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GEOGRAPHIC ACCESSIBILITY ANALYSIS AND EVALUATION OF POTENTIAL CHANGES TO THE PUBLIC TRANSPORTATION SYSTEM

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Abstract

In a society which aims to make a major step in the direction of sustainability, it appears necessary to promote efficient alternative modes of travel able to contrast the automobile-dominated urban travel markets. In this study, potential changes to the surface public transportation system in the City of Milan are evaluated. Surface public transportation system can be considered unattractive because of its lack of efficiency. One of the possible reasons that the service is not efficient is the stop spacing. Stop spacing is a significant part of the public transport service design as it affects passengers' walking time and the operating speed of a route, which affects both transit time and operating costs. A densely spaced public transport station obviously improves the geographic coverage and the accessibility, but also increases in-vehicle time and supply costs. On the other side, eliminating service stops speeds up the system and reduces the operating costs.

In the study new stop spacing models are evaluated with the purpose to get the service more efficient increasing the distance between the stops. Working on a broad scale, the model has been created for three different scenarios, with a target distance between the stops set to 400, 500 and 600 meters. Results indicate that eliminating some surface public transport stops (an average of 1.7, 2.5 and 3.4 stops per route for the three model scenarios) could reduce the travel time by, respectively, 3.0%, 4.4% and 5.7%. Results also indicate that the travel time could decrease more in an optimal situation, with traffic light priority and public transport fast tracks for public transport vehicles. The operating costs analyses show that the three different scenarios could reduce the annual cost per km till about 2%.

In the study, the analyses made on the mobility demand and on the accessibility were used to evaluate the effects of potential changes to the surface public transport stop spacing system. In particular, the model has positive results on the accessibility, since the accessibility level is lowered just by 1.0%, 1.5% and 1.9% of the cells.

The model also has positive results on the mobility. In particular, the analysis made on the mobility demand shows that the travel time averagely decreases for the three scenarios by 1.6%, 1.9% and 2.2%. The transportation time decreases by 2.0%, 3.7% and 5.0% and the pedestrian time changes by -0.4%, +2.8% and +5.2%. The pedestrian time is balanced by a more efficient surface public transport system.

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1 Introduction

1.1 Background

Sustainability is one of the most significant issues of modern societies. One challenge of a sustainable society is the transport system. The increasing automobile traffic has led to a situation of congestion, greenhouse gas emissions and air pollution, which has evidently renewed an interest in public transport, which is seen as an important component of the overall transportation planning and management of urban regions (Murray, 2003). It appears necessary to promote alternative modes of travel that contrasts automobile-dominated urban travel markets (Taaffe, Gauthier, & O'Kelly, 1996).

Public transport should be encouraged because it can accommodate a great travel demand and it can have a positive effect on the reduction of the traffic congestion, such as reducing the number of vehicular accidents, improving the air quality and a general improvement of the quality of life. To be able to have a good alternative to private mobility, the public transport has to be more efficient. The efficiency and the quality of a public transport service is perceived differently by the users and the service quality is based on several aspects, such as availability, frequency, travel speed, reliability and safety (Shrestha and Zolnik, 2013).

The intentions of good public transport planning policies are efficiency and quality and they are two key factors able to condition people behaviors. Evidently the more a system is efficient the more it is used by people and, at the same time, the more a person is close to a transit point, the use of public transportation is likely to increase. In modern societies, public transport needs to not only be faster, more reliable and more accessible to satisfy the population needs, but it also has to be more economically efficient.

To improve public transport usage, both access and service quality has to be improved. The surface transport service can be made attractive to the public by improved routing, express services, and minimizing the number of stops along routes (Murray, 2001). Stop spacing, in particular, is a significant part of the public transport service design as it affects passengers' walking time and the operating speed of a route, which affects both transit time and operating costs (Furth, Mekuria, San Clemente, 2007).

One of the key issues for determining the appropriate locations of bus stops is to have an understanding of how far people are willing to walk to get to the facilities (Ziari et al. 2007). The access and egress time and the characteristics of different population groups affect the perception of the quality of a service (Shrestha and Zolnik, 2013). Walking distances for accessing the transport vary among the different population groups and it is also worth investigating the effect of distance deterrence (on the total population and by groups) to gain a better understanding of population behavior regarding transit access (García-Palomares *et* al, 2012).

1.2 Problem statement

Stop spacing analysis have been conducted in several cities, both European and non-European, e.g. Boston (Massachusetts), Albany (New York) (Furth, Mekuria, San Clemente, 2007), Fairfax (Virginia) (Shrestha and Zolnik, 2013), Madrid (García-Palomares *et* al, 2012). So far no analysis has been done for Milan (Italy). In the city of Milan, the surface public transport net is organized in about 764 routes and 4711 aggregated stops. New stop spacing policies may appear as a good solution achieve a surface transportation system that is more efficient and less expensive. For this reason, stop spacing policies can also be considered as an interesting option and solution in this historical period strongly affected by the economic crises.

1.3 Aim

This study aims to make a contribution to the studies on the public transport efficiency, proposing potential changes to the surface public transport stop spacing system, and to those studies that analyze the access to public transport facilities on the basis of analysis of walked distances.

In particular, it aims to propose a framework to study the public transport as a whole system. The analyses of possible changes to the public transport system must not exclude the analyses of some of the factors that influence or are influenced by the public transport system itself. For this reason, the study follows a general-to-specific order and the proposed investigation workflow is based on the analysis of these aspects:

- the urban mobility demand: its goal is to investigate the origin and the destination of the movements and to make it possible to start examining, on a macro level, some of the factors that influence people's choice of travel mode. The urban mobility can be defined as the ability of people to move around an urban area. Mobility incorporates the transport infrastructure and services that facilitate these interactions. Mobility demand in cities is highly variable over the time and it varies together with the transformation of the city.
- the urban accessibility, integrating the walking path distance, the service availability and the frequency: the urban accessibility can be broadly defined as the ease with which activities at one place may be reached from another via a particular travel mode (Liu and Zhu, 2003). It aims to understand the strong and the weak accessibility areas, to examine other factors that influence people's choice of travel mode, to observe and to weight the importance of the

walking path distance and to have a useful tool to analyze potential changes to the public transport system

- the relationship between the accessibility, population and business activities density, to investigate where the accessibility should improve considering where people live and work.
- the development of a new stop spacing model with the goal of improving the surface public transport efficiency and minimizing the operating costs.

The case study is performed in Milan, Italy.

1.4 Disposition

The thesis is composed of 11 chapters and it can be roughly divided in four different parts: method, theory, analyses and results, and finally conclusions:

The first part (**chapter 2**) describes the general methodology used in this study, shows which is the thesis framework and workflow and how the different parts are connected each other.

The second part (**chapter 3** and **chapter 4**) is more theoretical and it contains a description of the case study (Milan) and a literature review of the themes analyzed in the thesis (mobility demand, accessibility and stop spacing policies).

The third and largest part of this thesis (from **chapter 5** to **chapter 9**) covers a description of the development phase of the analyses. Each chapter focuses on a different thematic and the analyses follow a workflow useful to analyze the public transport as a system and to deeply examine the new proposed stop spacing model. **Chapter 5** focuses on the mobility demand, **chapter 6** gets a bit more in the details focusing on the accessibility studies, **chapter 7** compares the accessibility results to the population and business activities distribution and **chapter 8** proposes a new stops spacing model for the surface public transport. **Chapter 9** combines the results obtained by the new stops spacing model with the accessibility analyses to study which is the impact of the new model on the accessibility.
In the final part of the thesis (**chapter 10**) the main result of the study is concluded.

1.5 Limitation

The thesis aims to study Milan public transport accessibility and to propose and evaluate the effects of potential changes to the surface public transport stop spacing system.

In the accessibility analysis, the threshold walking distance, that may vary according to different types of social groups, spaces, and transport facilities, has been set on the basis of previous studies, without using an empirical basis, and applying distance thresholds equally to all population groups and urban spaces.

The stop spacing model developed in this project is merely theoretical since it doesn't consider the time lost because of the traffic congestion and it considers that the public transport vehicles doesn't skip any stop. Furthermore, the model doesn't analyze all the aspects that can impact on transport speed, such as frequency and operating costs, providing traffic light priority for public transport vehicles or the construction of public transit fast tracks, etc. At the same time, the results are mostly focused on the travel time and the management costs and do not consider the effects on the congestion and the pollution. The analyses are also based on a macro-level and they do not allow to get into the details of each route.

2 Related work

2.1 Mobility Demand

Geographic mobility is the measure of how populations move over time from one location to another at various geographic levels. In 1885, E.G. Ravenstein highlighted, for the first time, important patterns and regularities of population movements and he overcame those theories that stated the fact that human movements appeared to go on without any definitive law.

Since then, many studies aiming to analyze, model and understand the process of human movements were carried out. If researches using census data were useful to provide an unprecedented insight into large scale human movement patterns, they were not able to capture a large fraction of human movement activities occurring daily within and between cities. This because the traditional work employing census data mostly provides a static viewpoint of the movements and suffers from limited spatial and temporal granularity in the description of human movements (Noulas, 2013).

Afterwards, the urbanization process led to necessary urban mobility analyses to gain knowledge on people's use of the urban space, how they commute to work, where they live, etc.. The principal method to acquire this knowledge was to conduct population representative surveys which made it possible to acquire information about the origins and destinations of trips in a city and about the transport used by commuters. Urban transport modellers in the 1970s exploited origin-destination matrices of city commuters and laid the foundations of novel mobility theories (Noulas, 2013). These kind of data are used for various aspects as urban transportation planning, job accessibility and human flow.

In 1990s, the launch of the second generation cellular technology (2G) signaled a massive change in human communications and mobile phones started spreading around. For the first time, human movements could potentially be tracked with a relatively high geographic precision and at a massive population scale (when a mobile user initiated a call or sent an SMS, the position could be recorded at the nearest Base Transceiver Station). All these phone data could be very promising for human mobility studies, but due to privacy concerns and the significant commercial value, telecommunication providers were extremely hesitant to share any information on call detail records with scientists. Years later, call detail records became sporadically available to various research groups and, in 2009, one of the first large scale analyses of human movement using call detail records was published (Noulas, 2013). According to Noulas (20013, p. 5) "despite the fact that the appearance of cellular data constituted a big step towards the understanding of human mobility on a large scale (compared to data received from surveys), it did not provide the opportunity for researchers to shed light on the multitude of movements taking place in cities every moment by millions of people. […] The study of human movement in the urban setting was still lacking quantitative evidence; the spatial granularity of call detail records was not standard and was bound to be accurate only up to a few hundred meters”.

Nowadays, new technologies are creating new interesting scenarios for the collection of mobility data which allow the recording of movements with spatial granularity. The widespread use of location-aware devices, including smart phones and GPS (Global Positioning System) enabled cars, provides powerful tools for collecting large volumes of time-resolved locations of individuals. In particular, the extensive use of the smartphones and of the social networks, a part signaling a massive change in human communications, is originating many new data eventually useful for mobility studies. These new datasets are expected to have a profound impact for the study of human mobility and behavior (Noulas, 2013). By exploring and analyzing the characteristics of this huge amount of individual location data, intra-urban human mobility can be potentially depicted.

2.2 Accessibility

Accessibility is an important characteristic of the urban areas and a crucial link between transportation and land use. As urban transportation planning is increasingly being considered an integral element of overall urban land-use planning, accessibility is becoming a key element in analyzing the efficiency of transportation systems, in predicting travel demand, in programming transportation investments, and in evaluating planning policies in the urban transportation planning process. Accessibility can be broadly defined as the ease with which activities at one place may be reached from another via a particular travel mode (Liu and Zhu, 2003). An accessible transport system is also essential to ensure equal opportunities for all people in society (Wu and Hine, 2003).

Geographic accessibility can be divided into place-based and person-based, where the latter also includes time. Place-based measures examine the proximity to desired activity locations from key locations in an individual's daily life, such as the home or workplace (Miller, 2007). Various place-based measures have been employed in the literature, including the travel distance to the nearest service location, the number of services within a particular areal unit or within a specified cut-off distance, and the gravity-based measures in which the attractiveness of services decreases with the extent of spatial separation from the origin. These measures have been criticized on many occasions for their lack of attention to the interconnectivity between an individual's activities and to the space-time constraints (Neutens et al, 2009). Then, they do not include the people perspective and the movements of people in time and space. Some advantages with the placed-based measures is that they are conceptually easy to understand and that do not need extensive data collection or too complex computation. Contrasting the place-based theories are the person-based ones, which instead incorporate both the time and space constraints on an individual level. The most fundamental concept of time geography is the space time path which represents the sequence of movements made by an individual in space-time. This idea was already recognized in the 1960s by the Swedish geographer Torsten Hägerstrand and became the basis of an universal approach for understanding the interdependencies between human beings, nature and technology, known as time geography (Neutens et al, 2010). As Hägerstrand (1970) agreed: regional science is about people and not just about locations.

There have been several studies that have compared placed-based and person-based accessibility measures and they showed that there are substantial differences between them. In particular they concluded that people-based measures are more appropriate to measure equity of public service delivery since they articulate interpersonal differences in accessibility. Kwan (1998) also states that there are two main limitations with the place-based measures: firstly, all travels start from the same location (see e.g. Hanson 1980 who shows that several stops to e.g. services are done to and from work); secondly, the time constraints are not.

From the early 1990s, the person-based approach grew its popularity primarily because GIS applications became available for implementing time geography's conceptual apparatus in empirically oriented research. Especially in the last decade, more and more researchers have published work at the intersection of time geography, transportation planning, accessibility analysis and geographical information science (Neutens et al., 2010).

Person-based accessibility analysis, in general, requires much more data than the place-based one and, for this reasons, they are usually suitable for small geographic region as an urban area. At the same time, nowadays, it appears necessary that the geographic accessibility studies on the public transport system incorporate information regarding the speed and the frequency of the service and not just the shortest distance measures to a service.

2.3 Public Transport Accessibility Levels (PTALs)

The accessibility model used in this study is the Public Transport Accessibility Levels (PTALs), developed in 1992, by the London Borough of Hammersmith and Fulham (Transport for London, 2010). This is a detailed and accurate method to assess the accessibility level of a point to the public transport network, taking into account walk access time and service availability (Transport for London, 2010).

PTALs model is used as a development planning tool in London and it has been “agreed by the London Borough-led PTAL development group as the most appropriate for use across London” (Transport for London, 2010, p. 1). PTALs model gives an indication of the relative density of the public transport network at specific locations. It effectively measures a combination of how close public transport services are from a given point and the frequency of services. It does not consider the destination of a movement and for this reason the egress time is not considered.

PTALs measure reflects:

- the walking time from a point of interest (it can be any location) to the public transport access points
- the reliability of the service modes available, adding a reliability factor
- the number of services available within the catchment
- the level of service at the public transport access points – i.e. average waiting time.

It does not consider:

- the speed or utility of accessible services;
- crowding, including the ability to board services; or,
- ease of interchange
- egress time.

The first step in PTALs calculation is to calculate the walking distance from the site (POI - point of interest -) to all the nearest public transport access points: bus and trolleybus stops, rail stations, underground stations and Tramlink halts. These stops are known as service access points (SAPs). Only SAPs within a certain distance of the POI are included (640m for bus, trolleybus and tram stops and 960m for metro and rail stations, which correspond to a walking time of 8 minutes and 12 minutes respectively at the standard assumed walking speed of 80m/min) (Transport for London, 2010).

The next stage is to determinate the service level and to incorporate a measure of service frequency by calculating an average waiting time (SWT) based on the frequency of services at each public transport access point. For each POI route information is only considered once. Where a route occurs twice or more - because it serves more than one SAP within the POI catchment area - the SAP that is nearest to the POI is used. Since at any SAP, routes will normally be bi-directional, the model considers the direction with the highest frequency. The average waiting time is considered as the average time between when a passenger arrives at a stop and the arrival of the desired service. It is estimated summing the average time a passenger would have to wait for a service to appear (estimated as half of the interval between service) by a reliability factor according to the mode of transport used (set at 2 minutes for buses and trams, at 0.75 minutes for metro, rail and trolleybus services) (Transport for London, 2010).

