public transport and consistent levels of walk access are therefore not to be expected.

Ellipse B highlights a series of stations - Varese, Lecco and Milano Porta Genova - that feature only a low percentage of users accessing the place by foot but three quite different attractivity scores. These examples tend to remark the uncorrelation between the walkability of the area and the number of services.

Finally, Ellipse C underlines a set of stations that present really high levels of foot access but tiny scores. Such stations are Vignate, Sannazzaro, Locate Triulzi, Milano Villapizzone and Milano Greco Pirelli. The first three are small stations that reasonably feature few services while Milano Villapizzone and Milano Greco Pirelli can potentially have great margins of improvement in the enrichment of the walking basin. The high frequency rate of the stations, combined with wide walking habits could be a factor for future requalification of the stations and their surroundings.

Figure 3.8 puts in comparison the yearly passenger flow of the stations with the station score. The R^2 coefficient shows a certain degree of correlation between the variables, meaning that the passenger flow can be considered as a possible proxy for the determination of the score, but not as a determining factor. There are indeed some anomalous stations, such as Milano Porta Venezia and Milano Repubblica (D) and Milano Centrale (E), that features really high scores while presenting very different levels of user traffic.

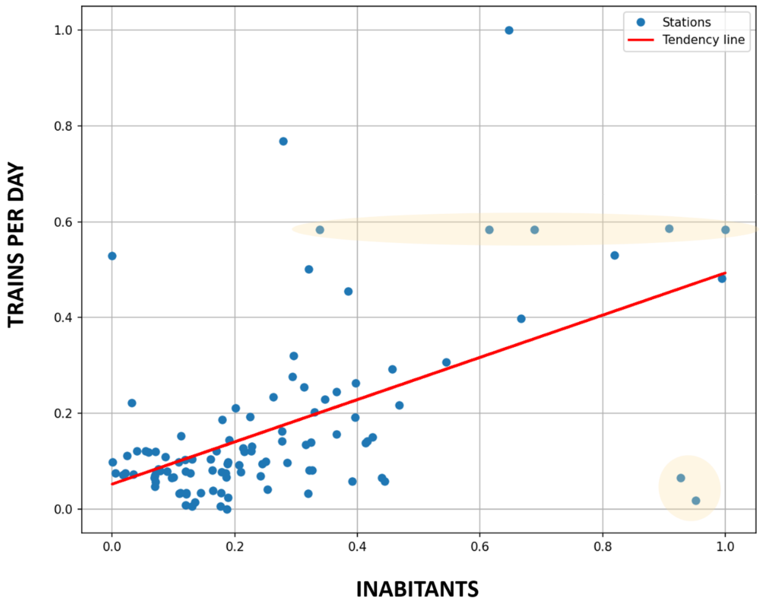

Figure 3.5: *Scatter plot of the number of inhabitants in the 15' basin against the number of trains per day.*

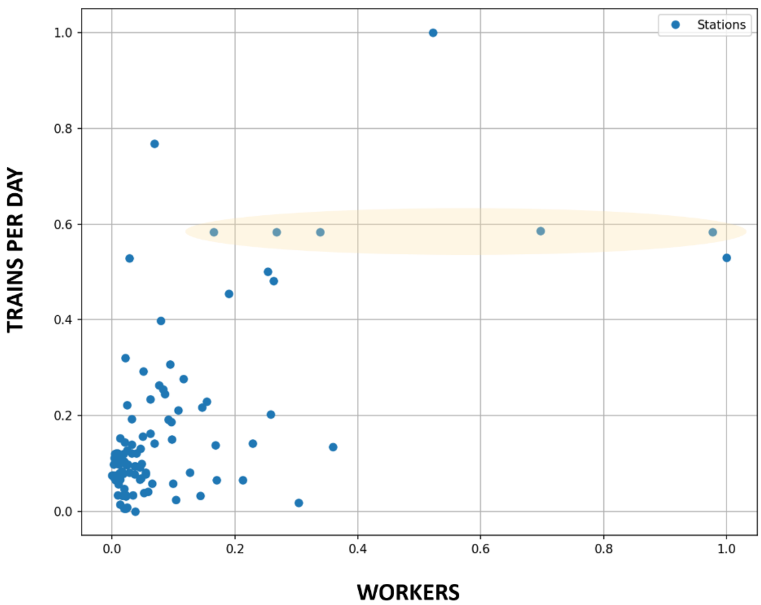

Figure 3.6: *Scatter plot of the number of workers in the 15' basin against the number of trains per day.*

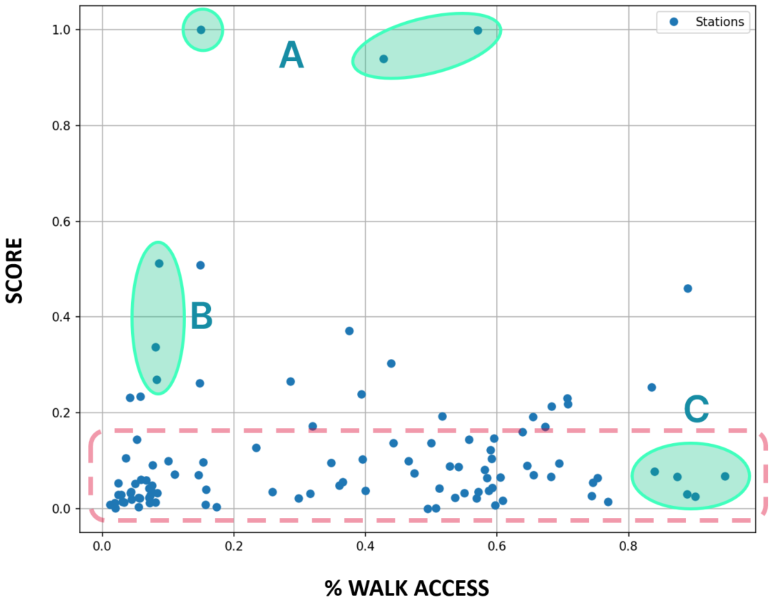

Figure 3.7: *Scatter plot of percentage of user reaching the station by foot and station score.*

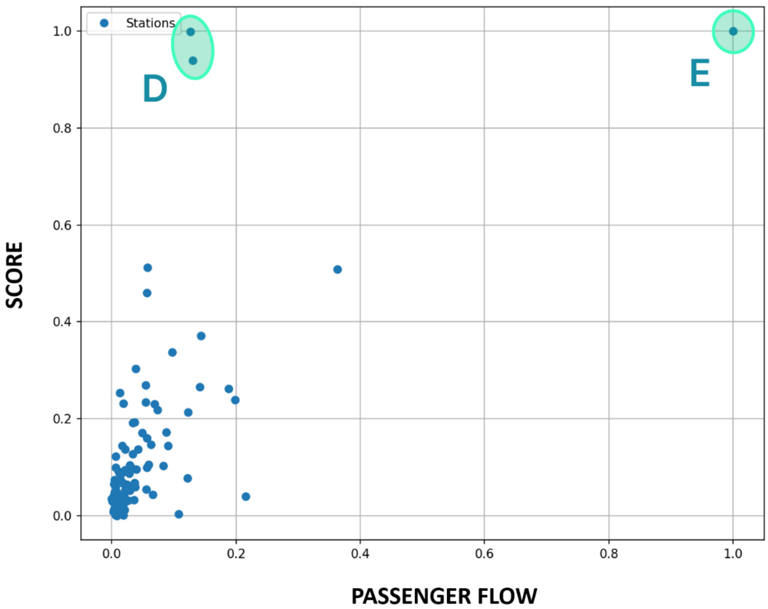

Figure 3.8: *Scatter plot of passenger flow and station score.*

Chapter 4

In-depth focus on relevant stations

The analysis conducted up until this point aimed at assessing the As-is situation on the stations of Lombardy region. The initial collection of georeferenced data allowed for a first understanding of the presence of services in the vicinity of the stations. The elaboration of a hierarchical criteria on the different types of activities - the AHP method - and the computation of a synthetic score allowed for an important classification of the rail nodes on an attractivity basis. Finally, the integration of data coming from the company market observer, along with further visualization of data points, permitted a complete overview of the situation and a better knowledge of the correlation of variables.

