Università degli studi di Milano-Bicocca

Data Science Lab Smart Cities

Final Essay

A set of metrics for evaluating the public transport system: the case of Milan city

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Abstract

The quantitative analysis of a public transport network plays a vital role in assessing its efficiency and identifying the areas in need of improvement. Focusing on the city of Milan, this project aims to evaluate its transport system in terms of stops density and proximity, rides frequency and variety, with an eye towards people with disabilities as well, by developing a set of indicators that can potentially allow a comparison not only between areas within the city but also between different cities. Density and proximity provide insights into how well stops are distributed throughout the city and how easily accessible they are to both the residents and visitors, while frequency and variety permit to understand how well the system caters to the needs of the commuters during the day. These metrics have been applied on 12 different 2-hour time slots, allowing us to highlight how some areas, especially in the southwest of the city, may require some improvements since they lack, primarly, proximity and density. Unexpectedly even some central neighborhoods like Navigli and Tre Torri sometimes fail to reach acceptable values.

1 Problem description and indicators

1.1 General context

Like all major cities, Milan boasts a thriving life that captivates both locals and visitors alike. Not only because it is home to a diverse range of venues, including bars, clubs, discos, restaurants and many more, which offer unique and engaging experiences, but also as a consequence of playing host to several prestigious global events that take place annually. These events attract people from all over the world and contribute significantly to the city's cultural and economic landscape. Among the most prominent events are the Salone del Mobile, Fashion Week, and Design Week, each of which sprawls throughout the city center, showcasing the latest trends and innovations in various industries.

Unfortunately, Milan also hides downsides: in recent years the perception of criminality in the city center has increased, due to more frequent thefts, muggings and other petty crimes, raising concerns among residents and visitors, fueling a sense of insecurity. This negative perception can also affect the use of public transportation during nighttime hours. The fear of becoming a target of criminal acts not only influences people's transportation choices but also contributes to the difficulty of finding parking in the city's most attractive areas. This additional challenge exacerbates the issue of nighttime traffic congestion, further diminishing the convenience and accessibility of navigating Milan. The high demand for alternative transportation options, such as taxis or private cars, as a safety precaution has resulted in increased vehicular traffic during peak nighttime hours. This surge in traffic, coupled with limited parking spaces in the city center and popular districts, poses a significant challenge for those seeking to explore Milan's nightlife or attend events. Finding parking in the vibrant areas of the city, where the energy of the nightlife and major events is concentrated, can be a discouraging

task. Limited parking availability often leads to frustration and inconvenience for both residents and visitors alike, as it requires careful planning and a willingness to explore more remote parking options or utilize parking facilities far from the desired destination.

1.2 Public transport indicators

For all the reasons above, public transport plays a crucial role in forging the urban mobility, offering safe, cheap and sustainable travel solutions, in addition to being extremely useful in the traffic management strategy as well as reducing the impact on environment of private transport. However, in order to ensure a high standard service, it has to face some issues:

- **Accessibility**: local public transport should be accessible to all people, including those with disabilities or reduced mobility. It is important that infrastructure and vehicles are designed to allow easy and safe access for all passengers.

- **Spatial coverage**: local public transport should cover as much territory as possible, ensuring that different geographic areas of a city or region are effectively connected. It is necessary to consider the transportation needs of different communities, including suburbs or rural areas.

- **Frequency and reliability**: a good public transportation system should offer frequent and reliable service. Transportation should be punctual and regular, allowing passengers to plan their trips efficiently. In addition, it is important that the service is available during peak and off-peak hours.

- **Costs and fares**: local public transport fares should be affordable and proportionate to the provided service. Ensuring affordable costs for passengers, for example by differentiating by age, group, income or usage frequency, mainly means encouraging the use of public transport at the expense of private transportation.

- **Environmental sustainability**: local public transport should contribute to environmental sustainability by reducing greenhouse gas emissions and air pollution. The adoption of environmentally friendly means of transportation, such as electric buses or hydrogen-powered trains, can contribute to this goal. In addition, bicycle use and pedestrian access to public transport stations and stops should be encouraged.