The next stage is to calculate the total access time (Access). A total access time for each route is calculated by adding together the walking time from the POI to the SAP and the average waiting time for services. This is then converted to an equivalent doorstep frequency (EDF) by dividing 30 (minutes) by the total access time, which is intended to convert total access time to a "notional average waiting time, as though the route was available at the doorstep of the POI" (Transport for London, 2010, p. 5).

A weighting is applied to each route to simulate the attractiveness of a route with a higher frequency over other routes. For each mode (rail, metro, bus, tram and trolleybus), the route with the highest frequency is given a weighting of 1.0, with all other routes in that mode weighted at 0.5.

Finally, the EDF and the weighting are multiplied to produce an accessibility index for each route, and the accessibility indices for all routes are summed to produce an overall accessibility index for the POI.

The accessibility index is then converted in a PTALs level. PTALs is categorized in 6 levels, 1 to 6 where 6 represents a high level of accessibility and 1 a low level of accessibility. Levels 1 and 6 have been further sub-divided into 2 sub-levels to provide greater clarity (Transport for London, 2010) (Table 3.1 and Table 3.2).

Table 2.1 PTALs computation example for a node (Transport for London, 2010).

Site	Service	Stop	Route	Distance	N. of rides / hour	Weight	Walk Time	SWT	Access	EDF	Accessibility Index
Node 1	BUS	TX08	F12	303	4	0.5	3.79	9.50	1329	226	1.13
		TW04	3A	408	6	0.5	5.10	7.00	12.10	248	1.24
		TW04	23	408	10	1	5.10	5.00	10.10	297	2.97
		TW03	125	511	6	0.5	6.39	7.00	13.39	224	1.12
	RAIL	East Finchley	CX	699	9	0.5	8.74	4.08	12.82	234	1.17
			Bank	699	9	1	8.74	4.08	12.82	234	2.34
											9.97

Table 2.2 PTALs legend (Transport for London, 2010).

PTAL	Range of Index	Description
1 a (low)	0.01 – 2.50	Very Poor
1 b	2.51 – 5.00	Very Poor
2	5.51 – 10.00	Poor
3	10.01 – 15.00	Moderate
4	15.01 – 20.00	Good
5	20.01 – 25.00	Very Good
6 a	25.01 – 40.00	Excellent
6 b	40.01 – +	Excellent

2.4 Stop spacing policies

Several studies have lead to knowledge about how to improve the efficiency of the public transport system. One way of doing it is via appropriate public transport stop spacing policies.

The location and spacing of surface public transport stops is one of the most important elements of the service planning process. Several studies show that the service can be inefficient because of the stop spacing (Furth, Mekuria, San Clemente, 2007) and that a proper spacing of stops can significantly improve the quality of the service by decreasing travel times (Wirasinghe and Ghoneim 1981; Kocur and Hendrickson 1982; Fitzpatrick et al. 1997; Kuah and Perl 2001; Saka 2001; Chien and Qin 2004; Alterkawi 2006; Ziari et al. 2007). The decision process to locate surface public transport stops can be complex: stop spacing has an effect on walking time, riding time, and operating cost. It has been studied that densely spaced public transport stations obviously improve the geographic coverage and the accessibility, but also increase in-vehicle time and supply costs. On the other side, eliminating service stops speeds up the system and reduces the operating costs. The accessibility level may vary and it can be both better or worst depending on where the new service stop is located (Shrestha and Zolnik, 2013).

Most transit providers have developed bus stop spacing standards to support service planning activity. A survey of the transit industry showed that 85% of respondents had adopted stop spacing standards, a substantial increase over the 62% of respondents in a 1984 survey reporting that they had done so (El-Geneidy, et al. 2006). Stop spacing standards are increasingly common in the transit industry because there are often intense conflict surrounding the location and spacing of stops and because stop spacing guidelines can be used to provide transit agencies with an objective way to resist pressure to add unnecessary stops or eliminate stops. Although stop spacing standards are common, the standards themselves are hardly uniform and this exposes the agencies to greater outside pressures (El-Geneidy, et al. 2006).

Stops, in northern European cities, are spaced much farther apart than those in comparable U.S. settings, yet European public transport systems are still able to capture a greater share of the urban travel market. “Bus stops in northern Europe, where transit has a much greater market share despite comparable levels of affluence, are generally located considerably farther apart than in the U.S.. One observer noted an average bus stop spacing between 400 and 500 m, and cited a recommendation of 300 m spacing from one Germany city official, versus the standard U.S. practice of 160 to 230 m (7 to 10 per mile)” (Furth and Rahbee, 2000, p.15). This distinction may contribute to a greater emphasis on maximizing service coverage and access in U.S. public transport systems (it is not uncommon for many transit riders to be within a walking distance of one quarter of a mile of several stops) versus a greater emphasis on maximizing operating efficiency in European systems (El-Geneidy, et al. 2006). Thus, although elimination of stops can result in reduced accessibility for some passengers, the aggregate reduction in accessibility from stop consolidation can be relatively small. A study conducted by New York’s Metropolitan Transit Authority in 1992 showed that after an increase in the distance between stops of more than 40%, resulting accessibility declined by only 12% (El-Geneidy, et al. 2006).

Some studies, as the one led in Firefax, Virginia (USA), show that the positive effects on travel time, pollution and management costs due to the elimination of some public transport stops are much more significant than the loss in the coverage of the service (Shrestha and Zolnik, 2013).

To discuss about stop spacing policies also means to study the walking path that people have to walk to access the public transport net. Changes on the walking path can have important consequences on the system efficiency. To analyze the impact on the walking distance is not easy and it has to avoid simplistic methods that do not consider the origin-destination (OD) matrix and that measure the walking distance without considering the real path (Furth, Mekuria, San Clemente, 2007).

3 Methodology

In this part, the general methodology in this study is described. The details of the methodology used for each specific analysis are described in chapter 5-8. The study is mainly divided into three parts: in the first one the focus of the research is the accessibility, in the second one the study focuses on the stop spacing model and in the third one the results of the model are studied considering the accessibility and the mobility demand (Figure 2.1).

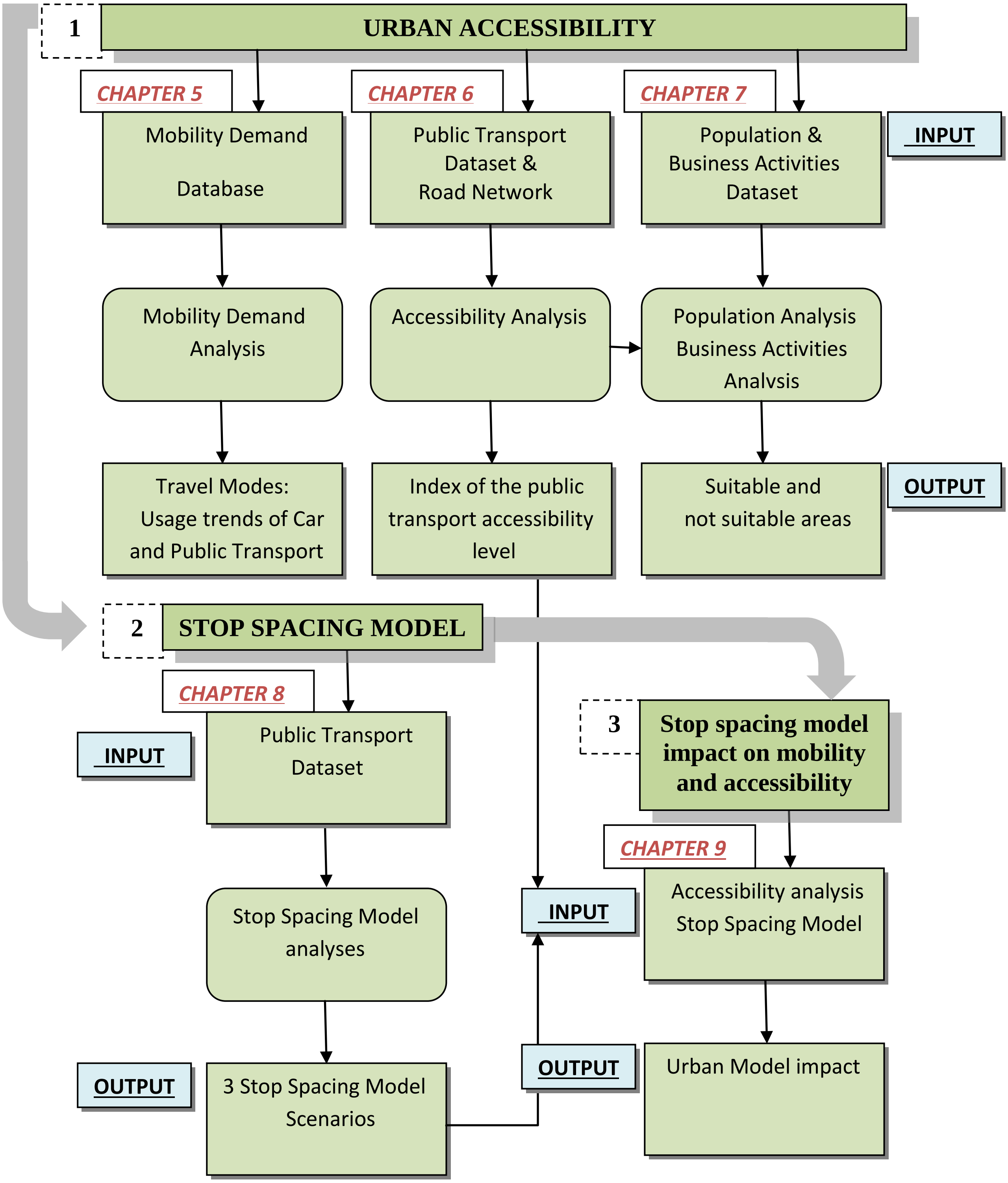


Figure 3.1 Methodology.

Part I: Accessibility analyses

The accessibility analyses aim to study some of the strengths and weaknesses of Milan public transport system and also to analyze some of the effects of the present public transport system itself. Figure 2.1 shows that the results of the accessibility analysis are also necessary to understand the impact of the proposed stop spacing model.

In this study, it was decided to perform the accessibility analyses in three steps: mobility demand analysis (chapter 5), urban accessibility analysis (chapter 6), accessibility analysis and population and business activities density (chapter 7). This follows a general-to-specific workflow and studying different aspects of the same theme.

1) *Mobility demand analysis*

Figure 2.1 shows that the mobility demand analysis is based on the data of Milan mobility demand database, which mainly contains the Origin-Destination (OD) matrix of the movements. In the database it is possible to get several information as the origin and the destination areas of the movements, the number of the travels made during the day, the time, the mode, the data concerning the family composition, the number of cars owned by person/family, etc. The data of the mobility demand database were collected by AMAT (Mobility and Environment Agency of Milan) in the mobility survey ("Indagine sulla mobilità delle persone nell'area milanese") of 2005-2006 (AMAT, 2006). The mobility survey was built in three different steps: on an interview of about the 10% of the families living in the metropolitan area of Milan (about 100.000 families), which aimed to observe all the movements made by all the components of a family (older than 11 years old) during the day before the interview; on an interview on about the 10% of the cars passing through 70 stations located around the city; on random interviews of users of the public transport system. The database was built considering 612 sub-urban areas, which define the origin and the destination areas of the movements. The definition of these sub-urban areas was made by the Mobility and Environment Agency of Milan considering the population, the services and activities located therein. For each of these areas the movements incoming and outgoing were recorded. This survey allowed to create the Origin-Destination matrix of the movements for the metropolitan area of Milan, which is particularly important for studies on the urban mobility.

The aim of the mobility demand analysis is to work on the mobility demand database to understand how people move in Milan and which travel mode they prefer depending on where they are and where they have to go. Accessibility and transportation consists in part of individual choices as, for example, what mode is used to get around (car, bus, bike, etc.) or at what time of day is the travel made, with how many people, etc. The analysis made in chapter 5 aims to understand, for each sub-urban areas, which is the usage trends of car and public transport system, the causes of this, and to produce, as output, two different data: one regarding the rate of the movements made by car and one concerning the rate of movements made by public transport. Together with the study of some of the characteristics of the public transport system, such as the capacity and the frequency, this allows to investigate, on a broad scale, some of the causes of people's choice of travel mode.

2) *Urban accessibility analysis*

The urban accessibility analysis is made using PTAL's accessibility model, which allows a detailed study of the accessibility and makes it possible to measure the accessibility level of each point of the city. It also allows to overcome those studies that strictly rely on population data and assume walking distance based on airline or rectilinear travel.

As explained in chapter 2, to compute PTAL's model it is necessary to have information regarding the location of the public transport stops, the frequency of the service and to be able to calculate the walking distance from a point of interest to the nearest public transport access points. For this, the urban accessibility analysis is based on the public transport dataset, which contains the vector data of the stops and the information regarding the frequency of the service, and on the road network, which allows to perform vector network analysis. Both the data were given by the Mobility and Environment Agency of Milan and were respectively updated to April 2014 and December 2013.

The analysis aims to study how the accessibility varies in Milan metropolitan area and to produce an output which consists in a raster representation of the public transport accessibility. Figure 2.1 shows how the results obtained in this part are particular important since they are used as input data for the analyses made on the population and business density and to the ones made in part 3.

3) *Accessibility analysis, Population and Business activities density*

The analysis of the population and business activities is based on the population and business activities dataset. The data was given by the Mobility and Environment Agency of Milan and it is updated to 2012. It consists in the point vector data of the street numbers to which is associated the population data and the number of business activities located.

The aim of the analysis is to study the population and the business activities density which makes it possible to understand which are the most and least densely populated areas and the location with a higher or lower concentration of business activities. Combining the population and business activities density analysis to the one made in the previous part ("urban accessibility analysis") also makes it possible to estimate the public transport use and to locate the areas where it is necessary or not to improve the existing public transport system considering where people live and work. Then, the analysis aims to produce as output a raster data of the population density, of the business density and of the combination of these two data with the results of the previous analysis.

Part II: Stop spacing model

With results from the accessibility analysis it is possible to start working on the stop spacing model (chapter 8). Stop spacing is an important determinant for planning a transport system which influences the service level as well as the accessibility and the cost of operation.

The analysis is based on the public transport dataset which, as stated above, contains the geo-referenced routes and stops as well as the information regarding the system (frequency, capacity, speed).

The aim of the model is to work on the public transport stops to improve the efficiency of the service. In particular, the study aims to analyze what happens if the stops spacing system changes, increasing the distance between the bus stops. As output, three different stop spacing system scenarios (with an increased distance between the stops) are created and proposed for the city of Milan.

Part III: Stop spacing model impact on mobility and accessibility

Once that the new stop spacing system scenarios are computed, it is necessary to study their impact on the reality. To do this, in chapter 9 the evaluation of the scenarios is based on the results coming from the studies made in the previous parts. In particular two kinds of analyses are proposed:

1. based on the origin-destination matrix, it is made a comparison on how passenger access and egress time changes with the new stop spacing scenarios;
2. based on the accessibility model studied in **part I** (PTALs), it is examined how the accessibility level changes simultaneously with the new stop spacing systems.

4 Study area

Milan is located in the western part of the Lombardy region, in the north part of Italy, and it is the second most populated Italian city (Figure 4.1). The study area is composed by the City of Milan and 39 municipalities[1] of Milan Metropolitan Area. The city of Milan has a population of about 1.3 million people (about 2.4 million considering Milan Metropolitan Area municipalities). The area of the municipality of Milan is about 180 km^2. Milan is also known as the main industrial, commercial and financial centre of Italy and it attracts about 800,000 commuters every day.

The Municipality of Milan is divided in three concentric areas (Figure 4.1):

- "Cerchia dei Bastioni" (Bastioni Ring) is the central area of the city and it corresponds to the perimeter of the medieval walls. Its area is equal to 8.2 km^2, approximately 4.5% of the whole territory of the Municipality of Milan. Some data related to this central area of the city: 77,950 residents (6%), 42,300 families, almost 25% of businesses in Milan, 39,000 persons/km^2 (daylight hours - in average), 140,000 persons/km^2 (daylight hours - picks within the historical center) (AMAT, 2014).
- "Cerchia Filoviaria" (Filoviaria Ring) corresponding to the trolleybus ring.
- Municipal Boundary, till the border of the City.