The next step that was envisioned in this thesis work is a more in depth analysis of some particular stations which appear of particular interest for the company and that could represent a development ground for future accessibility interventions. As a matter of fact, the efficacy of the monetary investment in civil works and urban renovation is more reasonably justified where the station already presents a sufficient level of attractiveness and where enough users already access the area by foot. Moreover, features like access time and permanence time may also represent an indicator of how close is the station to the concept of a 15 minutes city and, in general, on the idea of hyper-proximity of services and urban functions. Therefore, a series of station has been identified to be more precisely analysed from the point of view of the demand - namely the traffic flow, the user typology and the user's mobility habits - and the offer - represented by the number, type and spatial distribution of services throughout the station basin.

4.1 Criteria for stations selection

The final database features 105 stations, of which the complete set of information on the demand and offer side is available. Thus, starting from this dataset, a series of filters have been applied in order to identify what rail nodes present most of the preferable characteristics that would justify the expenditure of resources for better livability, accessibility and integration of services.

The general criteria that have been adopted for the selection are the following

Score - Stations with relatively high scores have been privileged. The score is a clear proxy for the attractiveness and the richness of the station in terms of services and opportunities.

Percentage of access by walk - The mode of access is of critical importance when developing a model built around the concept of proximity of urban functions. Therefore, the percentage of users arriving at the station by walking is believed to be a good indicator of the predisposition of the station in being friendly to pedestrians.

Access time - The time it takes for a user to reach the station plays a significant role in the understanding of how well the rail node is connected to the rest of the city. Both the percentage of passengers that take less than 15 minutes and between 15 and 30 minutes for their trip has been considered.

Passenger flow - The number of users that each year passes through the station is another clear index that denotes its significance in the entire rail network of the region.

These criteria could represent a useful guidance for the identification of relevant stations in the context of attractiveness and accessibility. Therefore, those filters have been applied on the initial list of stations in the order that has been presented, thus favouring the score as a first principle of selection, followed by the other three.

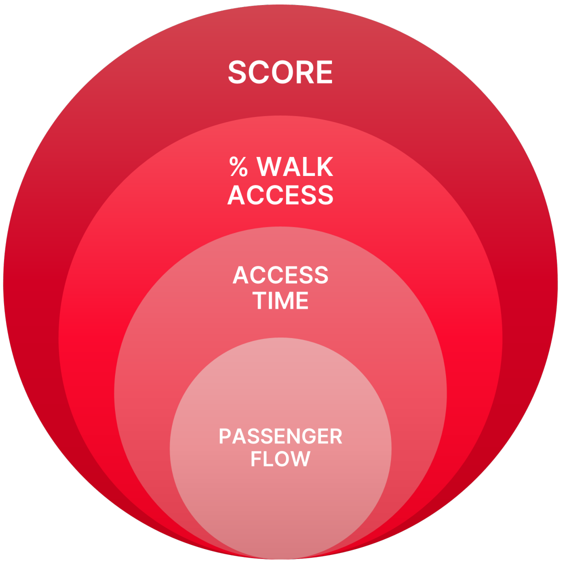

Figure 4.1: *Criteria used in the determination of the stations with the greatest potential of development. The score represents the first filter used in the analysis, followed by the other three.*

4.2 Selected stations

Two stations have been chosen to be analyzed more in-depth in order to understand what may be the motivations of their overall good capacity of favouring both the birth of services of different kinds and a high level of walking accessibility. The series of filters explained in paragraph 4.1 have been used to highlight which stations succeed to meet these criteria of chronourbanism.

Figure 4.2 illustrates the process of selection of the stations starting from the initial database of 105 stations. First, a cleaning process on the variables has been carried out, removing the station with passenger flow below the 5th percentile and above the 95th percentile, in order to obtain more stable and realistic results when computing statistics on the data. In fact, by excluding the largest and the smallest stations unwanted distortion in the analysis could be avoided. The resulting datasets therefore is composed by 93 stations. The filtering action has then been performed by the usage of the average values, meaning that, at each iteration, the stations which feature values of the fields above their overall average have been kept while the others have been discarded. The diagram in Figure 4.2 visually represents the different stages of selection, by picking out the stations that present a score above average (n.26), a percentage of users accessing the station by foot that is over the medium value(n.17) and then splitting the dataset into two categories - namely stations in which most users arrive at the station in less than 15' and stations that instead require between 15' and 30' of walking to be reached. Finally, a last filter on the passenger flow has been applied. The stations with a yearly number of passengers above the medium value of the dataset have been selected (highlighted in light green). This process therefore identified 13 station over 93 that simultaneously feature a score, a walk access, a walk access time and a passenger flow that is above average for the region.

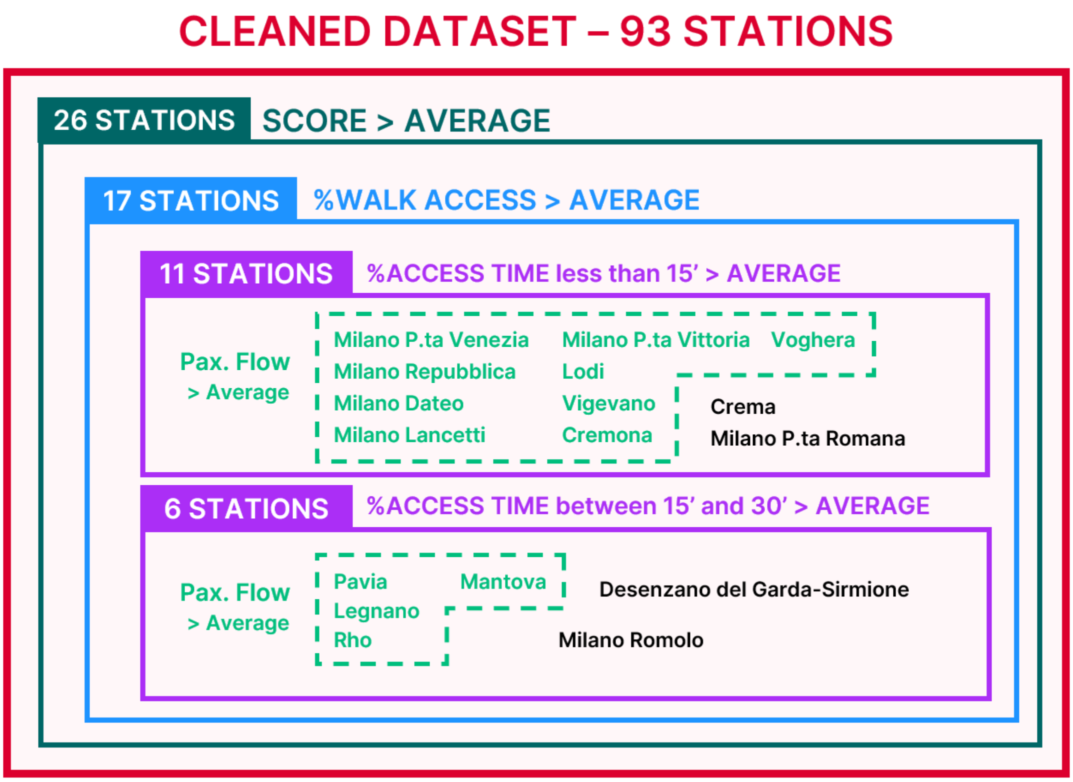

Figure 4.2: *Process of selection of the station from the initial database. A series of filters have been applied, obtaining in the end 13 stations.*

Table 4.1 shows the list of 9 stations, with access time by foot under 15 minutes, that emerged from the application of the above mentioned criteria. The table shows that several Milan stations and some medium-size nodes meet the conditions imposed by the filters. A choice on where a deeper analysis could be made can then be performed. Among these 9 stations, Lodi has been selected as the stations to be studied further for a series of reasons listed below:

- Stations included in the boundaries of the city of Milan should generally be considered as a separate entity, as they belong to a much more complex system of transport infrastructures (such as metro, tram and sharing mobility) that closely interact with the station environment. Therefore, the choice has been explicitly done toward a more traditional station, outside the characteristics of a metropolitan area.
- In the context of walking accessibility and the creation of a more livable urban environment around the station that promotes soft-mobility habits, Lodi presents the highest walking access of users among the non-Milan stations.
- Excluding Milan, Lodi maintains the highest passenger flow and the highest number of trains per day.
- The city obtains a quite high score, meaning that it has a good offering of services and decent attractivity capacity.