- **Integration with other transport modalities**: a good local public transport system should be integrated with other transport modalities, such as cycling, car sharing, or carpooling. This allows passengers to combine different type of vehicles to reach their destination more efficiently and conveniently.

- **Safety**: the safety of passengers and public transport staff is paramount. Infrastructures and vehicles should be designed prioritizing safety through, for example, the installation of surveillance

cameras, adequate lighting, and safe access to stations and stops.

- **Community Involvement**: it is important to involve the local community in public transportation planning and implementation. This can include public consultation, gathering feedback, and tailoring the service to the specific needs of the community.

In our work, the main goal is to analyze how the Milan public transport system addresses the first three issues, paying attention to the differences between the different time slots in which the lines operate.

1.3 Milan NIL structure

Being a big city, Milan is often divided in NILs (Nuclei d'Identità Locali, *local identity cores*), to have a better understanding of the differences between areas within the city. Specifically there are 88 of them [1], shown in Figure 1.1. They showcase the diversity of Milan's cultural heritage, traditions, and lifestyles. Each nucleus may have its own architectural style, local businesses, markets, or historical significance that contribute to the overall tapestry of Milan's urban fabric. These local identities add depth and charm to the city, offering an opportunity to explore different facets of Milan's personality. Therefore, the measures proposed in this analysis will be provided not only for each 2-hour time slot but for each NIL as well, in order to better highlight the inequalities between the different areas of the city and best meet our research question.

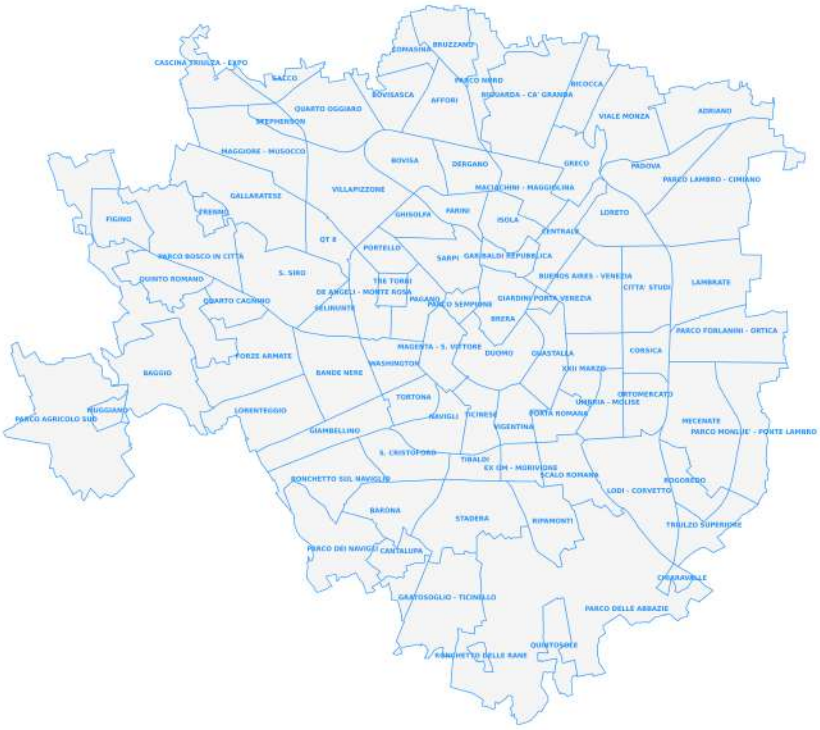

Figure 1.1: All 88 NILs of Milan city.