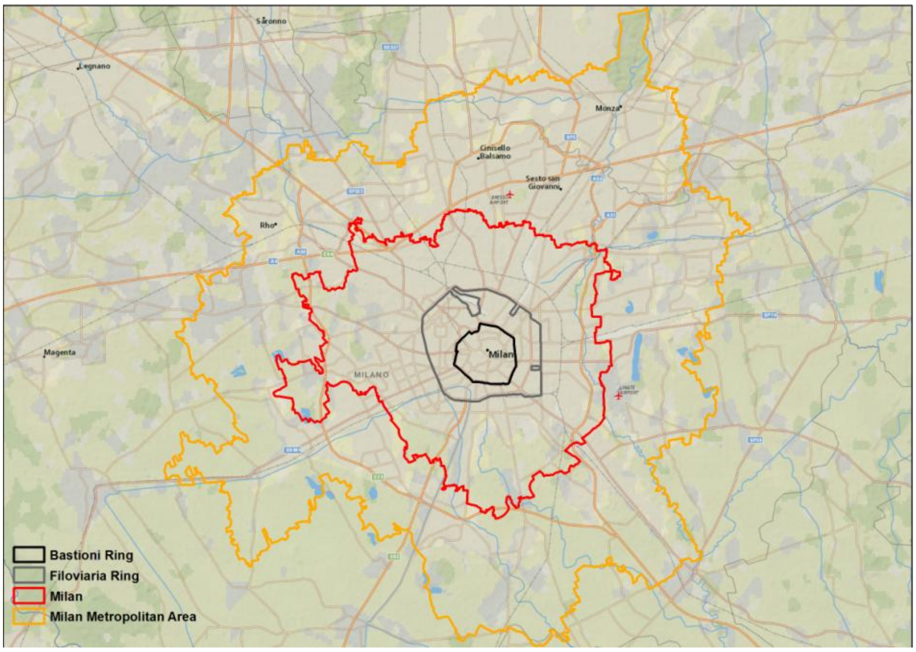


Figure 4.1 Milan and Milan Metropolitan Area.

[1] Arese, Assago, Bareggio, Basiglio, Bollate, Bresso, Brugherio, Buccinasco, Cernusco sul Naviglio, Cesano Boscone, Cinisello Balsamo, Cologno Monzese, Cormano, Cornaredo, Corsico, Cusago, Cusano Milanino, Gaggiano, Locate di Triulzi, Monza, Muggiò, Nova Milanese, Novate Milanese, Opera, Paderno Dugnano, Pero, Peschiera Borromeo, Pieve Emanuele, Pioltello, Rho, Rozzano, San Donato Milanese, San Giuliano Milanese, Segrate, Sesto San Giovanni, Settimo Milanese, Trezzano sul Naviglio, Vimodrone.

Milan internal public transport system includes metro, suburban railway, tram and bus networks. Besides the public transport system, the city also provides the possibility to use taxi, car and bike sharing.

The public transport net is organized in this way:

- Metro: the network consists in 4 lines (M1, M2, M3, M5) and 103 stations. The network is still on development: a new line (M4) should be completed by the 2018 and the M5 should be extended with 10 new stations by 2015.
- Suburban railway: consists of 10 lines connecting Milan to its greater metropolitan area.
- Urban Tram: its network is characterized by 17 urban lines and 1 interurban line (Figure 4.3).
- Bus: the net is composed by 133 bus routes (29 suburban routes) and 4 trolleybus lines (Figure 4.3).

Milan Municipality launched several measures to fight air pollution and traffic congestion including two road price schemes applied to the historical centre. The first, started in 2008 and called “Ecopass”, based on the “polluter pays principle”; the second and definitive scheme, launched in January 2012, called “Area C”, combines a Congestion Charge scheme with the banning of the most polluting vehicles (AMAT, 2014).

Figure 4.2 Old and new urban tram, trolleybus and Bus.

5 Mobility demand analysis

The study of the mobility demand is an important tool to investigate and to understand people's mobility behavior and people's choice of travel mode. This is also important to get the knowledge of the public transport potential demand, which is fundamental for the Municipality planning policies.

The mobility planning analysis is based on the mobility demand database and aims to comprehend how people move in the metropolitan area of Milan and which travel mode they prefer depending on the area. In particular, the analysis focuses on the movements made by car and by public transport.

5.1 Data

Table 5.1 shows the dataset used to perform the analyses made in this chapter. All data use the spatial reference system Monte Mario (Rome).

Table 5.1 Input Data.

INPUT DATA		
DATA	**TYPE**	**DESCRIPTION**
MILAN MOBILITY DEMAND DATABASE	Database	In the database is possible to get information such as the origin and the destination areas of the movements, the number of movements outgoing and incoming, the reason of these movements, the travel mode used and the user typology
ORIGIN-DESTINATION AREAS	Vector Data (POLYGON)	Sub-urban areas into which the metropolitan area of Milan has been divided. This data is associated to the information of the Milan Mobility Demand Database (Figure 5.1)
MILAN PUBLIC TRANSPORT SYSTEM	Vector Data	Data about the routes (polyline) and the stops (point) location. To the stops data is associated the information about the frequency and the capacity of the service

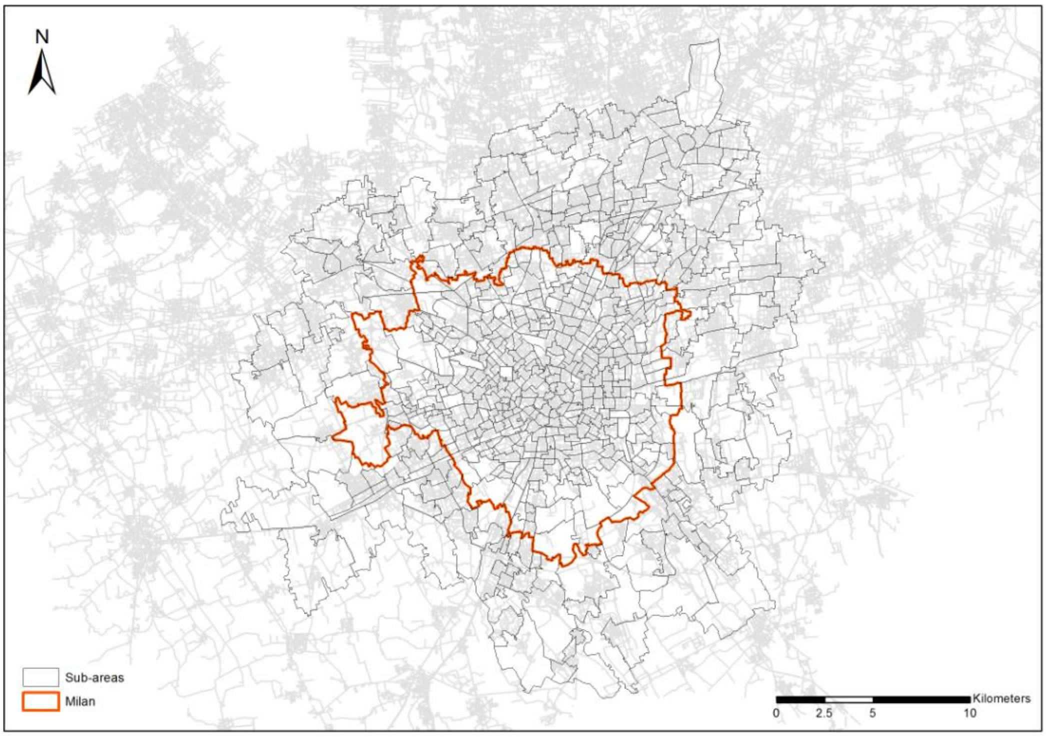


Figure 5.1 Areas for Origin-Destination analyses.

5.2 Methods

To understand how people move in the metropolitan area of Milan and which travel mode they prefer, it is necessary to work on the mobility demand database, which is built on a urban mobility survey.

Since the purpose of the study is to study the mobility demand at a large scale, the analysis is performed considering the origin and destination area of the movements and not the real origin and destination point of the movements. The analysis is computed for two different periods when the service works: 6.00 a.m.-12.00 p.m. and 8.00 a.m. – 9.00 a.m., in order to study the demand during the day and during the peak hour.

The principles of the analysis are based on:

- the study, for each origin and destination area, of the rate of movements made by car and using the public transport system to investigate the general cause of people's choice of travel mode
- the study of the frequency and capacity to analyze where the system is more or less developed.

The result of the analyses are raster representations of the mobility demand. Representing the mobility demand as a raster allows: first, to create a continuous surface, which guarantees a better spatial representation of the movements; second, to get a result that can be easily compared and used as input to the analyses made in the other chapters.

The following workflow is used:

1) From the mobility demand database, I extrapolated, for each sub-area, the rate of movements made by car or using the public transport system. For this, for each sub-area, I divided the total number of travels made by car or using the public transport system by the total number of movements (C_M and PT_M). For each sub-area, the total number of travels has to consider both the incoming and outgoing movements (origin+destination movements) (C, PT and T_M).

   $C_M = C / T_M$ *(1)*
   $PT_M = PT / T_M$ *(2)*

   C_M = car movements on the total movements
   PT_M = public transport movements on the total movements
   T_M = total movements (origin + destination)
   C = car movements (origin + destination)
   PT = public transport movements (origin + destination)

2) Represent in a map the analysis made in the previous step. For this, I performed an interpolation, which can be defined as the process of estimating unknown values at unsampled points from measurements made at surrounding sites (sampled points). Its purpose is to create a continuous surface.

   To perform an interpolation, the sub-area polygons need first to be transformed in points (using the polygon centroids) then, the information computed in the previous step is linked to these points and, finally, one of the interpolation algorithms is performed on the centroids.

   The estimation of the values among the sample points can be done using different interpolation algorithms. In this study, the maps are created using the Natural Neighbour algorithm. The Natural Neighbour algorithm finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas to interpolate a value (Sibson 1981). It is also known as Sibson or "area-stealing" interpolation. Its basic properties are that it's local, using only a subset of samples that surround a query point, that it does not infer trends and that it does not produce peaks, pits, ridges, or valleys which are not already represented by the input samples. The surface passes through the input samples and is smooth everywhere except at locations of the input samples (Esri, 2012).

3) To study the frequency and capacity of the system to analyze where the system is more or less developed I worked on the dataset of Milan public transport system. In particular, starting from the vector data of the public transport stops to which the frequency and capacity information was associated, I used the Point Density tool to produce two maps: one regarding the service frequency and one regarding the service capacity. The Point Density tool calculates a magnitude per unit area from point features that fall within a neighborhood around each cell (Esri, 2012). I set the search radius at 500 meters and in the radius distance, the frequency and capacity values are summed. The output values are computed in this way: the tool goes to a cell, looks for points in a defined search radius, sums them and then divides everything by the area of the search radius.

All the analyses made are carried out using ArcGIS 10.0.

5.3 Result

The maps in figure 5.2-5.9 show the results of the analyses made on the service frequency and capacity and on the movements made by car and using the public transport system. As explained above, the analyses on the frequency and on the capacity are interesting to analyze where the system is more or less developed, while the ones made on the rate of movements made by car and using the public transport system allow to investigate how people move in Milan metropolitan area. The combination of these analyses gives the possibility to understand the general cause of people's choice of travel mode.

The maps are made for the peak hour (8.00 am – 9.00 am) and the daily period (6.00 am – 12.00 pm) and the cell size is set at 50x50 meters.

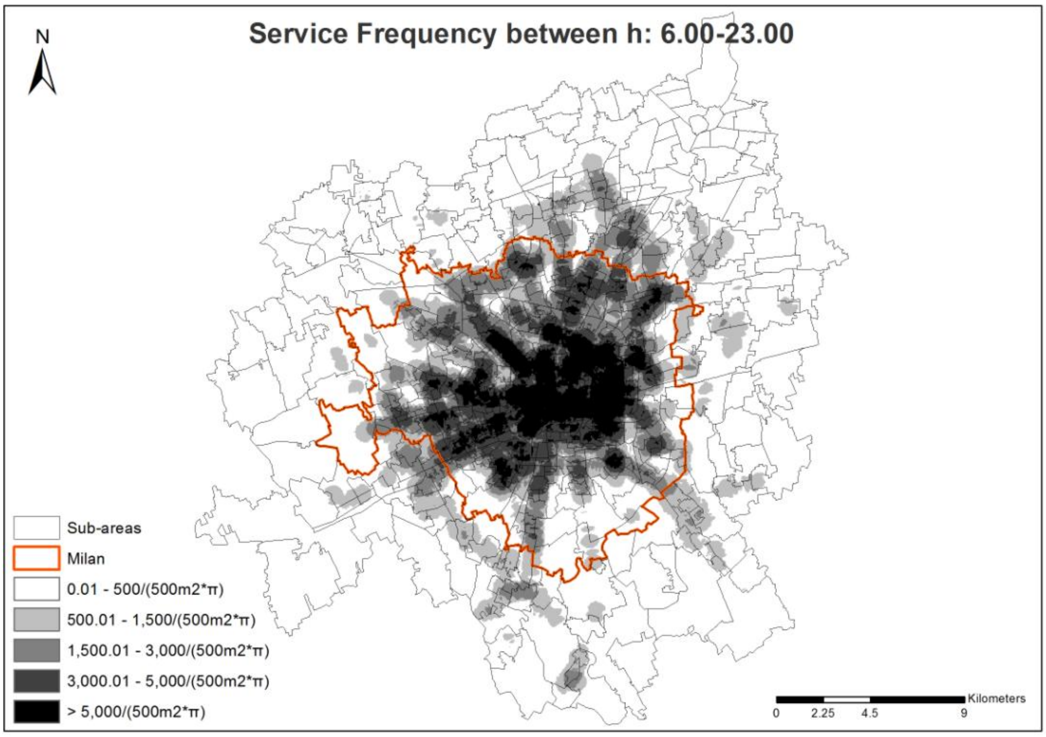


Figure 5.2 Analysis of the service frequency between h: 6.00 - 24.00.

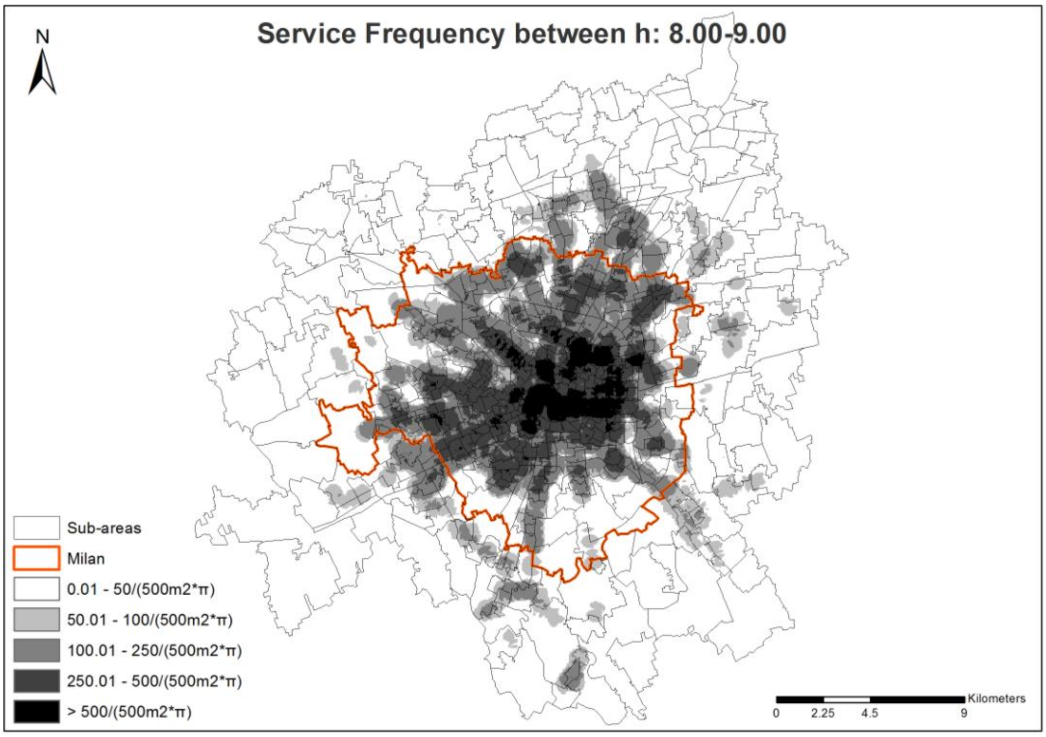


Figure 5.3 Analysis of the service frequency between h: 8.00 - 9.00.