Table 4.2 shows instead the resulted output of the selection, this time from the pool of stations that require between 15 and 30 minutes of walking to be reached. A total of 4 stations has been identified with features above the average. Among the four, Pavia has been selected for a thorough evaluation. In a way similar to Lodi, this station was chosen because of several reasons:

- Pavia presents the highest passenger flow of the four stations.
- The number of users that use to reach the station by foot taking between 15 and 30 minutes is the highest. Even though, in percentage terms, the city of Mantova reports the highest percentage of the users walking to the station, in absolute terms the city of Pavia still has a higher value, since Pavia manages a passenger flow that is above the one of Mantova.
- While not the highest of the pool, Pavia still obtains a quite high score, indicating a good vivacity of the area.

Station	**Score**	**Skew**
Milano Porta Venezia	49,5	1,41
Milano Repubblica	46,5	1,15
Milano Dateo	22,8	0,51
Milano Porta Vittoria	11,4	0,57
Lodi	10,8	1,08
Cremona	9,5	0,56
Vigevano	9,5	0,46
Milano Lancetti	8,5	1,06
Voghera	6,8	0,45

Table 4.1: *Pre-selected stations of the region featuring high percentages of users taking less than 15' of walking to reach them.*

Station	**Score**	**Skew**
Mantova	15,1	0,82
Pavia	10,7	1,18
Legnano	8,0	0,38
Rho	7,3	0,50

Table 4.2: *Pre-selected stations of the region featuring high percentages of users taking between 15' and 30' minutes of walking to reach them.*

4.3 Spatial GIS analysis

The two stations that were identified as a case study for more precise evaluation were subject of several analysis conducted through the ArcGIS software. These kind of spatial assessments have the objective of visualizing the distribution of services and activities in the city as well as understanding how the stations spatially relates to the majority of points of interest in the area. The GIS evaluation should therefore be seen as a complement to the numerical assessments of the stations carried out in Chapter 3, exploring now also the physical dimension of the urban organisation. This phase of the work carried out via GIS can be subdivided into three different analysis, each of them aiming at understanding a different characteristic of the city in which the stations is positioned.

4.3.1 Computation of the services centroid

The first geographical indicator that was elaborated is the centroid of all the services available in the 15 minutes walking basin of the station. The centroid - sometimes called "center of gravity" - is the point in the plane obtained as the geographical mean of all the points of a cluster. The centroid is therefore a good proxy for understanding where the majority of services lie in the walking basin and how close to the station this center of mass of the services is. The computation of the centroid has also been pondered by the weight assigned to each category of service in Chapter 3, meaning that the point will tend to shift towards the services that have been assigned with the greater importance (i.e. the ones with the highest weight).

The formula for the calculation of the centroid coordinates is shown below

$$C(x;y) = \left(\frac{\sum_{i=1}^{N} w_i \cdot x_i}{\sum_{i=1}^{N} w_i} ; \frac{\sum_{i=1}^{N} w_i \cdot y_i}{\sum_{i=1}^{N} w_i} \right)$$

where x_i and y_i are the coordinates of the i-th service present in the basin and w_i is the i-th weight of which each service belongs to.

4.3.2 Calculation of the directional ellipse

Another type of spatial analysis that was carried out was the computation of the directional distribution of the services through the Standard Deviational Ellipse. The method calculates the standard deviation of the x-coordinates and y-coordinates from the centroid to define the axes of the ellipse.

Standard deviations help understand the dispersion or spread of the data. When working with one dimensional data, the 3σ rule is the common rule indicating the percentage of data that will fall within one, two and three standard deviations of the mean. In a normal distribution, this would mean 68%, 95% and 99.7% of the data values will fall within one, two and three standard deviations respectively. However, when working with higher dimensional spatial data, this breakdown of percentages is rarely observed. A more appropriate rule derived from the Rayleigh distribution suggests that a one standard deviational ellipse will cover approximately 63% of the features, two standard deviations will contain approximately 98% of the features and three standard deviations will cover approximately 99.9% of the features. The generated ellipse therefore allows to see if the distribution of features is elongated and if it has a certain orientation in the space. This technique allows to understand whether the disposition of services around the station follows some peculiar pattern, which may represent a clue on how the city is structurally organised.

4.3.3 Elaboration of the service heatmap

The final analysis that was carried out was the creation of the density heat map of the services. This visual representation allows to catch what are the areas of the city in which the greatest concentration of services is located. The heat map makes use of a color scale to indicate the intensity of the represented feature: brighter colors stand for the "hottest" zones of the map, while darker colors are synonym of low services density. Moreover, the heat map can reveal particular distributions of the activities, such as most served roads, streets or major services conglomerates.

4.4 Selected stations: results

The methods described in Paragraph 4.3 have been applied to the selected stations of Lodi and Pavia, in order to understand their main spatial features and distribution of services around their respective railway stations. This kind of activity may be of particular utility for both the railway operator and the city municipality, as those two actors may exploit this gained knowledge on the urban structure of the station surroundings to understand where it is more effective to intervene with civil works and urban regeneration projects. These analysis should not be intended as a replacement for the actual on-field information gathering, but rather as a complement that could help the authority in the early stages of decision making. The following paragraphs will illustrate the As-is situation of the two stations.

The Appendix at the end of the document will list several other important stations of the region, presenting a spatial analysis for each of them.

4.4.1 Lodi

The station of Lodi is located in the south-east of Milan and represents an important railway node for the inhabitants of Lodi's province, connecting the southern part of Lombardy to Milan and the other more populous areas of the region. As of 2021, a total of 44,599 inhabitants live in the city [ISTAT data], ranking 20th among all Lombardy cities. Regarding the rail service offer, Lodi is served by the Passante Ferroviario with S1 line as well as major regional lines that connect it to other important urban conglomerates in the region. RFI reports a number of trains per day stopping at the station that is above average.

The ODM data indicate that the vast majority of train users move for working reasons, followed by schools or university and other various activities. The surveys carried out in Lodi also estimate that the vast majority of the users reach the station by foot, of which the almost totality of them manages to take less than 15 minutes of walk from their starting point. These results show that Lodi station is particularly favourable to pedestrians, not only allowing a major portion of the passenger relying on walking but also permitting them to have the train service within the 15 minutes isochrone.

Regarding the availability of services in the surroundings of the railway node, the station obtains a score of 10.9, putting itself in the top quartile of the scores of the entire Lombardy region. In fact, the 15 minutes walking basin presents high numbers of services of different kind. Figure 4.3 shows the partial scores of the stations gained in each category. The different typologies present quite inconsistent contributions (confirmed by a skew value of 1.08), with *Services to the citizen* and *Free time and leisure* activities that get the highest scores. Within the 15 minutes isochrone, Lodi presents in facts a multitude of restoration, shopping and amusement activities, therefore forming an attraction point not only for the city residents but potentially also for external people.

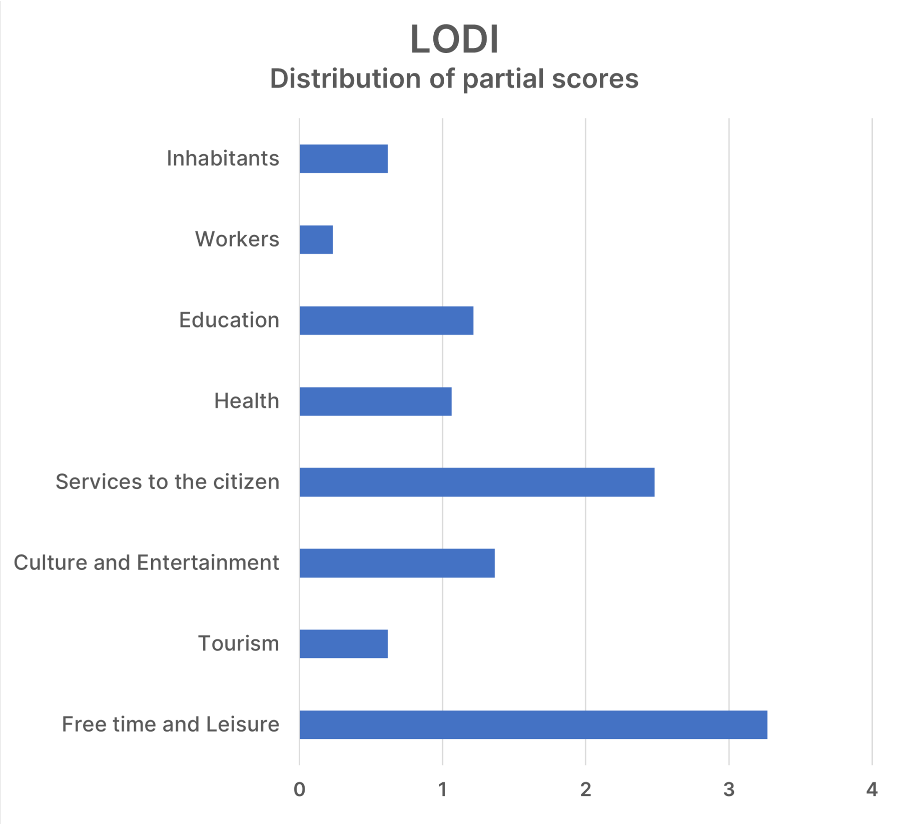

Figure 4.3: *Distribution of partial scores for the station of Lodi. Services to the citizen and leisure activities represent the largest contribution for the total score.*

Focusing instead on the passenger-score ratio, a value of 196,000 passengers per score point puts Lodi in the third quartile of the regional ranking, indicating a station that is not particularly efficient in terms of number of services related to the passenger flow.