[1] https://dati.comune.milano.it/dataset/e8e765fc-d882-40b8-95d8-16ff3d39eb7c, *dati.comune.milano.it*

2 Milan public transport system

Milan transport system (Figure 2.1) is composed by three main means of transport: tram, metro and bus (including trolleybus). Together they provide full coverage of the territory during daytime hours, reducing its offers during the night mainly to keep a cost-efficient management and allowing the maintenance of the lines. These three lines are all operated by the ATM S.p.a. (Azienda Trasporti Milanesi) company, entirely owned by the Milan municipality. The city also has a suburban rail network, consisting of 12 lines, to supplement the public transport system. Thanks to this complex public transport system, Milan is the city with the most usage of public transport in Italy chosen by 38% of the residents against the 35% who prefers private transport means [1]. Nevertheless Milan transportation system as it is make it difficult to reach several zones of the city from the centre in certain hours. To satisfy the demand of transport system, many alternative services are available in the sharing form (bike, scooter, and cars, both free-floating or station based), but the average cost-per-travel is higher than the public transport one [2]. Moreover, in order to reduce the use of private vehicles and thus pollution, the Municipality of Milan has implemented two low-emission zones: Area C, covering the central Cerchia dei Bastioni area, and Area B, a larger zone surrounding the city limits. These areas enforce restrictions on vehicles that fail to meet specific ecological requirements, aiming to limit their access. Such measures actively promote public transport as the preferred modality of transportation.

As of 2023, the local public transport system in Milan is organized with the following network:

- **Four metro** lines, M1 (red), M2 (green), M3 (yellow) and M5 (purple) with a total of 113 stations. Despite these relatively small numbers, Milan's subway system is actually the longest in Italy, measuring almost 97 km [3] and covering not only much of the city but also extending beyond its municipality allowing a connection to neighboring villages as well. Additionally, the network has been further extended recently, with the opening of the new M4 (blue) line from Linate to Dateo, estabilishing a connection with the city airport, providing a better service for both citizens and tourists. Moreover, the newest lines M4 and M5 are the first driverless ones, allowing an easier and better planning of the rides.

- **Seventeen trams** lines, the first mean of transport estabilished in Milan, covering a total distance of 157 km every day. Trams have been renewed many times over the century of activity, with more and more sustainable solutions.

- **119 total buses** lines operating in Milan, granting capillary connections to all parts of the city, some of these operating day and night, with 100 people capacity for each ride.