The frequency maps (Figure 5.2 and 5.3) show where the public transport is more frequent and, then, available. From the maps it is evident that the more an area is central the more the frequency level is high, both during the peak hour and the whole day. This can be explained by a higher public transport offer, in space and in time, which guarantees a greater availability. This is also obvious considering the commercial and tourist importance of the region.

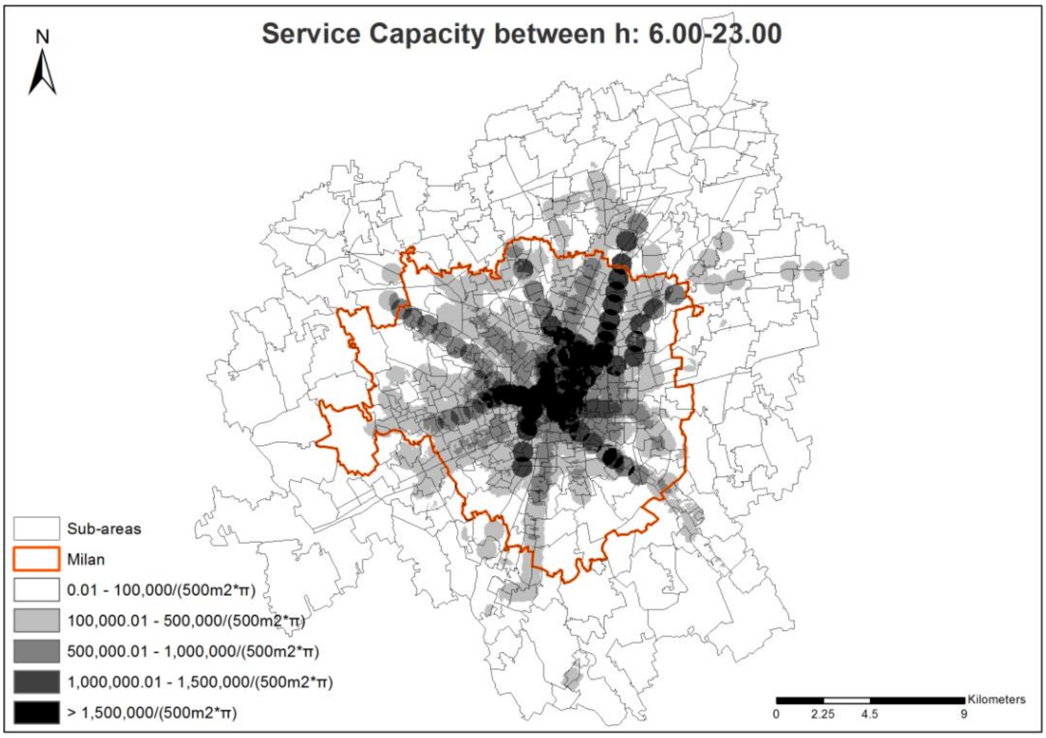


Figure 5.4 Analysis of the service capacity between h: 6.00 - 24.00.

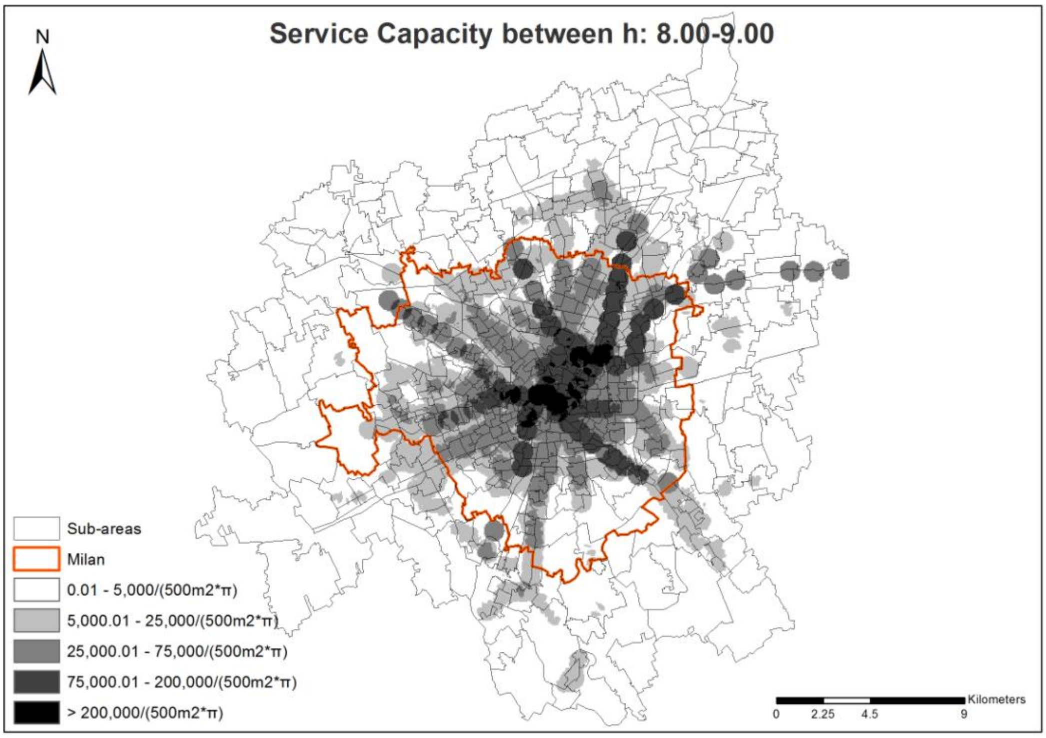


Figure 5.5 Analysis of the service capacity between h: 8.00 - 9.00.

The capacity maps (Figure 5.4 and 5.5) show where the capacity of the public transport system is higher. A part showing where the service offer is higher, these maps are useful to explain where the system is more developed and likely used. The analysis made highlights the urban corridors where the public transport service is more developed. In general, the east and the north-east part of Milan is more developed. This is also evident from the analysis on the frequency

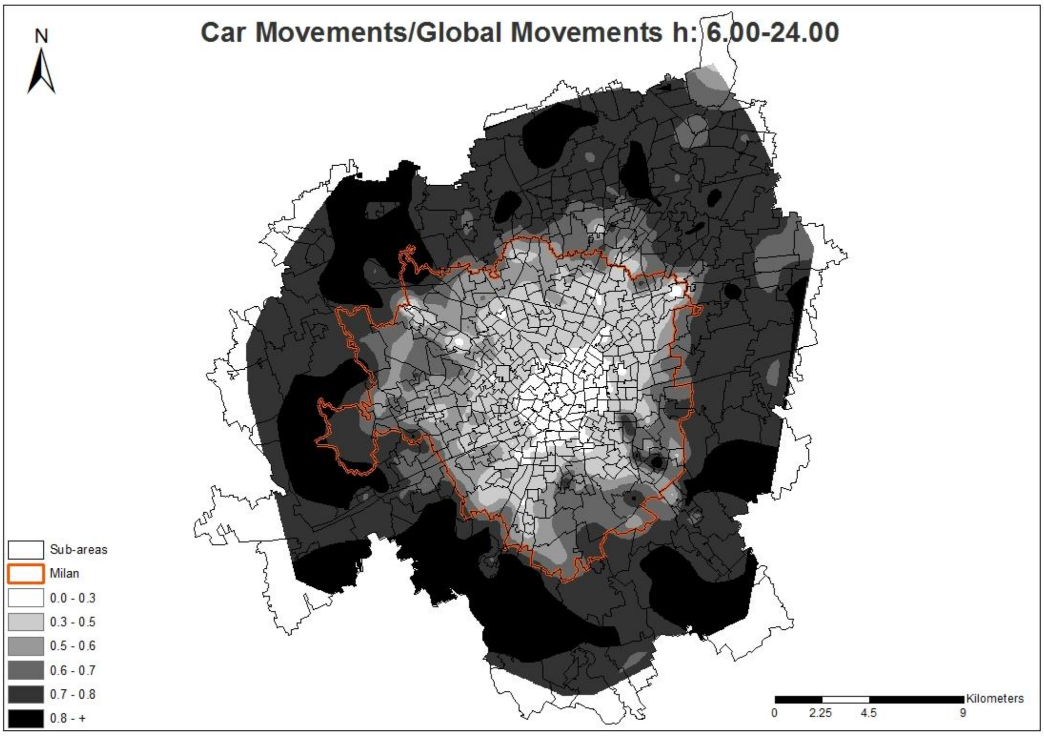


Figure 5.6 Mobility Demand Analysis – Car movements rate between h: 6.00 - 24.00.

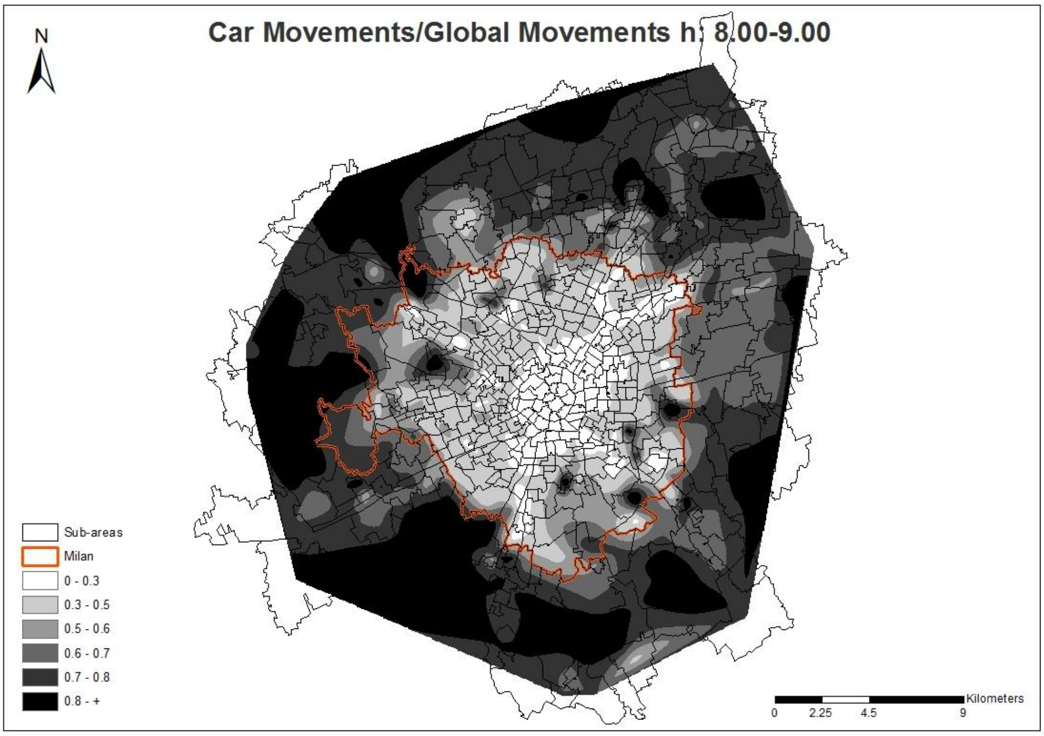


Figure 5.7 Mobility Demand Analysis – Car movements rate between h: 8.00 - 9.00.

The maps on the movements made by car highlight that the number of car movements on the total travels is higher in the hinterland region and it is lower in City centre (Figure 5.6 and 5.7). The results are similar for the peak hour and the daily period.

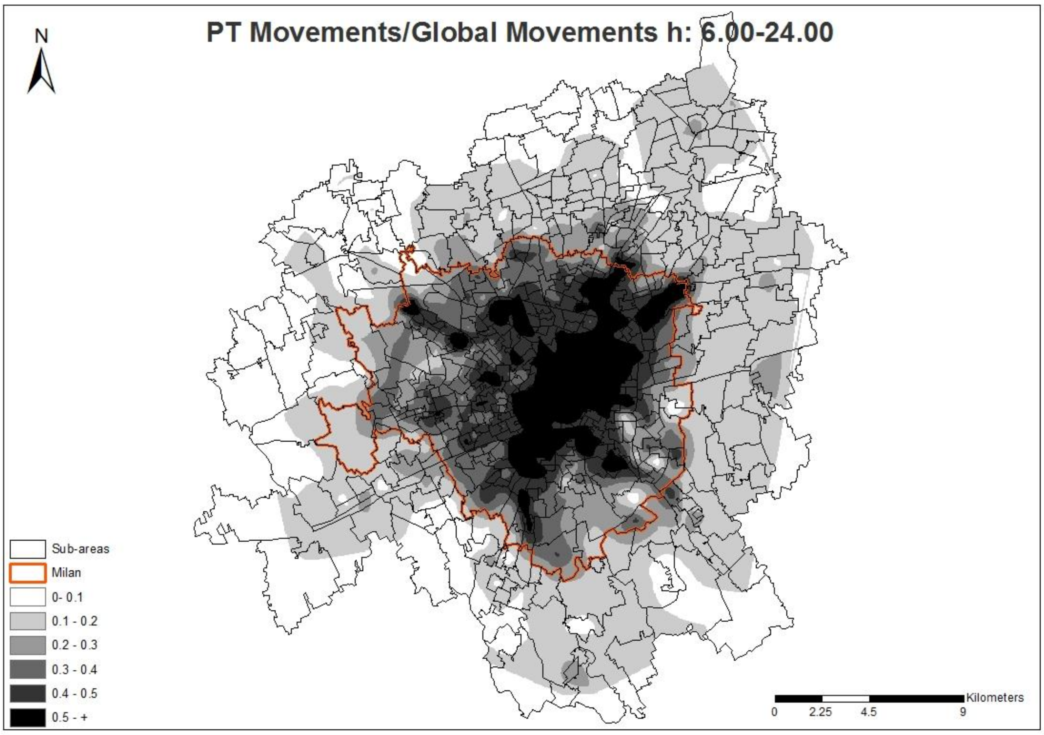


Figure 5.8 Mobility Demand Analysis – Public transport movements rate between h: 6.00 - 24.00.

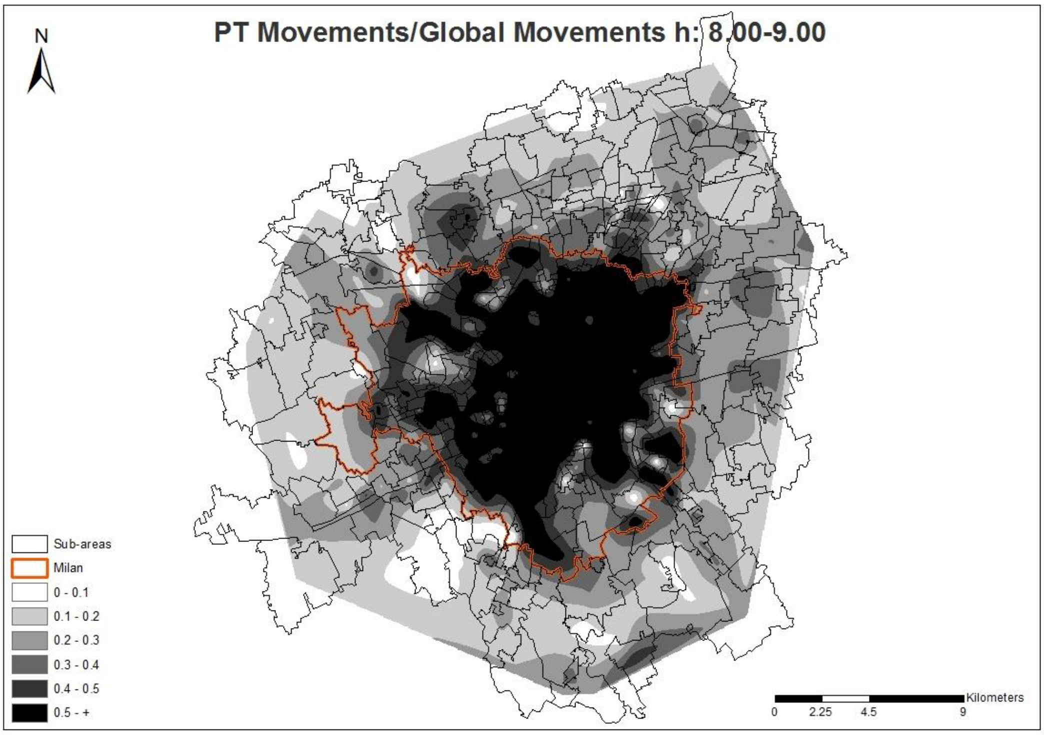


Figure 5.9 Mobility Demand Analysis – Public transport movements rate between h: 8.00 - 9.00.