Figure 4.4 and 4.5 picture the spatial analysis described in paragraph 4.3 applied to Lodi station. The 15 minutes walking basin is displayed in light blue color while the two train icons represent the entrances/exits of the station on the two sides of the railroad. The color scale of the heat map shows the places in which the highest density of services is present. Figure 4.4 displays all the services with equal weight, meaning that each category of activities has the same importance of all the others. The heat map evidences a greater concentration of services in the city center, with an especially hot cluster in the historical quarter.

Figure 4.5 picture instead another version of the heat map in which each single service has been weighted with the original value that has been associated to its category through the AHP method. This map therefore illustrates what is the density of services in the city when the importance of each point is determined also by the weight. The obtained result is quite different from the one of figure 4.4, showing now a more even distribution of activities in the basin.

Regarding instead the calculation of the centroid (green dot) and the directional ellipse (dashed green), it can be observed that the geometrical center of all the services is not far from the station and that the station itself is included within the ellipse boundary. Moreover, the eccentricity of the ellipse is not accentuated, indicating the lack of particularly shaped distributions of facilities. Overall, these remarks suggest that the station of Lodi is already quite well included into the urban network of activities and functions, and that, in a first analysis, it poses itself as a good model that well fits the concept of a "15 minutes station".

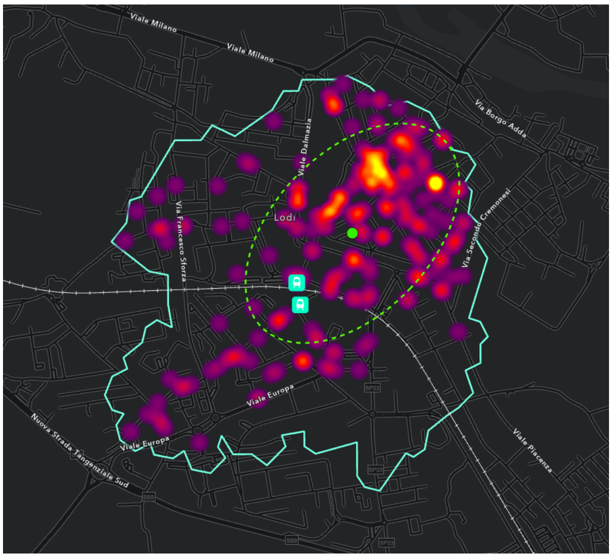

Figure 4.4: *Spatial analysis carried out on Lodi station. The non-weighted heatmap, the services centroid and the directional ellipse are shown.*

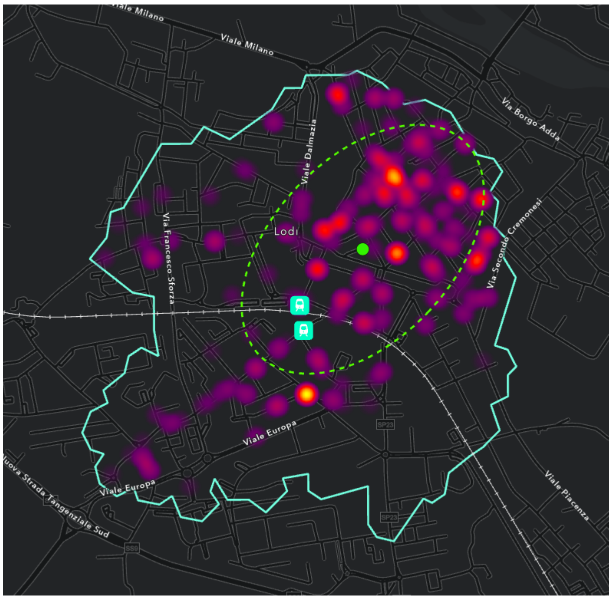

Figure 4.5: *Spatial analysis carried out on Lodi station. The weighted heatmap, the services centroid and the directional ellipse are shown.*

4.4.2 Pavia

The central station of Pavia represents another important railway node for the region. Its central position allows to serve a city of 70,964 inhabitants (ISTAT, 2021), marking the biggest urban conglomerate in the south-west of Lombardy. The stations accommodates for a vast rail services that includes both regional and inter-regional trains. The millions of passengers that each year use the train mainly for working purposes, but education related trips present really similar numbers. Moreover, about three quarters of the users reach the station by foot, with the vast majority of pedestrians that manage to arrive at the station within 15 minutes. Furthermore, a smaller but not negligible portion of users, however, still spends between 15 and 30 minutes of walking to take the train. Therefore, while Pavia station seems not to pose significant obstacles to pedestrians, there is still a portion of inhabitants that are excluded from the 15 minutes walking isochrone.

The pedestrian basin around the station includes a good amount of services, allowing the model to assign Pavia a score of 10.7, putting the station in the first quartile of the scores for the entire region. Figure 4.6 lists the partial scores for the station, highlighting a strong contribution of *services to the citizen* and *leisure* activities, followed by cultural attractions (as Pavia is also rich in terms of cultural heritage) and education. The calculated skew of the partial scores for Pavia station is equal to 1.18, remarking the uneven contribution of some typologies of services over others.

The passenger-score ratio shows a value of 330,000, that puts Pavia stations in the third quartile of the ranking, indicating a really consistent passenger flow with respect to the general offering of services of the basin.

Figure 4.7 and 4.8 show the two heat maps complemented with centroids and directional ellipses. As for Lodi case study, in Figure 4.7 the map presents all the points of interest with equal weights, evidencing high concentrations of services in the east boundary of the walking basin, towards the city center. Moreover, hot spots can be identified also in the center and in the top of the isochrone (University departments and San Matteo hospital respectively). Figure 4.8 shows the output of the analysis with the services weighted with the values elaborated through the AHP method, making more evident those activities that have been assigned to the highest weight. The hottest areas

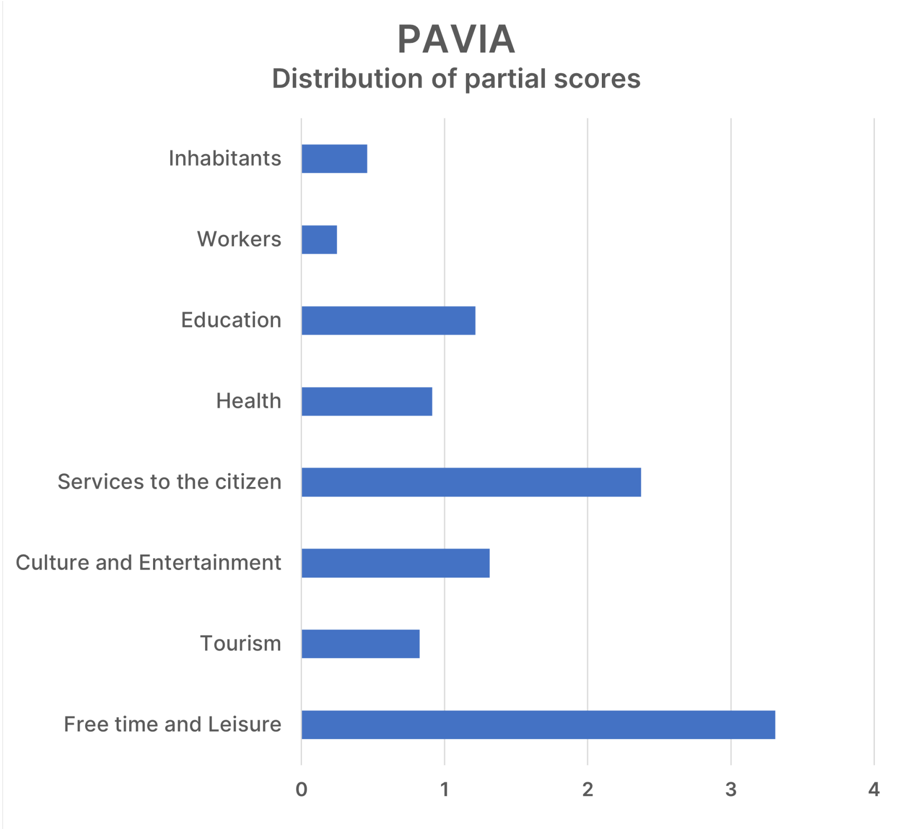

Figure 4.6: *Distribution of partial scores for the station of Pavia. Services to the citizen and leisure activities represent the largest contribution for the total score.*

of the map still remain in the city center, while three clear hot spots become even more relevant (schools and health facility in the south, services to the citizen in the east and San Matteo hospital in the north).