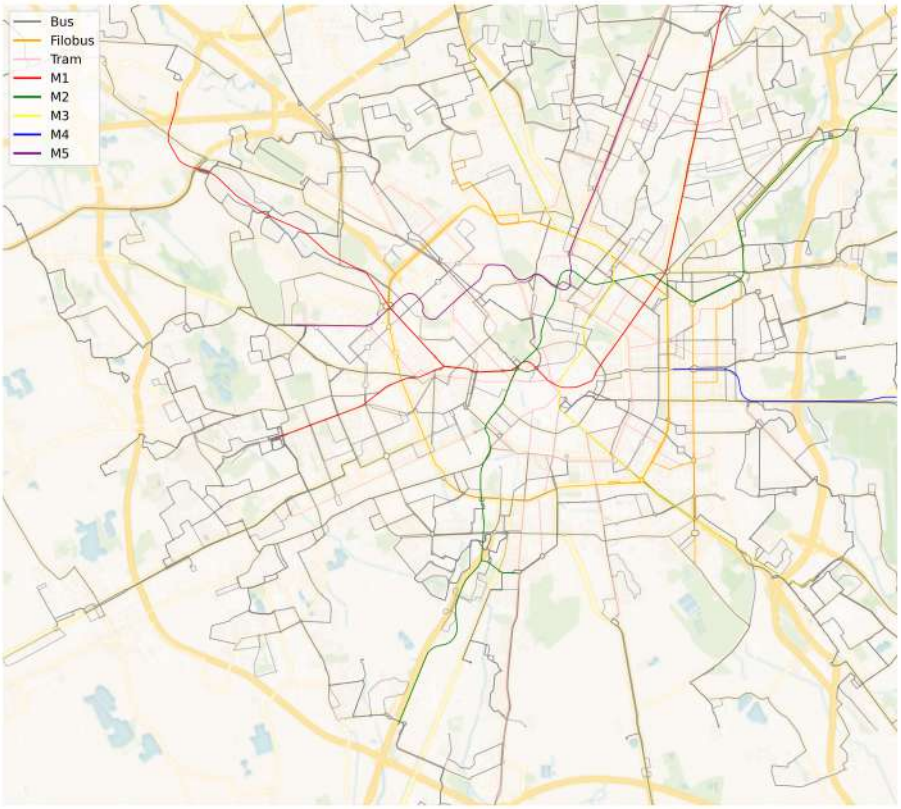

Figure 2.1: Milan public transport system.

3 Data analytics and metrics

3.1 Datasets and data preprocessing

To conduct this study, geoJson data from the Milan open data portal (https://dati.comune.milano.it/) were utilized. The available datasets included:

- **ATM - Urban surface line stops:** this dataset provides a map of surface public transportation stops, which can be correlated with routes (through route composition) and schedules to provide both the location of public service access points and a quantification of service offerings in terms of trips and frequency.

- **ATM - Urban surface line schedules:** this dataset presents a summary of schedules for surface lines, which can be correlated with routes and stops to provide a quantification of service offerings in terms of trips and frequency.

- **ATM - Metropolitan line schedules:** this dataset exposes a summary of schedules for metro lines, which can be correlated with routes and stations to provide a quantification of service offerings in terms of trips and frequency.

- **ATM - Urban surface line routes:** this dataset provides a map of the routes for the urban surface network (bus, tram, and trolleybus). Correlated with their respective schedules and stops (through route composition), the dataset allows for evaluating service frequency and availability on a geographic basis.

- **ATM - Metro line routes:** this dataset exposes a map of the routes for the Milan metro network. Correlated with their respective schedules and stations (through route composition), the dataset allows for evaluating service frequency and availability on a geographic basis.

- **NILs - Urban surface line routes:** this dataset provides a map of the 88 NILs (Local identity nucleus) in Milan, with their name and Area in square meters.

The processing phase of our project primarily focused on assigning lines to specific time slots of operation, as our goal was to calculate metrics for different times of the day. To accomplish this, we created two-hour time slots ranging from 0-2 to 22-24. For each trip, we divided the total number of daily trips by the number of time slots in which the trip was active. This approach resulted in the generation of three datasets:

- **Lines:** containing information about both surface and metro lines, including the respective time slots during which they operate.

- **Stops:** including all metro and surface line stops.

- **Routes:** linking table serving as an intermediate table, containing the identifiers of stops and routes.

3.2 Developed metrics

As previously mentioned in Chapter 1, our main goal consists of evaluating how the city of Milan and its transport network meets the needs of the population, focusing mainly on frequency, accessibility and spatial coverage issues. In order to do so, we developed a set of five metrics which can help to understand the quality of public transportation not only in Milan, but potentially in all big cities. These can be applied individually but also combined with each other to get an overview of the well served NILs of Milan compared to the others. To calculate each metric, we disabled the lines and stops that were not within the time slot we were considering, so as to obtain results that are more faithful to reality.

3.2.1 Frequency

The frequency of public transport lines refers to how often vehicles operate in a particular route during a specific timeframe. It can vary widely depending not only on the time of day, especially when comparing daytime to nighttime as shown in Figure 3.1, but also on the population density

of the area or the available resources and infrastructure. Frequency could also be understood as the waiting time between rides, but this aspect will not be taken into account, focusing only on the average number of rides per time slot.