The maps (Figure 5.8-5.9) highlight that the public transport movements are preferred in the central area, where the service offer is higher. Comparing Figure 5.8 and Figure 5.9, it is also possible to observe that the public transport rate in the central areas is higher during the peak hour. This is due to the high business concentration in the same areas.

5.4 Discussion

The analyses made on the frequency and on the capacity are interesting to understand which are the areas with a good or bad public transport offer and where the service is more likely used. In particular, the frequency analyses aim to study the service availability level for the peak hour and the daily time, while the capacity studies aim to show the number of people that the service can accommodate in the analyzed time period. Then, the combination of the analyses of the frequency and of the capacity allows to understand where the system is more or less developed, available and likely used. In general, it is possible to say that the service is more developed in the most central areas and is less developed in the hinterland regions. This is normal considering the number of people that are attracted every day by the city center. The results also highlight some urban corridors where the system is particularly developed. These corridors are the preferred routes to connect the hinterland regions to the central areas. The results show that more corridors could be created to connect better the hinterland areas to the central ones and that the main problem is the connection within the surrounding areas.

The analyses made on the movements made by car and using the public transport system highlight that the efficiency and the quality of the service can also influence the choice of travel mode made by people. In-fact, the results on the mobility demand show that the movements made by car are preferred and also more convenient where the system is less developed while the ones made using the public transport system are preferred where the service offer is higher. This reinforces the idea that the more a system is efficient and easy to access the more the use of public transport likely increases. The use of the public transport mode is also more convenient in the central areas, where the use of cars is less convenient because of traffic congestion and the parking areas are more crowed and expensive.

The analyses made above have to be considered with the results of the accessibility analysis (made in the next chapter).

6 Accessibility analysis

Compared to the analyses made in the previous chapter, the aim of this part is to examine more in depth the urban accessibility. In particular, its goal is to use the Public Transport Accessibility Levels (PTALs) model to have a detailed and accurate measure of the accessibility level of each point of the city, taking into account walk access time and service availability.

6.1 Data

Table 6.1 shows the dataset used to perform the analyses made in this chapter. All data use the spatial reference system Monte Mario (Rome).

Table 6.1 Input Data.

INPUT DATA		
DATA	**TYPE**	**DESCRIPTION**
MILAN PUBLIC TRANSPORT SYSTEM	Vector Data	Data about the routes (polyline) and the stops (point) location. To the stops data is associated the information about the frequency and the capacity of the service
MILAN ROADS	Vector Data	Dataset of the roads of Milan (polyline). This is transformed in a network dataset of the roads of Milan

6.2 Methods

The accessibility analyses are made using PTALs model principles. The choice of PTALs model is due to several reasons: first of all, it has been previously used in other important cities (as London) and it has been considered as a very appropriate tool to study accessibility and to help the urban planning; it gives an indication of the relative density of the public transport network; it considers the access time; combining the walk path to the frequency of the services, it provides an accurate measure of the accessibility level of each point of the city; its results are easy to read and to interpret; it allows to overcome the limits of the place-based analyses including a people-based perspective.

The output of the accessibility analysis is represented as raster and this allows to create a continuous surface which guarantees a better spatial representation of the accessibility. To create a raster output also allows to get a result that can be easily compared and used as input to the analyses made in the other chapters.

The following workflow is used to:

1) Delete from the roads dataset the streets where it is not possible to walk. The interest here is focused on the distance that people are willing to walk to reach a public transport stop. The model itself considers the walking time from the point of interest to the public transport access point.

2) Compute the PTALs accessibility index for each node of the network. The process can be broken down into a series of stages:

- First, since PTALS model takes into account the walk access time, the distance between the points of interest and the stops has to be computed. To do that, first it is necessary to define the points of interest, which are here considered all the nodes of the network, and to transform the roads dataset in a new network dataset to be able to perform vector network analyses. Then, the accessibility model is implemented in a python script where the following workflow is used to:

➢ create a buffer of 960 meters around each stop (from PTALs literature, the maximum distance from the point of interest to the access point is set to 960 meters);

➢ intersect the network nodes with the buffer created in the previous step and to select the nodes that can be connected to the stop;

➢ compute the shortest path from the station to each of the nodes inside the buffer. In the script, the ArcPy functions are implemented (ArcPy is a site package that comes with ArcGIS). The shortest path is computed using the "Closest facility" tool.

At the end of this step, a matrix is obtained of the shortest paths from each stop to all the nodes within a buffer of 960 meters.

- Use the shortest path matrix to compute the PTALs accessibility index for each node of the network. For this, it is necessary to:

➢ delete the records which go over these distance: for buses, trolleybuses and trams the maximum distance is set at 640 meters (about 8 minutes of walking time) while for metro and rails the maximum distance is set at 960 meters (12 minutes of walking time);

➢ if, from a node, it is possible to reach more stations belonging to the same line, the closest one is the one to be considered and selected.

- Compute the PTALs accessibility index for each node of the network.

$Total\ Access\ Time = Walk\ Time + SWT$ (1)

$EDF = 30/Total\ Access\ Time\ (minutes)$ (2)

$AI_{MODE} = EDFmax + (0.5 \times All\ other\ EDFs)$ (3)

$AI_{TOT} = \Sigma(AI_{MODE\ bus} + AI_{MODE\ trolleybus} + AI_{MODE\ tram} + AI_{MODE\ metro} + AI_{MODE\ rail})$ (4)

SWT = K + 0.5 * (60 minutes / number of rides) → This represents the “Average Waiting Time”, which is the average time between when a passenger arrives at a stop or station, and the arrival of the desired service.

K = is a ‘reliability’ factor relating to the reliability of the service, which may be derived from observed survey data for each service at any time of day. If services are operating to schedule then K=1; however, in the absence of up-to-date and accurate survey data, K is set at 2 minutes for buses and trams, at 0.75 minutes for metro, rail and trolleybus services.

WALK TIME: walking distance (meters) / 80 (meters/min)

3) Create the accessibility map using an interpolation algorithm. Since the accessibility level varies a lot in the space, the interpolation is made using the Inverse Distance Interpolation (IDW) interpolation in ArcGIS 10.0 with a power of 2. This method assumes that the variable being mapped decreases in influence with distance from its sampled location (Esri, 2010) and this is why it has been preferred to the Natural Neighbour algorithm used in the previous part.

The analysis is made for the morning peak hour 8.00 am – 9.00 am

6.3 Result

Based on the analysis made in the case study, it was decided to keep the scale proposed by the PTALs literature (Figure 6.1). The cell size is set at 50x50 meters.

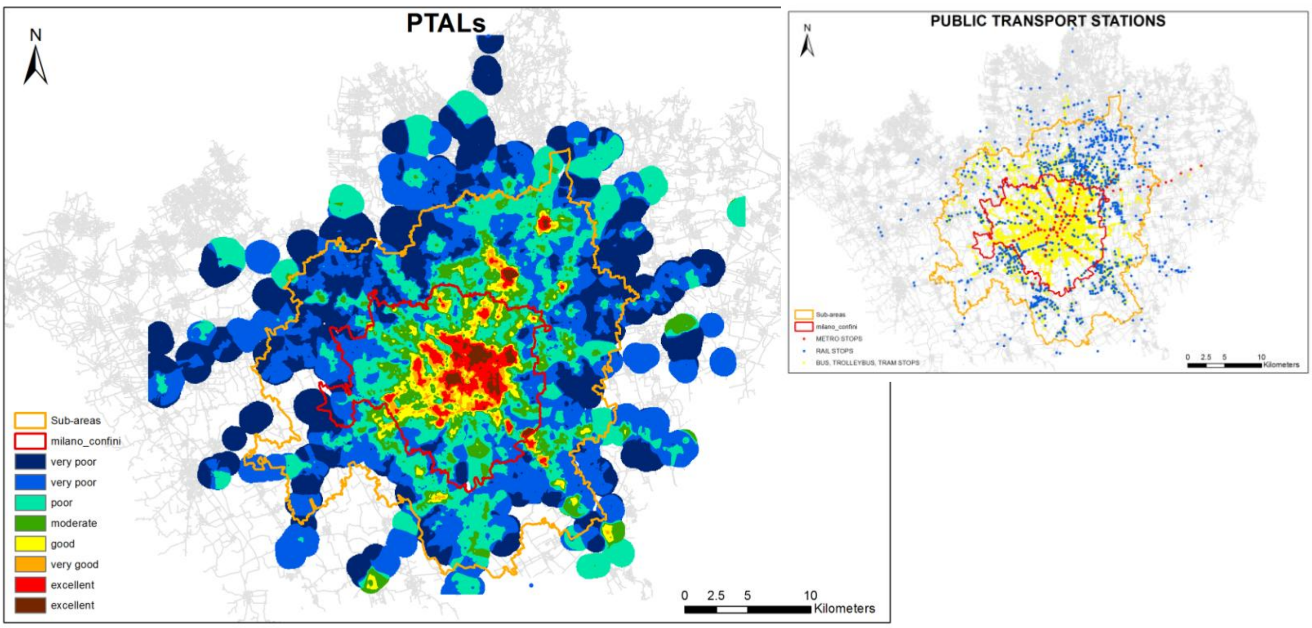


Figure 6.1 PTALs analysis – h:8.00-9.00.

The aim of this analysis is to map the accessibility on an urban macro level. The analysis shows that there is a difference between the accessibility in the City of Milan and the hinterland area (Figure 6.1). The dark red areas are the ones with the highest accessibility level, while the dark blue areas are the ones with the lowest level. In the hinterland area, the accessibility level is on average poor and this is generally due to a lower density of the public transport stops and to a lower frequency of the service routes. Focusing instead in the City instead (Figure 6.2), the situation is different: in the Bastioni Ring the accessibility level goes mostly from good to excellent; in the Filoviaria Ring the accessibility level goes from poor to excellent; in the City Boundary region the situation is very heterogeneous and it varies from very poor to excellent. It is also evident that the north-eastern region has higher accessibility values.

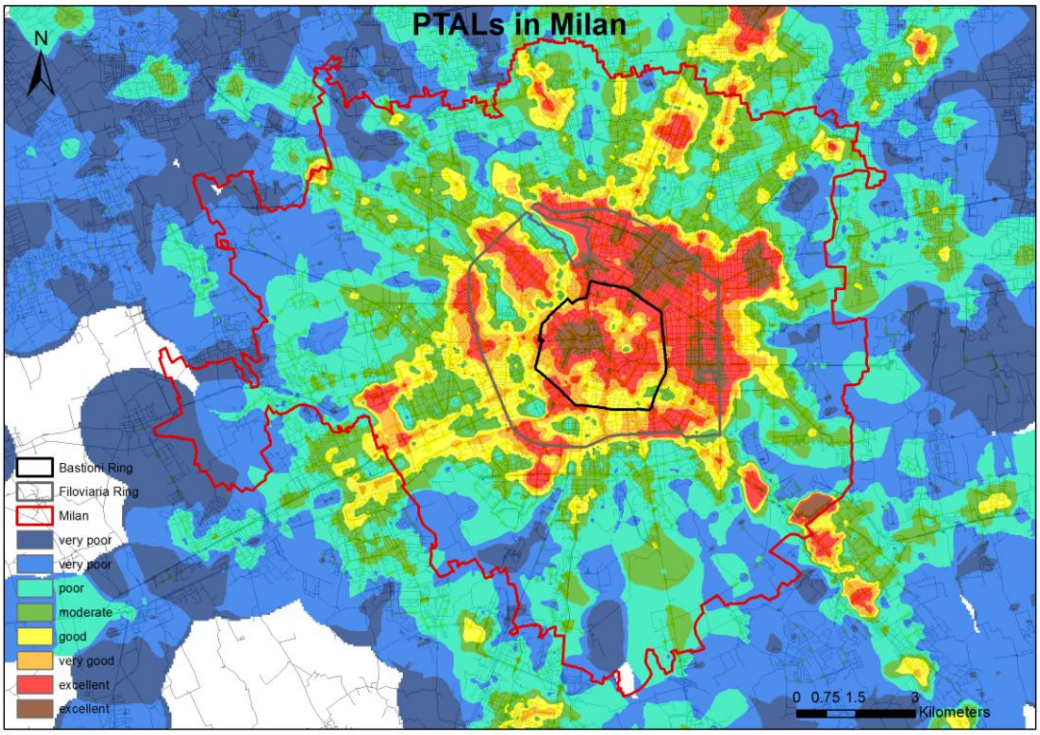


Figure 6.2 PTALs analysis in Milan – h:8.00-9.00.

This results are completely consistent with the analysis made in the previous chapter. Looking at figures 4 and 5, it is possible to see that the public transport frequency and capacity maps have their higher values in the northeastern area (where the accessibility values are excellent).

6.4 Discussion

The PTALs approach is surely interesting because it deeply examines the importance of the walking path and of the service availability, but it does not consider such aspects as the destination of a movement, the speed of a service, the crowding of a service or the ease of interchange.

Accessibility analyses are generally complex since both the distance to access to the public transport net and the public transport offer and efficiency have to be considered. These are two key factors that influence each other. The people's walk distance to access stations plays a fundamental role in the ultimate use made of public transport. The more people who live and/or are employed in close proximity to transit, the greater the likelihood the service will be used (Murray et al, 1998). At the same time the quality of a service is important to attract people. The service quality is usually based on availability, frequency, travel speed, reliability and safety.

The results of the PTALs analysis are consistent with the ones made in the previous part: in general, the car use is greater where the accessibility is lower and, conversely, public transport use is greater where the accessibility is higher. This is particularly important since it means that the accessibility level influences people's behavior and mobility choices. A good accessibility level can contrast the private mobility, producing a positive effect on the pollution and the environment. The mobility choices are also influenced by the public transport ease of interchange which, as stated above, is not possible to evaluate using the PTALs model.

The public transport ease of interchange is a key aspect analyzing the hinterland area since to study the accessibility of the City of Milan also means to study the accessibility of Milan metropolitan area. From the analysis made, it looks that the accessibility in the hinterland area has to improve. This is particularly important considering the high number of commuters that Milan attracts every day.

7 Integrating accessibility, population and business activities

The aim of this section is to combine the population and the business activities data with the accessibility results obtained in the previous chapter. Estimates of the population and business activities with access to transit are important to estimate public transport use. In particular they are essential for understanding: 1) where to improve the current public transport system; 2) where to locate future network extensions; and 3) where to locate new public transport stations. Combining the population data with the PTALs model results aims to improve the more simplistic place-based analyses.

7.1 Data

Table 7.1 shows the dataset used to perform the analyses made in this chapter. All data use the spatial reference system Monte Mario (Rome).

Table 7.1 Input Data.

INPUT DATA		
DATA	**TYPE**	**DESCRIPTION**
MILAN POPULATION	Vector Data (POINT)	Dataset of the population of Milan, associated to the street numbers.
MILAN BUSINESS ACTIVITIES	Vector Data (POINT)	Dataset of the business activities of Milan, associated to the street numbers.
PTAL's RESULT	Raster Data	Results of the accessibility analysis made in the previous part

7.2 Methods

The study of the population is done using the population data that is associated to the street numbers. The raster representation of the population and business activities data has some advantages: it allows the opportunity to produce a more realistic map of the population and business density; a raster representation allows to create a continuous surface, which guarantees a better spatial representation of the population and business density; it produces results easy to be interpreted and easy to be combined with the accessibility results; this approach allows to create an accurate combination of population, business activities and accessibility, which aims to overcome place-based analyses.