The centroid and directional ellipses indicate instead that the geometrical center of all the services lies really close to the city center (in the weighted version of the map the centroid is only slightly shifted to the west) while the directional distribution remarks that the spread of activities is marginally oriented on the north-south axis. Moreover, Pavia station is located on the edge of the elliptical boundary, pointing out that the railway node is not part of the larger cluster of city services. This matter can potentially be the reason why the ODM surveys report that a significant portion of passengers still do not manage to reach the station in less than 15 minutes of walking, since for many citizens the station is located in the opposite side of the city center.

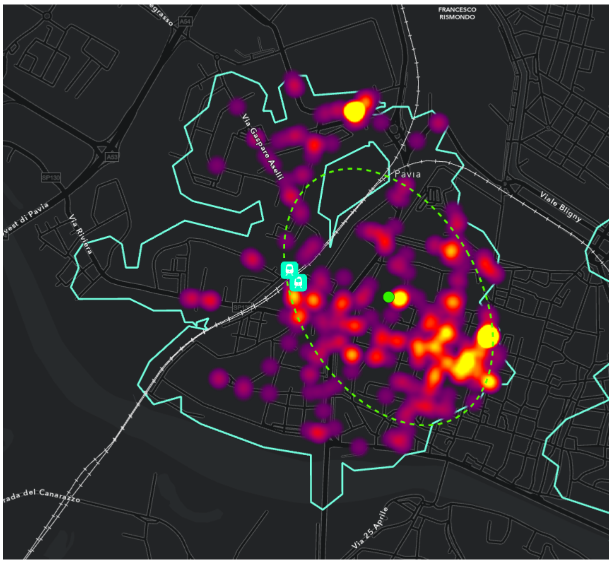

Figure 4.7: *Spatial analysis carried out on Pavia station. The non-weighted heatmap, the services centroid and the directional ellipse are shown.*

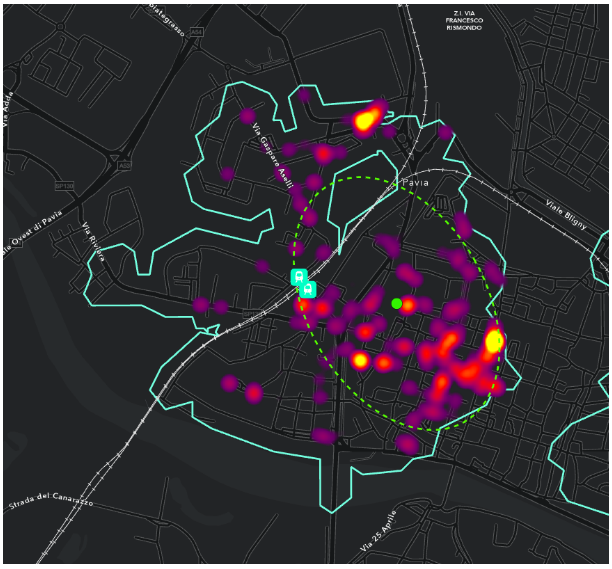

Figure 4.8: *Spatial analysis carried out on Pavia station. The weighted heatmap, the services centroid and the directional ellipse are shown.*

4.5 Focus on health and education vocated stations

As a final step to the work on the regional stations, it was decided to take a conclusive analysis on the most important urban poles for health and educational services respectively. The reason behind such a choice was the project carried out by RFI and Regione Lombardia on the identification of stations to develop new plans for intervention and urban regeneration in key areas. Particular interest emerged for stations with main health and educational facilities. RFI, on its side, provided the public authority with technical support for such analysis. This paragraph, therefore, sums up the results of these assessments.

4.5.1 Health-centered stations

The first part of the evaluation consisted in the identification of those stations in the region that present particular inclination for health services, offering especially important facilities from the point of view of quality or quantity. To achieve such a task and obtain meaningful results, the previously developed mathematical model based on the AHP method and the generation of specific weights for each category of services (see Paragraph 3.3.1) was revisited to highlight in a more evident way the health services.

Previously, the first iteration of the AHP method assigned, through the usage of a matrix, a preference weight to each couple of service categories, creating in the end eight final weights that indicated the relevance of the single typology of service in the city. This second iteration of the AHP method was slightly modified in the chosen preference weights to increase the importance of health facilities with respect to the others, with the aim to make health-focused cities more evident in the score ranking. The new output weights assigned to the different categories are displayed in Table 4.3, next to the original values used in Paragraph 3.3.1. The health sector has therefore been assigned with the highest value (0.393), while the others have seen their weight reduced.

Besides the revisiting of the AHP weights, a second modification to the scoring system has been performed. The original scoring mechanism proposed in the previous chapters saw as input the number of services present in the 15 minutes walking basin for each category. Hence, the final score of the station had been calculated as a weighted

Service category	Updated Weight	Original Weight
Inhabitants	0.179	0.243
Jobs	0.179	0.243
Education	0.097	0.152
Health	**0.393**	**0.152**
Tourism	0.054	0.103
Culture and Entertainment	0.047	0.051
Services to the citizen	0.032	0.036
Free Time and Leisure	0.017	0.020

Table 4.3: *Weights from the revisited AHP method with a focus on health, for comparison the original weights are also displayed.*

sum of the different services (s_j) with their respective importance factor (w_j).

$$Score_{station} = \mathbf{s} \cdot \mathbf{w} = \sum_{j=1}^{8} s_j \cdot w_j$$

In order to further increase the importance of health services around the station, the number of health services to be used as input in the scoring formula has been modified to consider not only the simple presence of an hospital or an health center but also its physical capacity and ability to attract users. By doing so, a health facility is not anymore considered with a mere numerical value that solely denotes its presence in the city but with an actual performance score that describes its importance.

To assign an *ad-hoc* score to each single health facility present in the station database, public data provided by the Lombardy region on all the hospitals of the region has been used. The dataset provides information about the user flow and the typology of medical service that has been provided by each facility. Table 4.4 lists the features that were considered for each hospital and their relative weight that was assigned to each of them. The weights that were chosen for each criterion have been assigned to highlight the most important features that make an hospital stand out in the territory, such as the total number of hospitalized people and the amount of surgical operations that are performed in each structure. The choice of this weights shall not be intended as a replacement of a complete analysis on the performance of the regional hospitals, but as a first approximation method to assess a ranking of the structures.

Criterion	Weight
Number of hospitalizations	0.5
Number of surgical hospitalizations	0.2
Number of repeated hospitalizations	0.1
Number of returns in surgery	0.05
Number of transfers	0.1
Number of voluntary discharges	0.05

Table 4.4: *Criteria used to score hospitals in the region. A simple set of weights is proposed to assess the capacity of the medical structure.*

Therefore, each hospital has been assigned with a score that describes its public service capability. Table 4.5 illustrates an example of scoring of the hospitals, reporting the six criteria that have been utilized for the assessment and the calculated final mark for every hospital. This score has been used as an input for the computation of the general score of the city, that now considers health services with a greater degree of importance. This process therefore allows to understand what are the station with the greatest vocation towards medical services. The final results are reported in Table 4.6, showing how Bergamo, excluding the Milan stations, results with the highest score.

Bergamo station

The station of Bergamo has been identified by the model as the best urban pole from the point of view of health services. Obtaining a score of 19,9, it marked itself as an important center for the consistent presence of an important medical structures within reach of walk. Moreover, the already good quantity of additional services of other categories, makes Bergamo particularly attractive for a wide spectrum of activities. Figure 4.9 shows the location of the nearest health facility on top of the heatmap of all the services present within the 15 minutes walking isochrone.