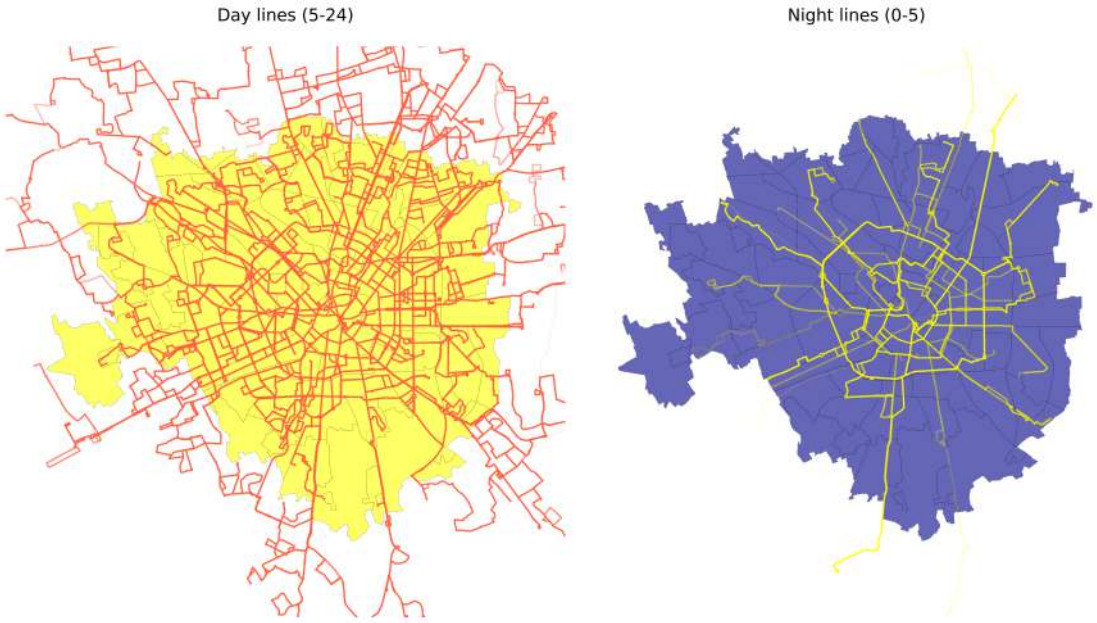

Figure 3.1: Milan rides on different times of the day. Nighttime shows a huge decrease not only in rides frequency but also in coverage, especially outside the Milan's municipality.

3.2.2 Accessibility

Public transport accessibility for people with disabilities is a crucial aspect of creating an inclusive and equitable society. Accessible transportation options ensure that individuals with reduce mobility can travel independently, allowing them to freely access education, employment opportunities, healthcare services, social activities and more, leading fulfilling lives.

We thought to assess how good Milan makes up for these limitations by counting the rate of operating stops having adequate infrastructure. However, this data gap regarding over 6,200 stops diminishes the overall reliability of this metric. Nevertheless, it remains a significant indicator underscoring the importance of addressing this concern.

3.2.3 Variety

Public transport system often encompasses a diverse range of means of transportation, serving as crucial components of urban travels, providing numerous benefits to individuals, communities, and the environment. As already said, Milan's network is well equipped in this respect, being composed of metro, trams, buses and trolleybuses. The last-mentioned are a type of electric buses that draw power from overhead wires using two or more trolley poles, thus not entailing both air and noise pollution. Basically, they combine the features of buses and trams since, unlike the latter, they can maneuver

around obstacles and change lanes, adapting to traffic conditions.

This indicator has been computed as the average number of vehicles per time slot, relying on the idea that greater variety increases the opportunities for movement, enabling people to choose the most suitable option based on their needs and preferences.

3.2.4 Density

Density of a public transportation system refers to the concentration of stops and stations along its routes. Milan's network quite meets this criterion, even in large areas, although some of them definitely appear less dense and provided, mainly in the southern part of the city, as Figure 3.2 shows. The optimal density varies depending on factors such as the size and characteristics of the urban area, population density and existing infrastructure. We focused on the first variable, computing the metric as the ratio of the number of stops within a NIL to its area in square kilometers.