The following workflow is used:

1) Create a map of the population density and a map of the business activities density.

2) Combine the PTALs map with the population density map created in Step 1

All the analyses made were done using ArcGIS 10.0.

The maps created in S**tep 1** are created with the Point Density tool starting from the vector data of the population and business activities. The search radius is set to 200 meters and the cell size is set to 50 meter.

The intersection (**Step 2**) is done using the Raster Calculator tool. Before using this tool, it is necessary to reclassify PTALs, Population Density and Business Density raster layers. Table 7.2-7.3 shows the reclassification classes used for PTALs, population and business density.

Table 7.2 PTALs and Population Density reclassification and intersection.

		PTALs					
Population Density		Very Poor	Poor	Moderate	Good	Very Good	Excellent
	Very Low						
	Low						
	Medium						
	High						
	Very High						

Table 7.3 PTALs and Business Density reclassification and intersection.

		PTALs					
Business Density		Very Poor	Poor	Moderate	Good	Very Good	Excellent
	Very Low						
	Low						
	Medium						
	High						
	Very High						

Considering the accessibility levels coming from the PTAL's analysis made in the previous part and the business and population density levels, the red cells indicate where the values of the intersection between PTALs and the density are not good, and the green cells indicate where the values are good.

7.3 Result

The results show: the population density map (Figure 7.1); the business activities map (Figure 7.3); the map related to the intersection between PTALs and the population density (Figure 7.2); the map related to the intersection between PTALs and the business density (Figure 7.4). The cell size is set at 50x50 meters.

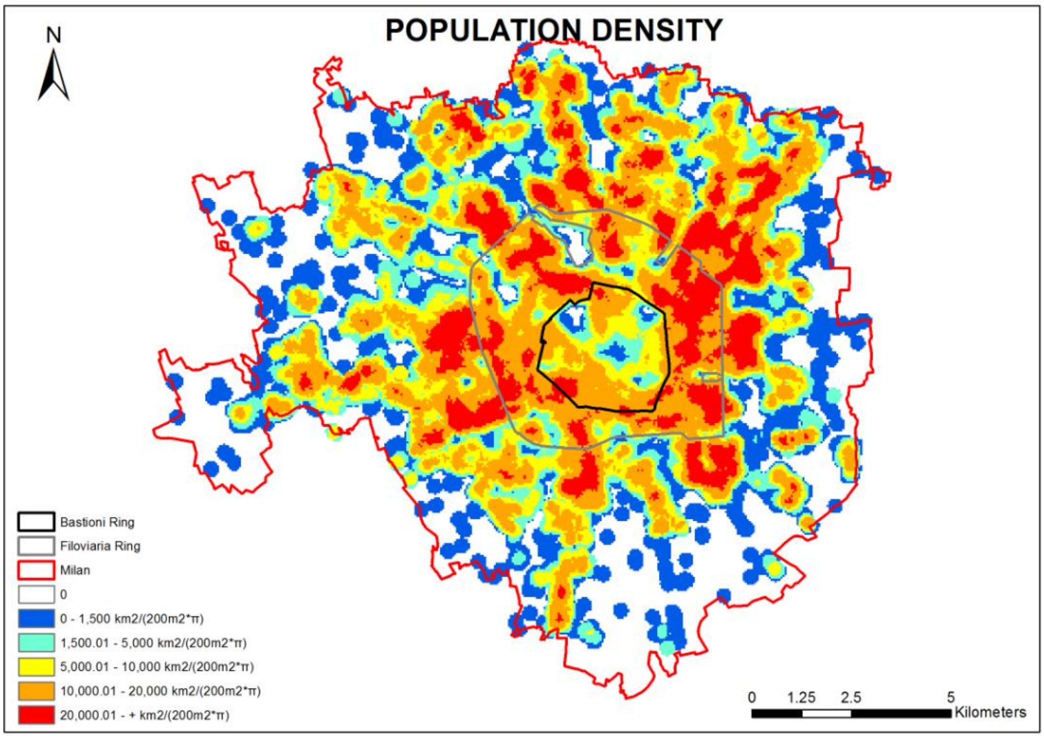


Figure 7.1 Population Density.

The population density map (Figure 7.1) allows one to understand which are the less (blue areas) and more (red areas) populated regions: Milan centre is not highly populated (this is obvious considering the high number of activities concentrated in it); the Filoviaria Ring is highly populated; and the density in the Municipal Boundary is variable.

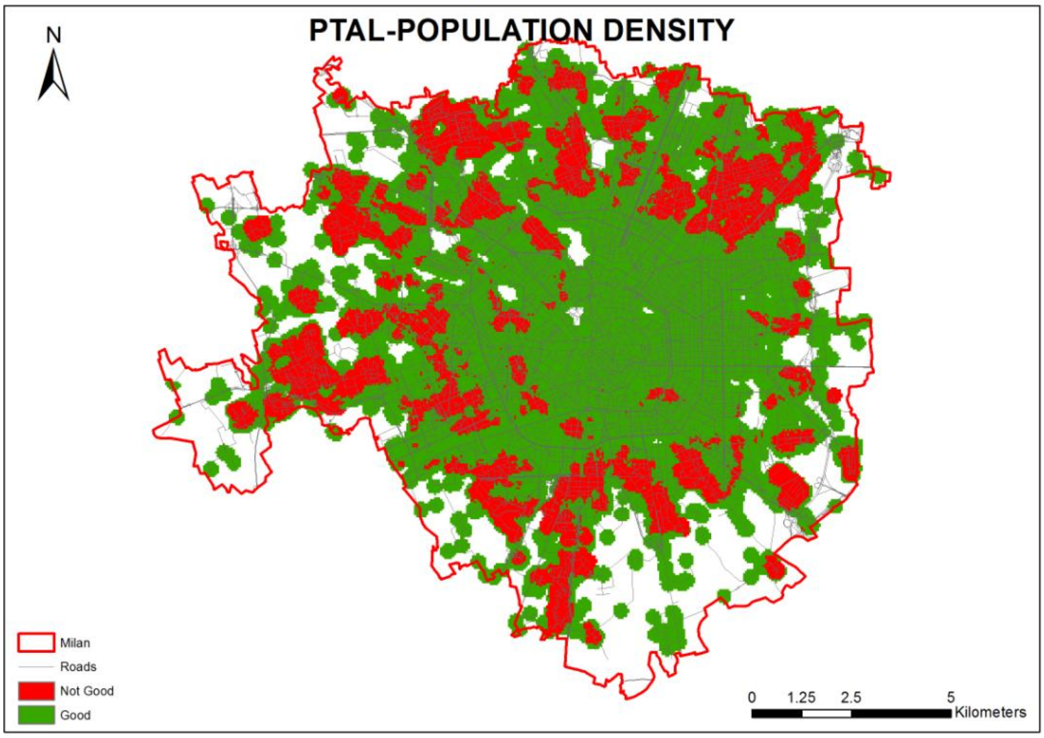


Figure 7.2 PTALs and Population Density intersection.

By intersecting the population density values with the PTALs analysis (Figure 7.2), it is possible to obtain a map reflecting all of these values. The suitable areas represent about the 72% of the intersected areas.

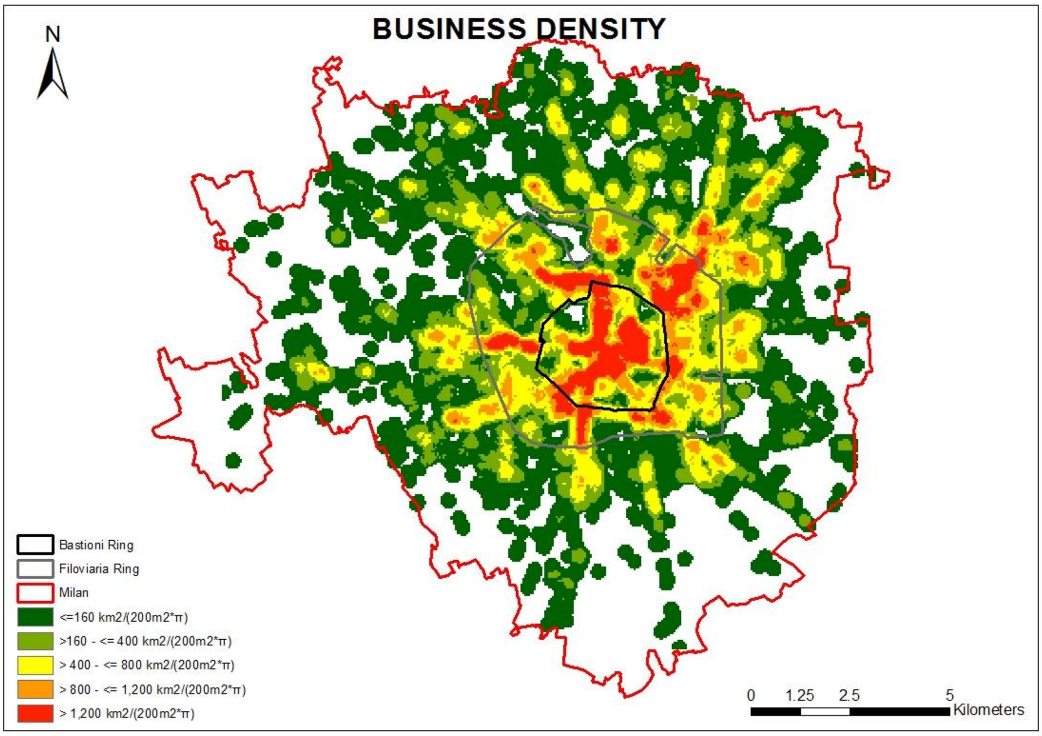


Figure 7.3 Business Density.

The population density map (Figure 7.3) allows one to understand which are the areas with a lower (green areas) or higher (red areas) business concentration. In general, the areas with a low population density and a high accessibility level are the ones with a high business concentration.

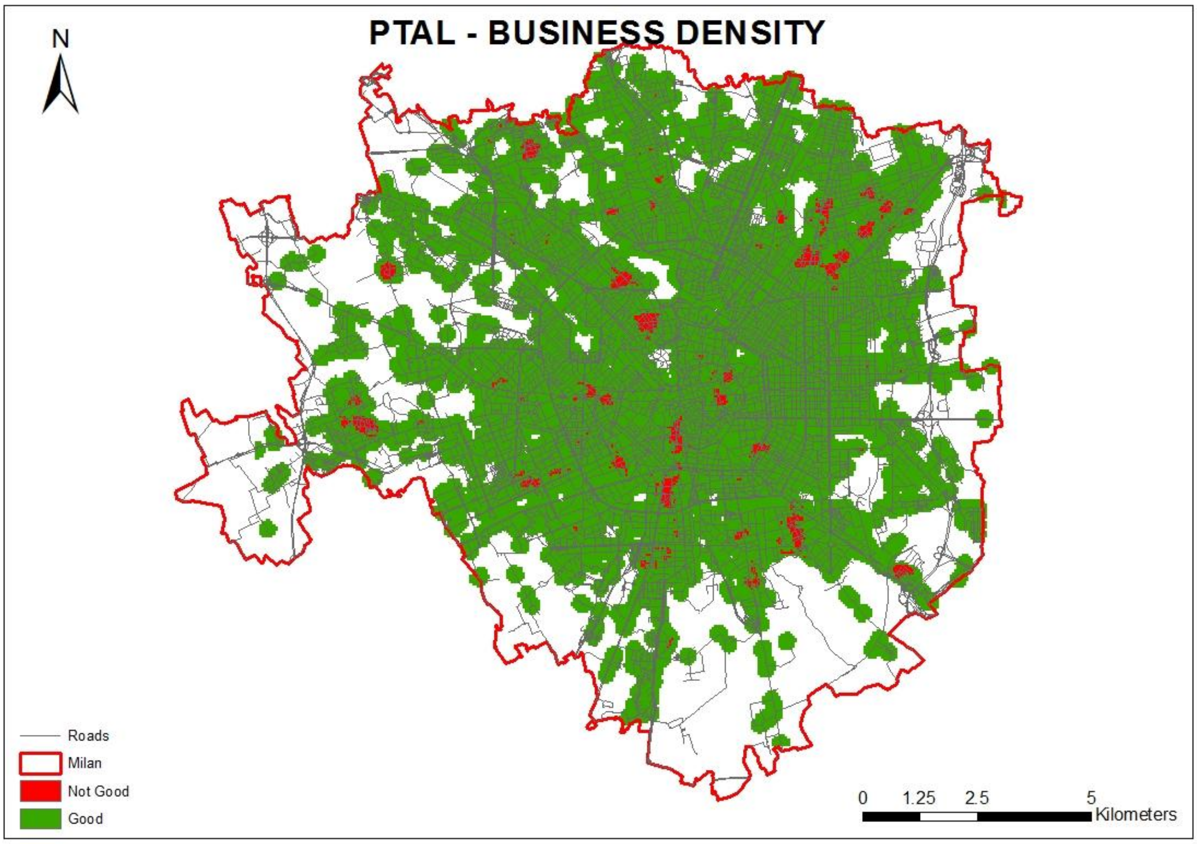


Figure 7.4 PTALs - Business Density.

By intersecting the business activities density values with the PTALs analysis (Figure 7.4), it is possible to obtain a map reflecting all of these values. The areas with a low accessibility level and a high business concentration represents about the 2.5% of the intersected areas.

7.4 Discussion

By intersecting the population density results with the PTALs results, which take into account both the walk access time and the service availability and frequency, it is possible to overcome the limits of the place-based analyses including a people-based perspective that focuses on individuals in space and time. Place-based measures examine the proximity to desired activity locations from key locations in an individual's daily life, such as the home or workplace (Miller, 2007). These measures have been criticized on many occasions for their lack of attention to the interconnectivity between an individual's activities and to the space-time constraints (Neutens et al, 2009).

Furthermore, coverage analyses (understanding how many citizens can reach a public transport stop in a limited distance or amount of time) make it possible to obtain an initial approximation of the population served and the potential demand, but their all-or-nothing functions are also a disadvantage because they consider the population inside the area covered to be served by the network and the population outside it to be without service.

They also assume that all the population inside the coverage area has the same degree of accessibility to transit (living 100 meters from a station is not the same as living 600 meters away) and that accessibility outside the area is non-existent, when some riders are willing to walk a distance that is somewhat greater than the pre-established coverage limit in order to access a station (García-Palomares, et al., 2013). Transportation planning, often based on aggregate, place-based forecasting methods that view travel demands as functions of place and space, should then focus more on people.

The analyses show that the intersection between the output coming from PTAL's analysis and the population density one gives positive results for the 72% of the cells. This result is consistent considering that about the 77% of the population has at least a "moderate" accessibility level.

The analysis does not make any distinction on the different population groups, based on the age, gender, etc.

8 Stops spacing model

In this chapter, a new stop spacing model for Milan surface public transport system is proposed and developed. The aim of the model is to work on the public transport stops to improve the efficiency of the service. The number of stops contributes significantly to time delays at bus stops because of acceleration/deceleration delay and dwell time delay. In particular, the goal of the proposed model is to study what happens if the stops spacing system changes, increasing the distance between the bus stops. In the study, it has been decided to create three scenarios, with a target distance between the stops set to:

- 400 meters
- 500 meters
- 600 meters.

The analyses are made on the macro-level. This approach shows how the public transport system could generally change on an urban level with new stops spacing policies (in terms of speed, accessibility, management costs, etc.), but it doesn't get into the details of each route.

8.1 Current situation and data

To work on the model, the dataset of the Milan public transport system is used. As stated in the previous chapters, it contains the geo-referenced routes and stops as well as the information regarding the system (frequency, capacity, speed).

All data use the spatial reference system Monte Mario (Rome) and are provided by AMAT (Mobility and Environment Agency of Milan).