Structure name	Station	N° of hospitalizations	N° of voluntary discharges	N° of transfers	N° of repeated hospitalizations	N° of returns in surgery	N° of surgical hospitalizations	HOSPITAL SCORE/1000
OSPEDALE POLICLINICO S. MATTEO	PAVIA	35762	61	114	1493	175	6622	**19,4**
CLINICHE GAVAZZENI SPA	BERGAMO	13850	13	27	448	114	4476	**7,9**
POLICLINICO SAN PIETRO	PONTE SAN PIETRO	13530	30	77	363	23	2459	**7,3**
ISTITUTO CLINICO CITTA' STUDI	MILANO	12865	9	3	412	46	2591	**7,0**
OSPEDALE BOLOGNINI	SERIATE	12679	19	30	417	147	2819	**7,0**
OSP. S. ANTONIO ABATE	GALLARATE	12651	67	17	650	31	2368	**6,9**
OSPEDALE FATEBENEFRATELLI E OFTALMICO	MILANO	10295	78	31	516	43	2251	**5,7**
OSPEDALE CIVILE	VOGHERA	9796	72	35	523	21	2072	**5,4**
POLICLINICO DI MONZA	MONZA	9192	14	7	282	36	2667	**5,2**
ISTITUTI CLINICI ZUCCHI	MONZA	9072	1	4	225	13	2064	**5,0**

Table 4.5: *Scores assigned to the hospitals of the region - at no more than 15 minutes from their respective rail station - in order to assess their capability to offer health services.*

STATION	ORIGINAL SCORE	SCORE with HEALTH CRITERION	SCORE VARIATION (%)
Milano Porta Venezia	49,6	**47,0**	-5,2
Milano Centrale	49,6	**45,7**	-7,9
Milano Repubblica	46,6	**43,2**	-7,3
Milano Porta Garibaldi	25,2	**25,2**	-0,2
Milano Porta Genova	25,4	**24,4**	-4,0
Milano Dateo	22,8	**24,4**	6,6
Bergamo	18,5	**19,9**	7,6
Pavia	10,7	**17,5**	64,3
Lecco	16,7	**15,3**	-8,6
Mantova	15,1	**13,8**	-8,6

Table 4.6: *TOP 10 stations in order of score, considering the new criterion for assessing health services. For comparison, the original score is reported as well as the percentage variation.*

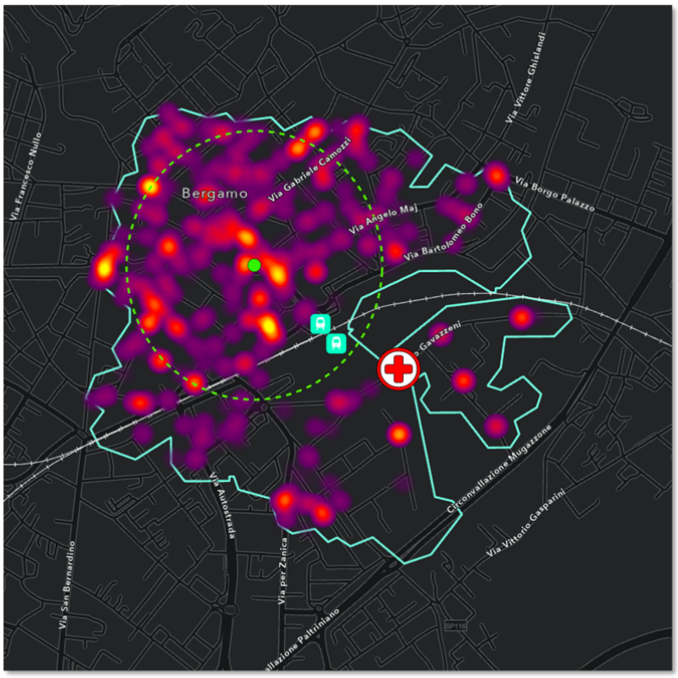

Figure 4.9: *Bergamo heatmap showing the services of all the categories as well as the position of the main health facility in the basin.*

4.5.2 Education-centered stations

The second part of the evaluation consisted in finding a series of stations that particularly excel in the offering of educational services, such as schools and universities. In a similar way to what has been done for health services in the previous paragraph, the model based on the AHP method has been revisited with different weights and inputs to highlight in a more evident way the educational facilities.

The AHP preference indices have therefore been modified to increase the importance of education with respect to the other services. The new weights assigned to the different categories are displayed in Table 4.7, next to the original values used in Paragraph 3.3.1. The educational sector has therefore been assigned with the highest value (0.347), while the other typologies have been assigned to a reduced weight. Moreover, considering the relevance of universities as important generators of mobility in the region, additional data regarding the number of enrolled students in the different departments have been integrated into the model [data provided by the Ministry of Public Education]. This would allow to not only consider the presence of universities in the territory, but to also take into account the actual number of potential users that may use the services of rail stations.

Service category	**Updated Weight**	**Original Weight**
Inhabitants	0.175	0.243
Jobs	0.175	0.243
Education	**0.347**	**0.152**
Health	0.142	0.152
Tourism	0.074	0.103
Culture and Entertainment	0.040	0.051
Services to the citizen	0.030	0.036
Free Time and Leisure	0.018	0.020

Table 4.7: *Weights from the revisited AHP method with a focus on education, for comparison the original weights are also displayed.*

In order to identify the education-centered stations in the region, three cases have been analysed. The first regards the analysis of only the stations of the region that offer high schools within the 15 minutes walking range. The second deals with the assessment of the stations that offer both high schools and university departments in the walking basin. The third case considers instead the whole dataset of stations, regardless of the presence of educational services. This distinction was done to better evaluate the performance of the stations at different levels of education, in order not to loose relevant information with a single general analysis. As a preliminary estimate, Figure 4.10 shows the results of a data elaboration previously carried out by RFI, listing the number of high schools and university present in main Lombardy stations with a walking radius of 3km. This evaluation can be useful as a general identification of education-oriented stations. The analysis that will be carried out in this work focuses instead more on the concept of proximity, considering only the 15 minutes walking basin.

The first assessment therefore focused on the identification of those stations that offer the greatest amount of high schools within the 15 minutes pedestrian isochrone. The new calculated weights reported in Table 4.7 have been used in the weighted sum of the services present around each station to better evidence the presence of secondary levels schools. The new obtained score for each station now highlights the best rail nodes of this category. The results are presented in Table 4.8, where Bergamo stands again as the best station (excluding major Milan stations), with a score of 21.2.

The second assessment is centered on the identification of the best stations in terms of both high schools and university offering. The sub-dataset that is being used considers only those station that present at least a university department within a 15 minutes walk. Among those, the updated weights shown in Table 4.7 have been exploited to calculate the new attractivity scores for the stations. Table 4.9 reports the final scores and compares them to the originally calculated ones. Lecco obtains the highest score among all the stations, with a score equal to 20.1. The third and final evaluation consists in finding the overall best stations of the region from the point of view of education. In this case, the complete dataset of the region has been used and no separation between high schools and university has been adopted. Table **??** shows the updated scores next to their original values.

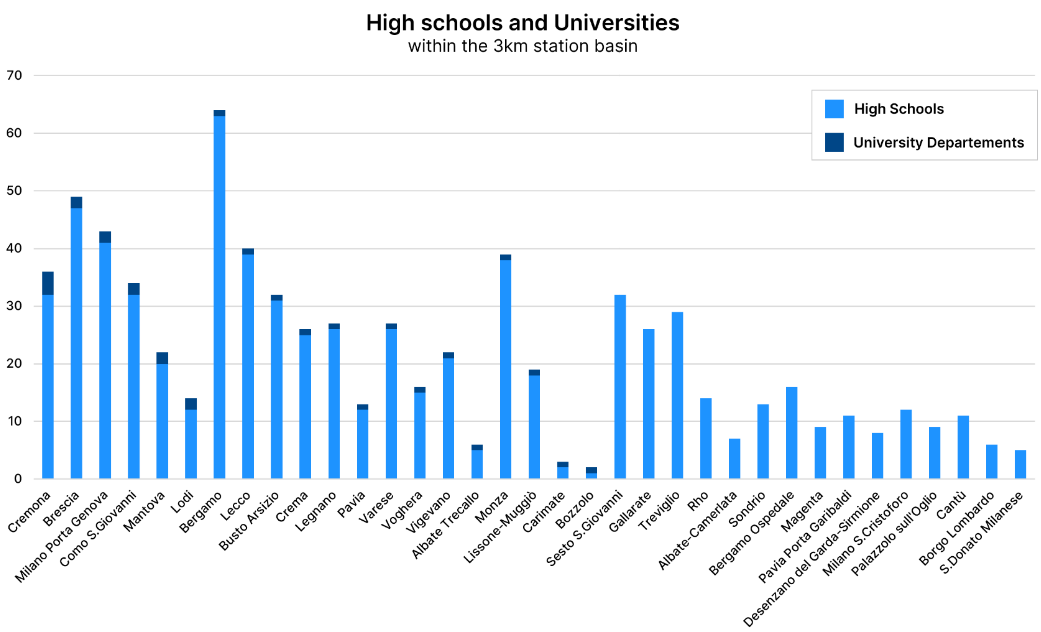

Figure 4.10: *Number of schools and University departments in major cities of the region*