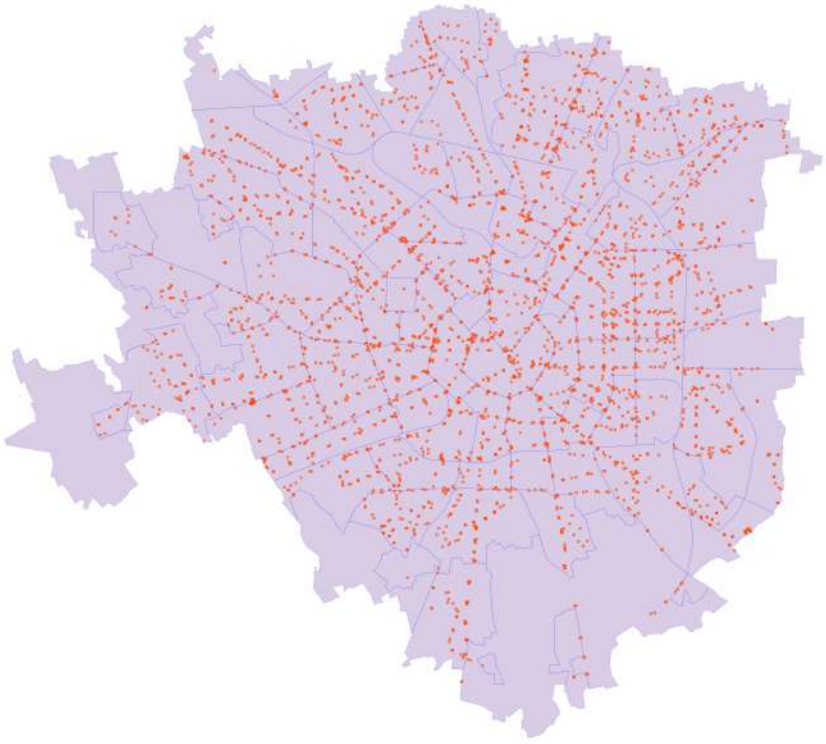

Figure 3.2: All stops within the municipality of Milan.

3.2.5 Proximity

Directly related to the concept of network density, the proximity can be conceived as an indicator of stops distribution. Figure 3.2 suggests that an even distribution is not always achieved, especially towards the outlying areas of the city. People living or working in those areas may face longer travel times and inconvenience in accessing essential services and amenities. This can particularly impact individuals who rely heavily on public transport, such as low-income communities or elderly people.

Understanding such component as the average distance to the nearest stop, to assess it we generated, within each NIL, 1000 random points coming from a uniform distribution, measuring for each one the distance to the nearest station (which can also be located within the neighboring NILs), and averaging all. This is to simulate a random point where a person may be, and the distance they would have to walk to use public transport.

4 Results

Since our primary goal consists in analyzing the Milan public transport system by identifying the discrepancies between NILs, we will examine those that we found to be outliers (with values of the metrics significantly deviating from the average) mainly to be able to suggest which areas require attention and improvements.

- **Density**: the city has an average stop density of 86/km^2 but basically all NILs diverge from this value, with 14 of them exceeding an average per day of 150 stops/km^2. These include, as expected, heavily frequented and touristic areas like DUOMO, CENTRALE and NAVIGLI. On the other hand there are more than 20 NILs below 50 stops/km^2, especially southern areas such as QUINTOSOLE, PARCO DELLE ABBAZIE or PARCO AGRICOLO SUD, with the last one presenting an average of only 1 stop/km^2. Those mentioned are suburban NILs, greener areas compared to the rest of the city so it's an unsurprisingly result. Instead, what stands out is TRE TORRI with its below-average 34 stops/km^2, despite surely being a more relevant neighborhood.

- **Proximity**: Milan as a whole has an average distance to the nearest station equal to 220m. In most NILs this is below 500m. The only ones with higher values are those that present large green areas such as CASCINA TRIULZA and QUINTOSOLE, even though these are not only very far from the center but also less populated, consequently it is not such relevant. However, some NILs from 2 to 4 have an average distance of more than 500m but still within a kilometer, such as BOVISA, BAGGIO and SACCO, as shown in Figure 4.1. The idea of walking such a distance could disincentivize the use of public transportation.