The stop spacing analyses focus on the Milan surface public transport system, which is characterized by 154 lines (17 urban tram, 4 trolleybus and 133 bus lines), 764 routes and 4711 aggregated stops.
The total length of the net is about 6,129 km and the routes length varies from a minimum of about 0.4 km to a maximum of about 23 km.

The average distance between two stops instead is approximately 412 meters and the minimum distance is about 52 meters, while the maximum one is approximately 12 km.

The modal value of the distribution of the distance between the stops for the public transportation modes (bus, tram and trolleybus) is 250 meters (>=250 and <300 meters) (Figure 8.1).

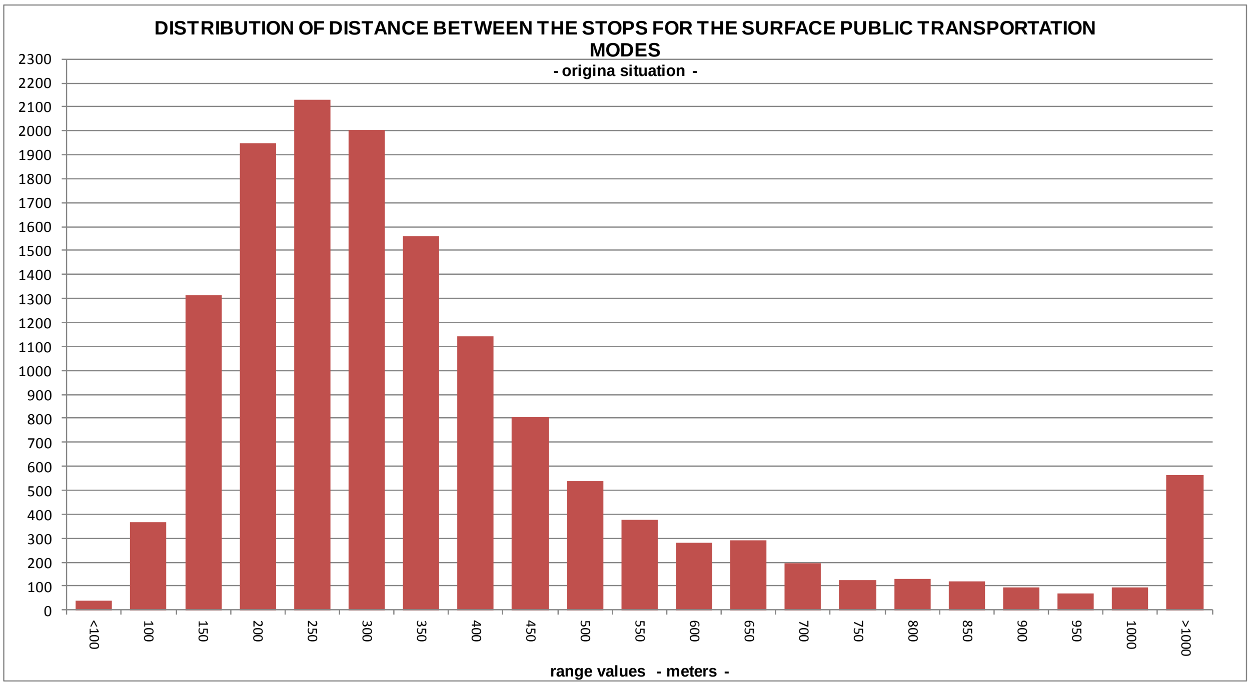


Figure 8.1 Distribution of the distance between the stops for the surface public transportation modes, including: tram, trolleybus and bus.

8.2 Methods

The new stop spacing model is created working on the distance between consecutive stops, which is one of the aspects that affects more the quality of the service. The purpose of the study is to increase the distance between the stops to improve the service efficiency. In the analysis, three different scenarios (400, 500 and 600 meters of target distance between consecutive stops) are created and this allows to better study the impact of the model on the City public transport surface system. The scenarios are decided considering the present condition. If, in the original scenario, the distance between the stops is longer than the target distance, the original scenario is kept. Otherwise the target distance is considered as the maximum possible distance.

To increase the distance between stops, the model is based on the possibility to move, and eventually to eliminate, some of the surface public transport stops. To do this then, it is first necessary to find a way to select those stops that can't be moved or eliminated. Since the analyses are made on a macro-level, it is not possible to get into the detail of each route and the stops that can't be move or eliminated are selected considering the characteristics of the stop location and a precautionary approach, which wants to avoid the movement or elimination of too many stops.

Once that the new stop spacing system is created for each scenario, it is possible to evaluate its impact on the travel time. To consider the impact of the model on the total travel time, the study made in 2013 in the city of Firefax, Virginia, by Shrestha et al. is considered. This study is chosen because it has a simple approach to evaluate travel time changes (approach that matches with the need to perform an analysis at a broad level). Compared to the study made in Firefax, in this study the impact of the acceleration and deceleration distance is considered. This allows a more realistic analysis.

The following workflow is used:

1) Decide which is the target distance between two consecutive stops. In this study, three different scenarios are created: 400, 500 and 600 meters.

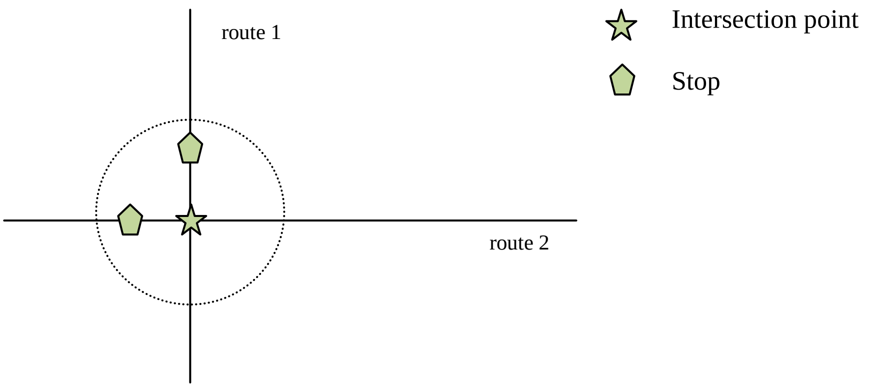
2) Work on the existing public transport stops system to develop the three different scenarios for a new stop spacing model. The process can be broken down into a series of stages:

- select, from the existing public transport stops system, all those stops that can't be eliminated or moved because of their importance. In particular, there are 5 kind of stops that can't be eliminated or moved:
  - the first and the last stop of each route
  - the stops that are close to an underground access. (To find these stops: create a buffer of 150 meters around each underground stop; intersect the buffers created with the surface public transport stops.)
  - the stops that are close to the intersection of different routes.
    - ✓ find the points where the routes intersect. To do this:

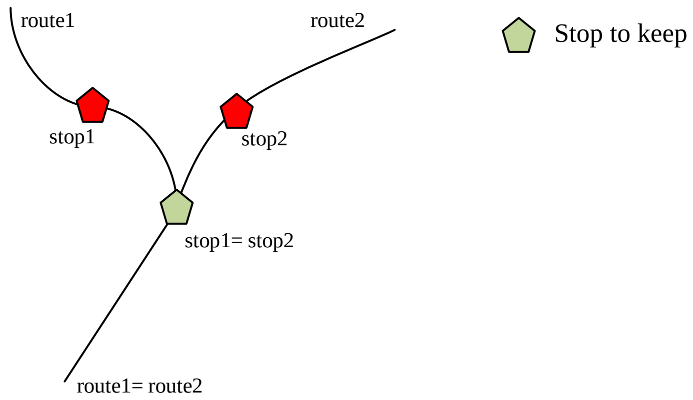
      - for each route, merge in one line all the segments that compose the route itself. A dataset with all the merged routes is now available.

      - intersect the dataset above with itself and set the output type as "point". The intersection points are now available

      - delete the identical intersection points.
    - ✓ create a buffer of 100 meters around the intersection points
    - ✓ intersect the buffer created at the previous step with the aggregated stops (without considering if the stop is valid for more than one route) of the surface public transport.
    - ✓ if the buffer intersects with more than one stop, then consider those stops as permanent (that can't be eliminated or moved).



- the stops before or after the bifurcation point between different routes:
  - ✓ when the first stop is valid for two or more routes and, for the same routes, the next stops are different (or the opposite).



- the stops connected by a segment of a route that is equal or longer than 150% of the set distance between two consecutive stops (e.g. set distance 400m → >= 600m). In this way, if the stop distance in the original scenario is longer than 150% of the target distance, the original scenario is used. This is set to avoid very long segments of a route (e.g. a suburban route) being split during the analysis. This is also set to keep just the very long segments.

- Delete all the other stops.
- At this point, some of the stops of the original public transport system have been saved, while others have been deleted. To produce the new stop spacing system, it is now necessary to create new stops. The new stops are located considering the set target distance between the stops for the three scenarios (400, 500, 600 meters).

  To locate the new stops, the following stages are computed: for each route, merge in a new line the consecutive segments that are not split by a stop that can't be move or eliminated; split the merged segments depending on the set distance between two consecutive stops

(400, 500 or 600 meters). To find where the segments split (equivalent to the stop location), the following steps are implemented in a Python[2] script:

$N = L/d$ (1)

if the remainder of N is = 0

then:

$D = L/N$ (2)

else:

$D = L/(\lfloor N \rfloor + 1)$ (3)

N = number of parts in which the segment has to be split

D = the length of each part in which the segment is divided

L = length of the segment

d = set distance between two consecutive stops (400, 500 or 600 meters)

In the example below (Figure 8.2), there is a route and there are four stops placed 200 meters from each other (***a***). Considering the analyses described in the previous steps, the first and last stops can't be moved or deleted, while the second and the third can (***b***). The segments that are not split by a stop that can't be move or eliminated are merged together (***c***). Setting the target distance between two consecutive stops at 500 meters, the segment is split in 2 parts and a new stop is created (***d***).

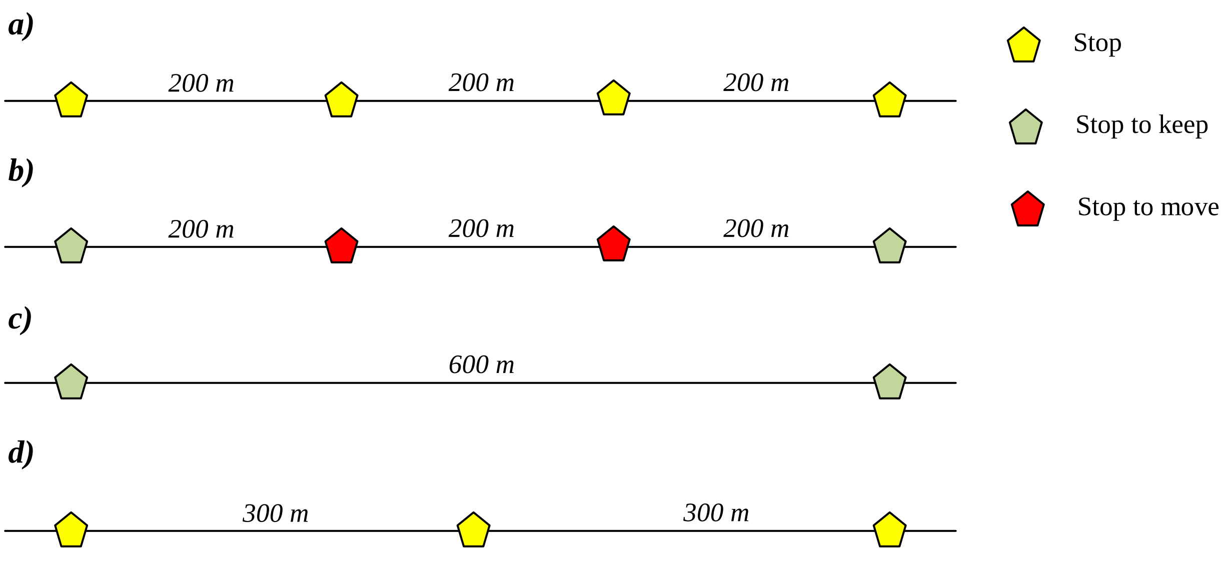


Figure 8.2 Example: how to locate new stops.

[2] The Python script is based on the script available on http://www.maprantala.com/2011/05/01/quick-dirty-arcpy-batch-splitting-polylines-to-a-specific-length/

- Compute the number of stops per route for the scenarios created and compare it with the original situation. Keep the original routes where the number of stops don't change or increase.
- For each scenario, a new stop spacing system is now created.

3) Compute the travel time for the scenarios created.

$$Tacc/dec = (V/acc) + (V/dec) \quad (4)$$

$$L_1 = ½ * acc * Tacc^2 \quad (5)$$

$$L_2 = ½ * dec * Tdec^2 \quad (6)$$

$$Tv = (L_T – (N – 1) * (L_1 + L_2)) / V \quad (7)$$

$$Tbus = N*(Tacc/dec + Tw) + Tv \quad (8)$$

Tacc/dec = acceleration/deceleration delay (acceleration time + deceleration time)
V = bus cruising speed
acc = acceleration
dec = deceleration
Tacc = acceleration time
Tdec = deceleration time
L_1 = acceleration length per stop
L_2 = deceleration length per stop
L_T = routes length
N = total number of stops
Tv = time for the bus to make a one-way trip at cruise speed. The one way trip length does not consider the acceleration and deceleration length.
Tw = dwell time delay
Tbus = total bus travel time

Data for the dwell time delay (Tw), acceleration (acc) and deceleration (dec) comes from direct observations made by the Mobility and Environment Agency of Milan on the service. The dwell time delay (Tw) differs route by route (from 2 sec to 49 sec), while the acceleration (acc) is set to 1.2 m/sec^2 and deceleration (dec) to 0.8 m/sec^2. The bus cruising speed (V) is set to 35 km/h that is considered as a realistic value based on the surface public transport observation, where the speed of the service was tracked.

All the analyses are made for the peak hour (8:00-9:00) and they are done using ArcGIS 10.0.

8.3 Result

The total travel time equation *(8)* is used to compute the time that the public transport vehicle takes to make one-way trip on the routes with the original stop spacing and with the scenarios proposed. The first part of the equation is characterized by the total delay, which depends on the number of stops for each route. The equation doesn't consider such aspects as time lost because of traffic congestion or traffic lights, and one assumption of equation *(8)* is that the vehicle doesn't skip any stop.

The table and the plots below (Figure 8.3 – 8.5) show how the distribution of the distance between the stops for the surface public transportation modes changes. The modal value in the original situation is 250 meters (Figure 8.1). With a target distance set to 400 meters, the modal value is 300 meters, while with a target distance of 500 and 600 meters the modal value is 400 meters.

Table 8.1 Distribution of the distance between the stops for the surface public transportation modes.