STATION	ORIGINAL SCORE	SCORE WITH H.S.	SCORE VARIATION (%)
Milano Centrale	49,6	**45,4**	*-8,4*
Milano Porta Venezia	49,6	**43,6**	*-12,0*
Milano Repubblica	46,6	**40,9**	*-12,2*
Milano Porta Genova	25,4	**23,3**	*-8,4*
Milano Porta Garibaldi	25,2	**21,6**	*-14,4*
Milano Dateo	22,8	**21,4**	*-6,3*
Bergamo	18,5	**21,2**	14,9
Brescia	13,2	**12,9**	**-2,5**
Sondrio	11,5	**12,4**	7,8
Milano Lambrate	11,9	**11,6**	**-2,3**

Table 4.8: *TOP 10 stations in order of score, considering the new weights to assess the presence of high schools. For comparison, the original score is reported as well as the percentage variation.*

STATION	ORIGINAL SCORE	SCORE WITH H.S. AND UNIV.	SCORE VARIATION (%)
Lecco	16,7	**20,1**	20,0
Milano Greco Pirelli	3,9	**13,4**	245,2
Varese	13,4	**12,6**	**-5,9**
Mantova	15,1	**12,4**	**-17,7**
Cremona	9,5	**11,2**	17,4
Milano Romolo	7,2	**9,2**	27,7
Milano Villapizzone	3,4	**8,7**	156,2
Crema	6,1	**7,5**	22,9
Vigevano	9,6	**6,2**	**-35,3**
Busto Arsizio	5,0	**5,8**	16,3

Table 4.9: *TOP 10 stations in order of score, considering the new weights to assess the presence of both universities and high schools. For comparison, the original score is reported as well as the percentage variation.*

STATION	ORIGINAL SCORE	OVERALL EDUCATION SCORE	SCORE VARIATION (%)
Milano Centrale	49,6	**45,4**	**-8,4**
Milano Porta Venezia	49,6	**43,6**	**-12,0**
Milano Repubblica	46,6	**40,9**	**-12,2**
Milano Porta Genova	25,4	**23,3**	**-8,4**
Milano Porta Garibaldi	25,2	**21,6**	**-14,4**
Milano Dateo	22,8	**21,4**	**-6,3**
Bergamo	18,5	**21,2**	**14,9**
Lecco	16,7	**20,1**	**20,0**
Milano Greco Pirelli	3,9	**13,4**	**245,2**
Monza	13,0	**13,0**	**-0,4**

Table 4.10: *TOP 10 stations in order of overall education score, considering the whole dataset of stations. For comparison, the original score is reported as well as the percentage variation.*

Lecco

The station of Lecco has been identified by the model as the best urban pole from the point of view of secondary level and university services. The station basin stands out as a really rich cluster with consistent presence of important educational structures in proximity of the station. Furthermore, the already vast offering of additional services of other typologies, makes Lecco a particularly attractive pole also for other urban activities. Figure 4.11 shows the location of schools and university departments on top of the heatmap of all the services present within the 15 minutes walking isochrone. A denser distribution of activities can be identified in the west side of the railroad, while the density of schools appears quite homogeneous throughout the entire basin.

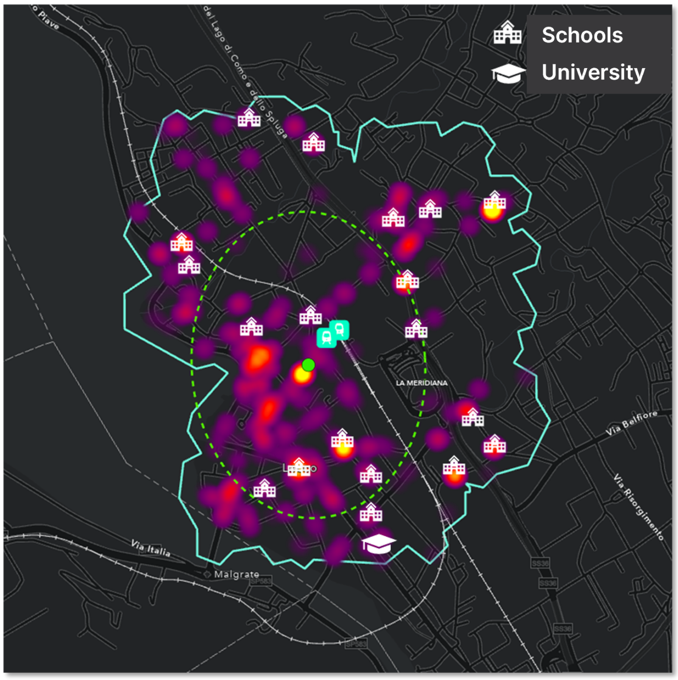

Figure 4.11: *Lecco heatmap showing the services of all the categories as well as the position of high schools and university departments in the basin.*

Chapter 5

Conclusion and future development

The presented work had the objective of developing the concept of the "15 minutes city" around the railway station. The research involved the study of this concept from the existing - yet limited - available literature and its expansion towards the vision of a proximity-based rail station, proposing a real case study as an application.

The investigation of this increasingly discussed concept regarding the valorization of the railway node as an important piece in the urban environment lead to the development of a precise methodology of analysis, that allowed to establish a fixed set of evaluations that should be carried out to understand the potential of a station in terms of accessibility and attractivity. The entire work relied on a data-driven approach, in order to implement a reliable and systematic evaluation of the railway stations in the Lombardy region. A subsequent clustering activity was performed, followed by a ranking methodology through the AHP multi-criteria technique. The different kinds of services located around the station were therefore evaluated and a numerical score was developed for each station, representing its level of attractiveness. Additional data regarding the habits and mobility patterns of real users allowed for a better understanding of each unique situation of the station and permitted to select some relevant railway nodes in order to study them more deeply.

The selected stations that demonstrated good potential in terms of pedestrian accessibility and variety of services have been further explored in ArcGIS with special georeferenced tools, in order to assess the density and distribution of activities within the 15 minutes walking basin.

These implemented techniques are believed to positively support the decision maker in the identification of areas of intervention, where urban regeneration works could be performed to increase walkability, cyclability and to better connect an integrate the station to the services that are present around it. These potential investments in the urban environment can positively affect the utility and the perception of the station, allowing it to be really considered as the "second door of the home". A station that is capable of renew itself and, at the same time, offer an acceptable transport service, could see many more users using it as an integral part of their everyday life.

The developed model for scoring the stations proved itself to be flexible and adaptable to different kind of analysis. A deeper research on the most vocated stations in terms of health and educational services, in fact, allowed to identify the main regional poles for such kinds of services.

As future developments, improvements could be introduced in the mathematical model to better understand the weighting of the different typology of services, also with the help of on-field surveys and additional expert's opinion. Moreover, the proposed spatial analysis on the urban structure of the city and its distribution of activities could be complemented by extra simulations on traffic and pedestrian flow, to figure out how and where people move throughout the urban environment and provide practical information to the decision maker. Overall, an extensive analysis of the as-is situation at different levels is of paramount importance to understand the unique context of each specific case and guide the railway operator and authorities into the development of future projects.

Appendix A

GIS analysis for Lombardy stations

Hereafter, additional maps regarding the spatial analysis conducted through the GIS software are presented. The locations shown below regard the principal railway nodes of the Lombardy region that have not been analysed in previous chapters. The figures propose the three main tools for the exploration of the urban structure of the cities, namely the *services centroid* (green circle), the *directional distributional ellipse* (dashed green line) and the *density heatmap* (in its weighted version).