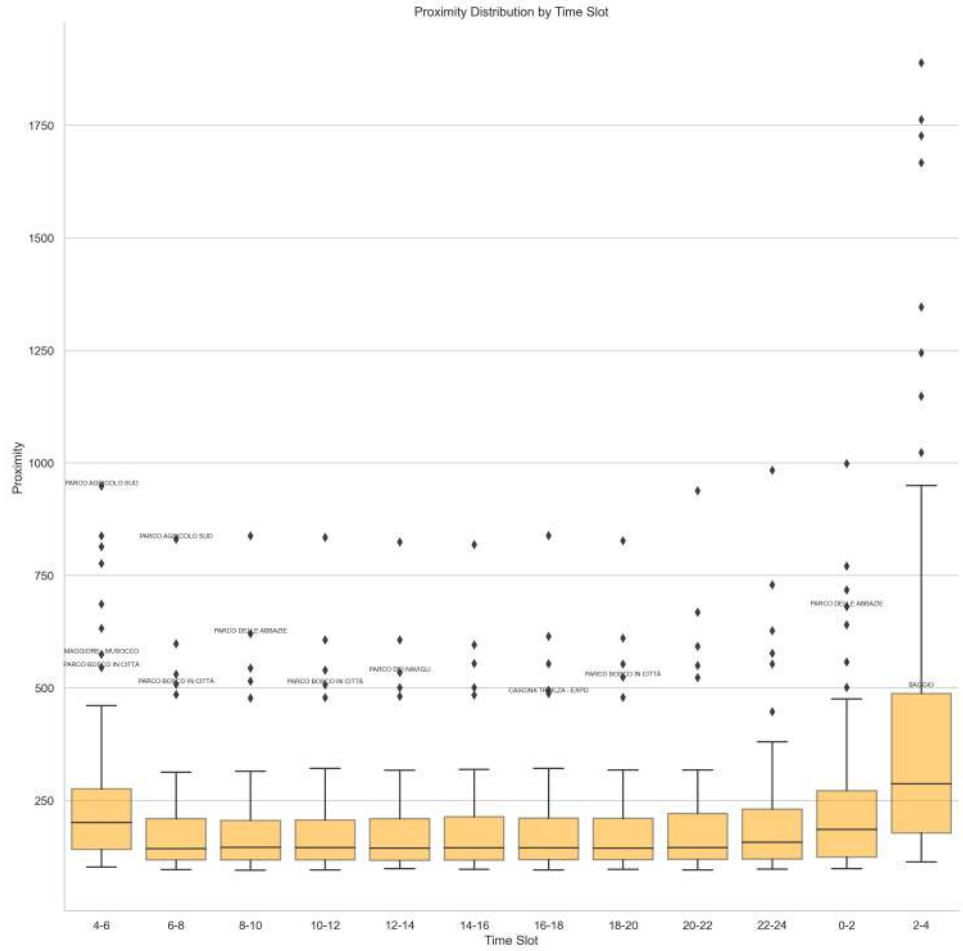

Figure 4.1: Average proximity in different Time slots. There's a big difference in the 2-4 time slot, compared to the others.

- **Frequency**: in general, an average of more than 1000 trips pass through Milan every hour. The best served NILs in any time slot are DUOMO and BUENOS AIRES. All NILs have at least 2 rides that run every hour from 6 a.m. to 8 p.m. In the remaining hours, we see that even the NILs mentioned above, to which we add CANTALUPA, which is also a suburban NIL, lack this requirement in at least one time slot.

- **Diversity**: almost all NILs (66 out of 88) have at least two types of transportation available in the lines running through them. In the map below, we can see which NILs have more means of transportation available:

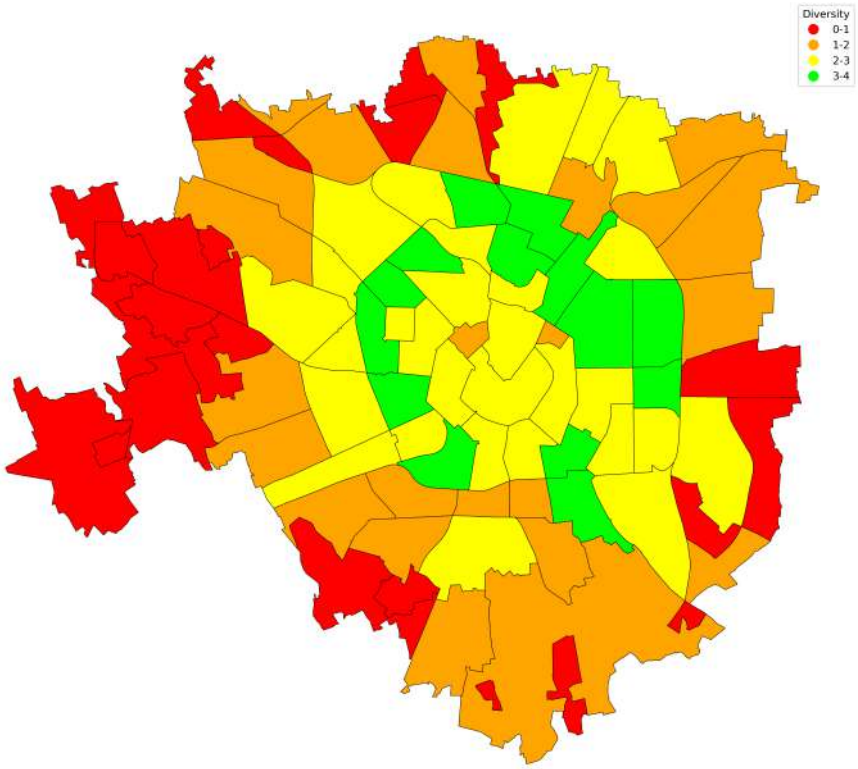

Figure 4.2: Diversity across NILs. It is possible to identify the differences between the circles of Milan, with the westernmost part served by at most one line.

- **Accessibility**: recalling the incompleteness of data regarding this metric, results showed that only 23% of all stops within Milan's municipality have the proper infrastructure to accommodate the needs of people with disabilities. This value is significantly influenced by GIARDINI PORTA VENEZIA area since all its stations are built for people with reduced mobility as well. The remaining NILs can't even achieve 60%, although about 10 of those have an accessibility rate of almost 50%, which can be considered a fairly good result. Finally it is worth to highlight NAVIGLI and, once more, TRE TORRI with a value of, respectively, 0,05% and 0%.

5 Conclusions and future developments

Overall the city of Milan seems to meet the requirements, even though most suburban areas proved to be less covered as might have been expected. What indeed stands more out is how some central NILs, where the number of tourists may be higher, fail to reach acceptable values, especially when evaluating accessibility.

Obviously, the original data format did not facilitate the analysis work. Having the schedules of individual rides available would have facilitated more precise calculations, as well as the development

of other metrics, such as average wait. It should also be noted that this analysis does not directly take into account the heterogeneity of the population and the proportion of green areas to population centers, as well as the flows of people on public transportation. In addition, incomplete accessibility data prevented giving a clear indication of the actual presence of entrances for people with disabilities at stations. A future analysis could include the development of a function that, taking into account the location of stops and lines available and the distance from the center, minimizing the number of active lines, if optimized can improve the indices up to certain thresholds.

References

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[2] M. Ciuffini, S. Asperti, V. Gentili, R. Orsini, and L. Refrigeri, *6° Rapporto nazionale sulla sharing mobility.* Sezione mobilità della Fondazione per lo sviluppo sostenibile, 2023, curato da Massimo Ciuffini.

[3] A. Torti, M. Galvani, V. Urbano, M. Arena, G. Azzone, P. Secchi, and S. Vantini, "Analysing transportation system reliability: the case study of the metro system of milan," Politecnico di Milano, Tech. Rep., 2021.