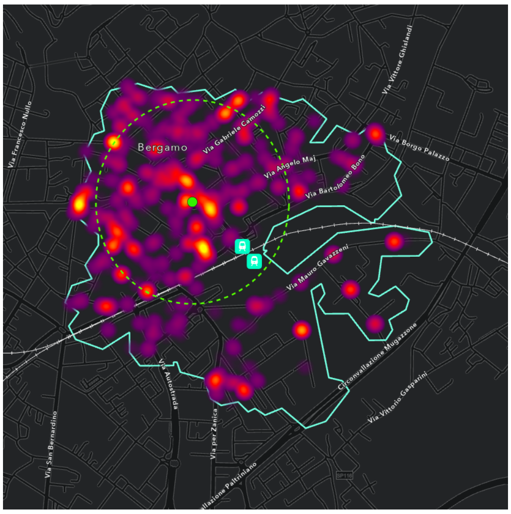

Figure A.1: *Bergamo station*

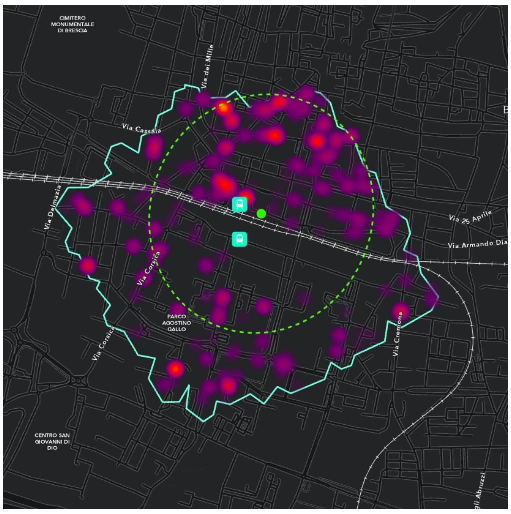

Figure A.2: *Brescia station*

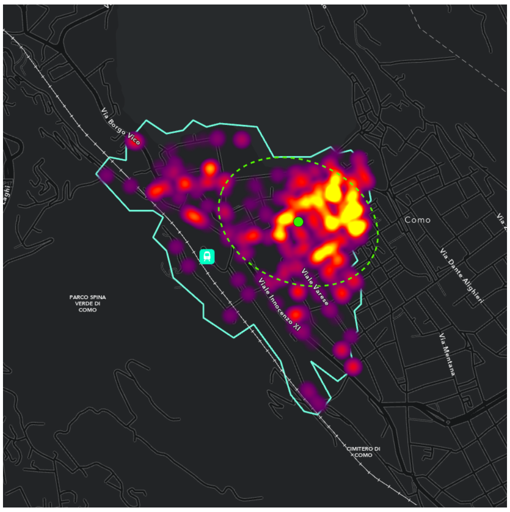

Figure A.3: *Como station*

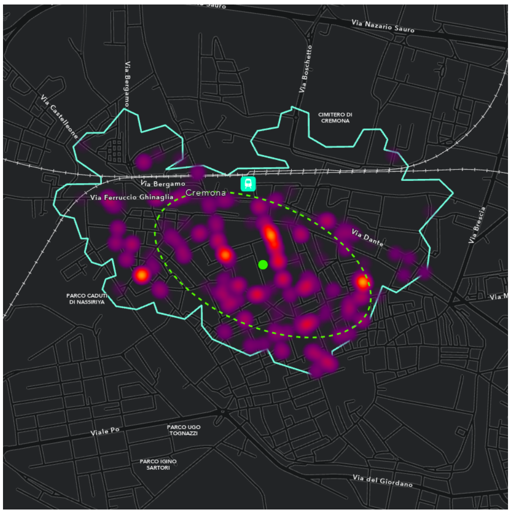

Figure A.4: *Cremona station*

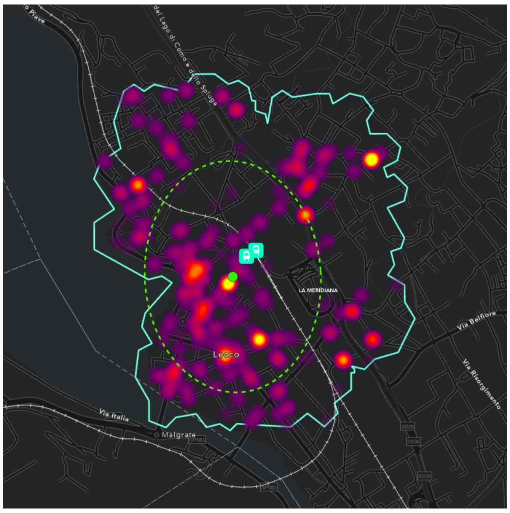

Figure A.5: *Lecco station*

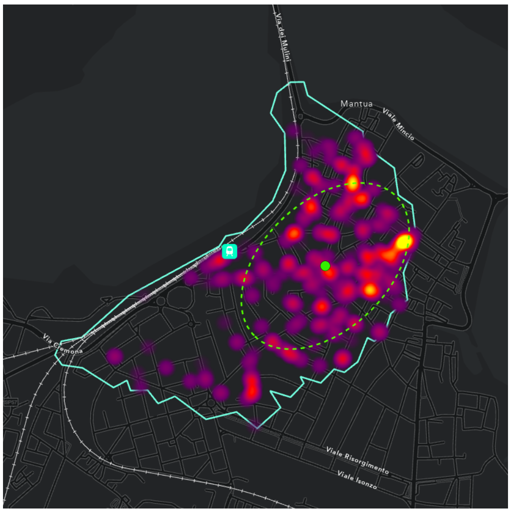

Figure A.6: *Mantova station*

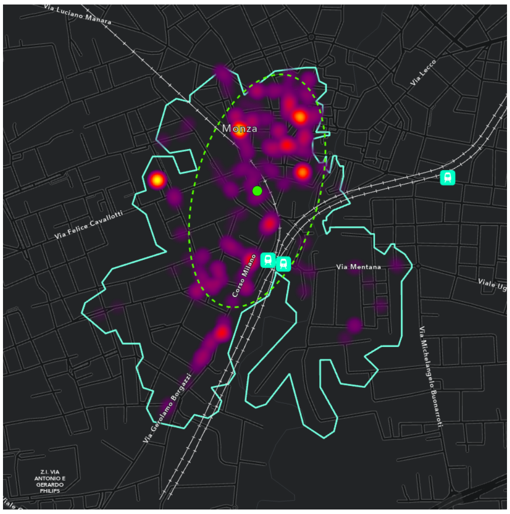

Figure A.7: *Monza station*

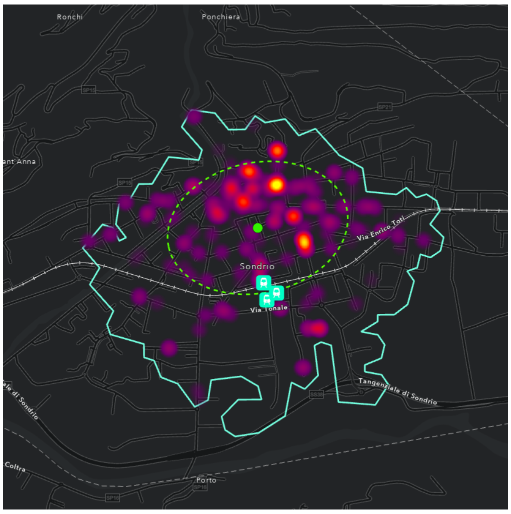

Figure A.8: *Sondrio station*

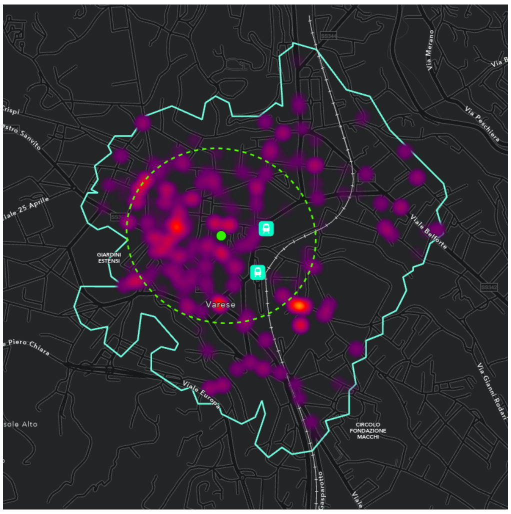

Figure A.9: *Varese station*

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