DISTRIBUTION OF DISTANCE BETWEEN THE STOPS FOR THE SURFACE PUBLIC TRANSPORATION MODES		
TARGET DISTANCE	**MODAL VALUE**	**MEAN VALUE**
Present Condition	>= 250 – < 300 m	431 m
400 m	>= 300 – < 350 m	444 m
500 m	>= 400 – < 450 m	469 m
600 m	>= 400 – < 450 m	497 m

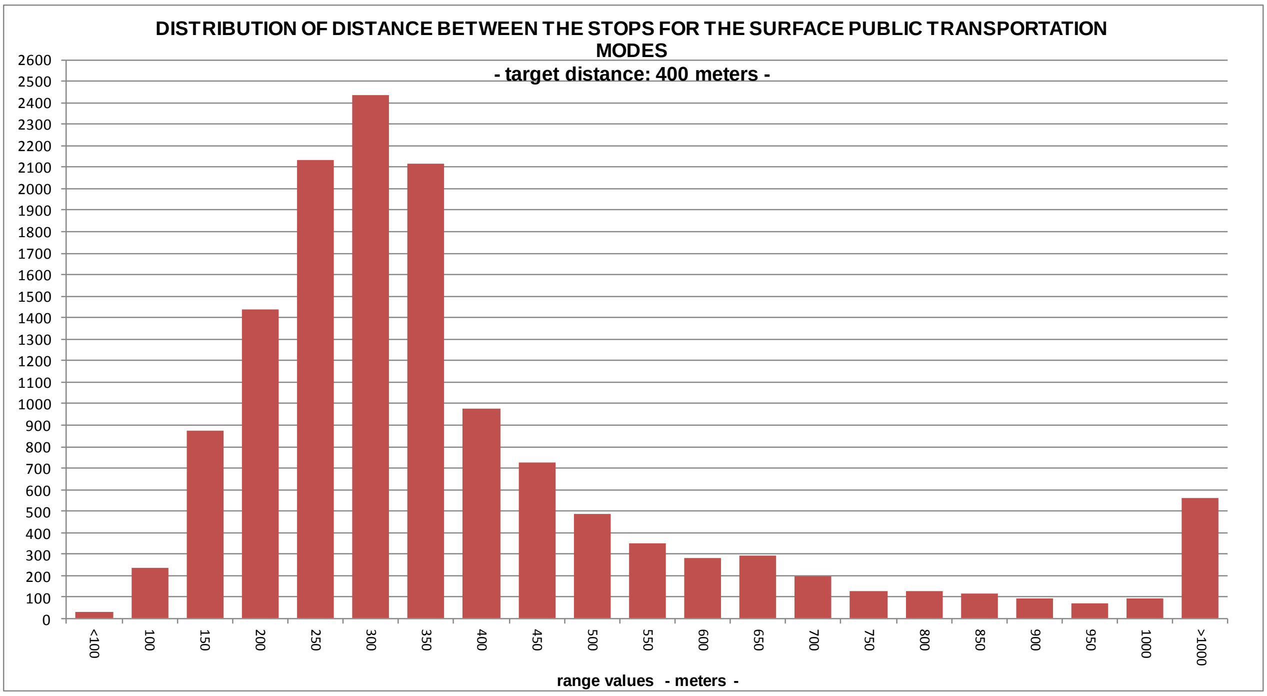


Figure 8.3 Distribution of the distance between the stops for the surface public transportation modes – scenario 400 m – .

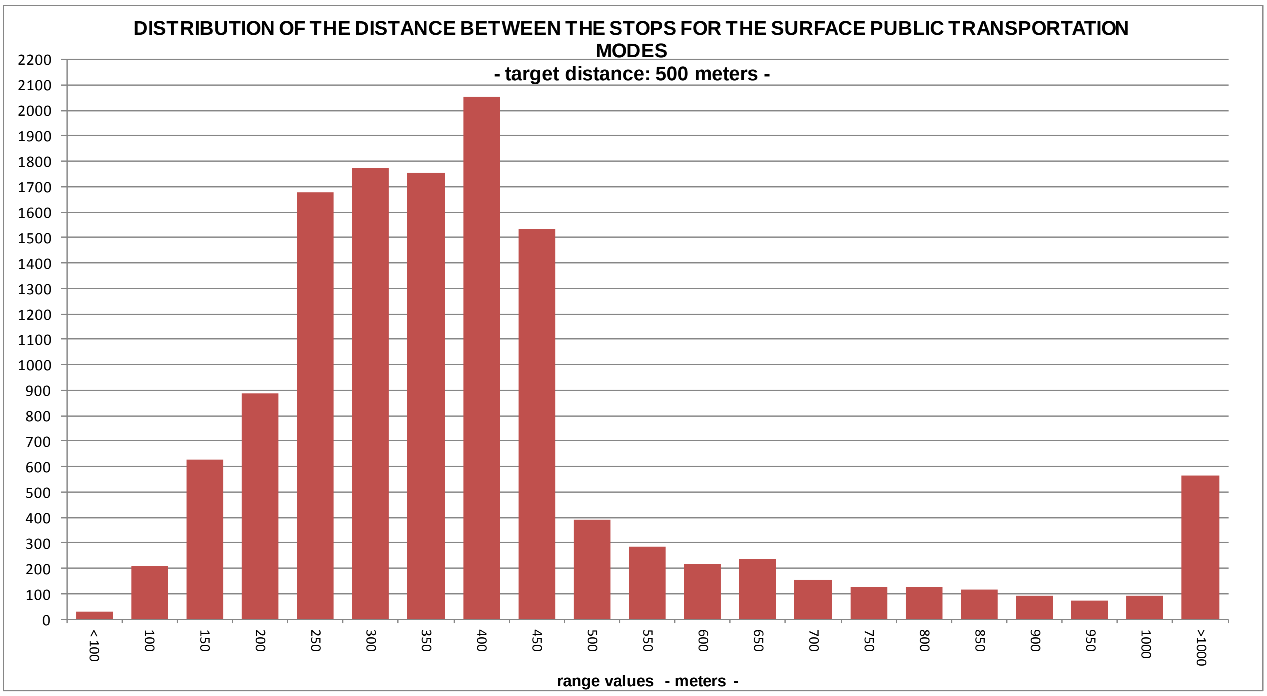


Figure 8.4 Distribution of the distance between the stops for the surface public transportation modes –scenario 500 m – .

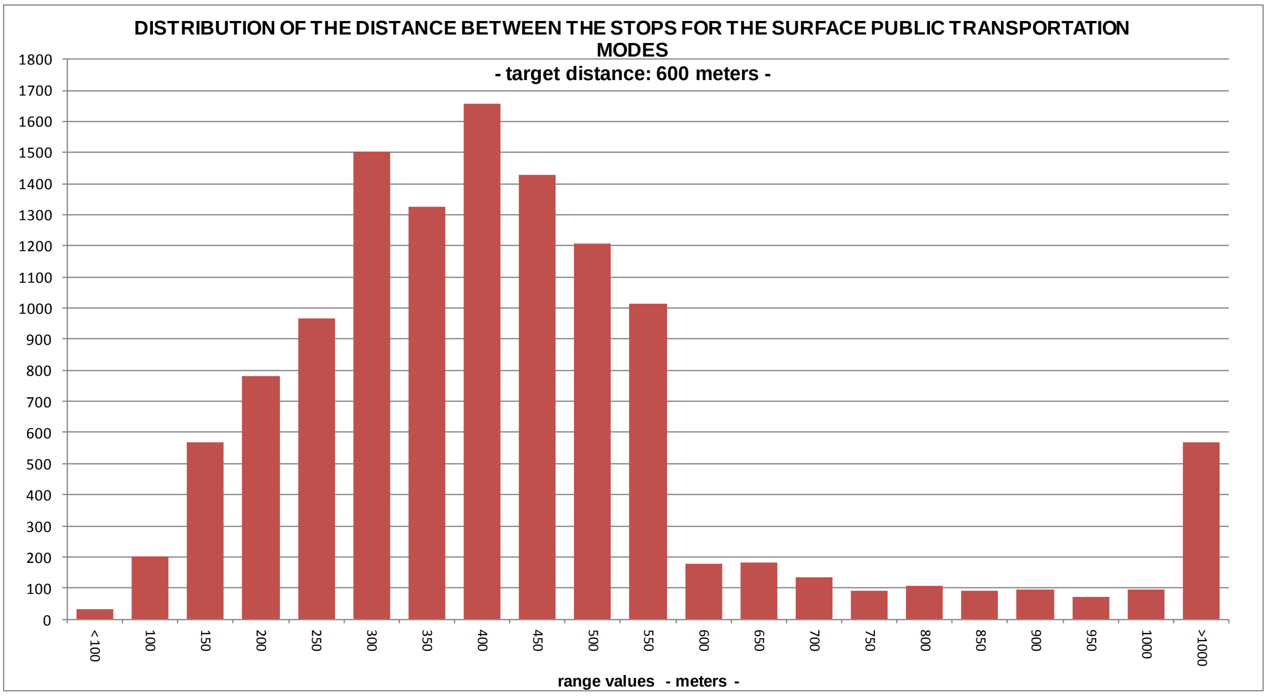


Figure 8.5 Distribution of the distance between the stops for the surface public transportation modes –scenario 600 m – .

Table 8.2 shows the change of the number of available stops. Considering all the routes, the total number of stops is 14,986 (an average of 19.6 stops per route). With a scenario of 400, 500 and 600 meters, the average number of stops per route decrease, respectively, to 19.1, 18.1 and 17.1.

Table 8.2 Stops Comparison.

	N. STOPS	AVERAGE N. STOPS PER ROUTE	% CHANGED ROUTES	% MUTABLE STOPS	AVERAGE STOPS ELIMINATED ON CHANGED ROUTES
ORIGINAL	14986	19.6	-	-	-
400 m	14573	19.1	32.2%	29.6%	-1.7
500 m	13827	18.1	59.7%	32.9%	-2.5
600 m	13097	17.1	73.4%	34.2%	-3.4

It is important to highlight that not all the routes change their stop spacing system. As explained in the methodology, for some routes the original stop spacing system is kept (when the number of stops doesn't change or increases). Considering 400 meters as target distance between the stops, 32.2% of the routes are subjected to a stop system change and 29.6% of the stops of all the routes can be moved or eliminated. When the target distance is set to 500 meters, it is possible to work on the 32.9% of the stops and the stop system changes by the 59.7%. In the last scenario (600 meters of target distance between the stops) instead, the 34.2% of stops can be moved or eliminated and 73.4% of routes is subjected to a stop system change.

Considering just the routes where the stop spacing system changes, the average number of eliminated stops is, respectively, 1.7, 2.5 and 3.4 stops per route.

In the table below (Table 8.2), it is possible to see how the distance between the stops changes. In particular, it shows the average distance between the stops for the old stop spacing system and for the new ones. The distance increases by the 8.0% when the target distance between the stops is set to 400 meters, by the 13.0% when it is set to 500 meters and by the 18.5% when it is set to 600 meters.

Table 8.3 Changes on the distance between the stops (considering the routes subjected to stop spacing system changes).

	AVERAGE OLD DISTANCE (m)	AVERAGE NEW DISTANCE (m)	Δ DISTANCE
ORIGINAL	-	-	-
400 m	324.9	350.8	8.0%
500 m	356.2	402.4	13.0%
600 m	381.5	452.1	18.5%

In the table below (Figure 8.4), it is possible to see how the travel time decreases for the routes subjected to changes: for the three scenarios (target distance of 400, 500, 600 meters), it respectively decreases by the 3.0%, 4.4% and 5.7%.

Table 8.4 Changes on the travel time on the routes subjected to changes.

	AVERAGE TRAVEL TIME (sec) Present Stop Spacing System	AVERAGE TRAVEL TIME (sec) Proposed Stop Spacing System	Δ TRAVEL TIME
PRESENT CONDITION	-	-	-
400 m	1296.09	1257.55	-3.0%
500 m	1322.17	1264.26	-4.4%
600 m	1350.04	1273.33	-5.7%

When the distance between the stops increases, the access and egress time will eventually get longer. Length of distance will be dependent on the pedestrian network. In general, the distance will never be longer than the increased length between the stops divided by two.

The results of the analyses also highlight how the effects of a stop redistribution would be higher in an optimal situation with traffic light priority and public transport fast tracks for public transport vehicles, where the vehicles can get to cruising speed without any problems and can reach a higher cruising speed. For example, if cruising speed was 50 km/h (not 35 km/h as set before) both for the original situation and for the three scenarios analyzed (respectively 400, 500 and 600 meters of target distance), travel time would decrease by 3.9%, 5.8% and 7.6%.

The results would also be better considering the possible results coming from the construction of a public transport fast tracks with traffic light priority. Comparing then a situation where the vehicles can get to a cruising speed of 35 km/h with one where they can reach a cruising speed of 50 km/h, travel time decreases by 15.2%, 19.0% and 22.4% (present stop spacing system) and by 10.5%, 12.1% and 13.4% (proposed stop spacing system) (Table 8.5).

Table 8.5 Travel time – cruising speed 35 km/h and 50 km/h – on the routes subjected to changes.

	AVERAGE TRAVEL TIME (sec) Present Stop Spacing System (35km/h)	Δ TRAVEL TIME *Proposed Stop Spacing System* ***(35 km/h)*** *– Present Stop Spacing System* ***(35 km/h)***	AVERAGE TRAVEL TIME (sec) Present Stop Spacing System (50km/h)	Δ TRAVEL TIME *Proposed Stop Spacing System* ***(50 km/h)*** *– Present Stop Spacing System* ***(50 km/h)***	Δ TRAVEL TIME *Proposed Stop Spacing System* ***(50 km/h)*** *– Present Stop Spacing System* ***(35 km/h)***	Δ TRAVEL TIME *Proposed Stop Spacing System* ***(50 km/h)*** *– Proposed Stop Spacing System* ***(35 km/h)***
Present	-	-	-	-	-	-
400 m	1296.09	-3.0%	1170.77	-3.9%	-15.2%	-10.5%
500 m	1322.17	-4.4%	1179.61	-5.8%	-19.0%	-12.1%
600 m	1350.04	-5.7%	1194.01	-7.6%	-22.4%	-13.4%

It is also important to say that to reach a cruising speed of 35 km/h, the distance between the stops needs to be longer than 98.5 meters, while it has to be longer than 200.9 meters for a cruising speed of 50 km/h.

8.4 Discussion

In this chapter is proposed a way to work on the stop spacing system of the surface public transport net to increase system efficiency on several aspects such as the travel time and the management costs. A new stop spacing system could also have a positive effect on other aspects not included in the research such as the environmental pollution.

The model only focuses on the stop spacing system and it doesn't consider other aspects that can positively impact transport travel time, such as traffic light priority for public transport vehicles or public transport fast tracks.

Table 8.3 shows the travel time reduction for the three different studied scenarios. Setting a target distance between the stops of 400 meters, the travel time decreases by 3.0%, while the distance between the stops increases by 8.0%. When the target distance is set to 500 meters, the travel time decreases by 4.4% and the distance between the stops increases by 13.0%. For the last scenario instead, the travel time decreases by 5.7% compared to an increase by 18.5% of the distance between the stops. It is important to qualify this estimate because it doesn't consider traffic effects and it assumes, as mentioned above, that public transport vehicles stops at all available stops. Since this is not likely, it means that potential travel time reduction would probably be less.

The results refer to a model that is based on a macro-level. One of most important aspects to consider in the model is the choice of stops that can't be moved or eliminated. In this work, 5 different stops typologies are considered as immutable:

- the first and last stop of each route;
- each stop that intersects a buffer of 150 meters from an underground stop;
- the stops that intersect a buffer of 100 meters from the point where different routes intersect (it is necessary that at least two stops fall into the buffer);
- the stops before or after a ramification between different routes;
- the stops connected by a segment of a route that is equal to or longer than 150% of the set distance between two consecutive stops.

This is considered a precautionary approach since it doesn't allow movement or elimination of many stops. In particular, for the three studied scenarios the rate of mutable stops varies by 29.6%, 32.9% and 34.2% (24.2%, 27.5% and 28.8% if considering the stops as aggregated) and this allows an elimination of an average of 1.7, 2.5 and 3.4 stops per route.

With studies on a micro-level, the number of eliminated stops could eventually increase, decreasing travel time more. Micro-level studies could also take to a redistribution of the routes themselves where the nowadays net is ineffective.

The results of the analyses also highlight how in an optimal situation with traffic light priority and public transport fast tracks for public transport vehicles, where the vehicles could reach a higher cruising speed, travel time would decrease by 3.9%, 5.8% and 7.6%.

The scenarios for the new stop spacing system also show some economic benefits. To estimate the financial impact of the three scenarios, all the operating annual costs which impact the public transport system management costs are analyzed. Annual operating costs can be roughly divided into three categories[3]: operations (operator's wages, fringe benefits and services), maintenance (including fuel and lube, tires, etc.) and general administrative (including wages and benefits). The economic studies are based on the economic analyses made by the City of Milan and they produce an annual cost per km.

By introducing a new stop spacing model it is shown that, at a cruising speed of 35 km/h, the annual cost per km could decrease by about 0.5%, 1% and 2% for the for the three scenarios analyzed (respectively 400, 500 and 600 meters of target distance). The saved money could be invested in the improvement of other aspects of the service.

[3] For company reasons, it is not allowed to specify the values of the costs analyzed

9 Stop spacing model impact on mobility and accessibility

In the previous chapter, a model has been developed to create a new stop spacing system for the City of Milan surface public transport service. In particular, three possible scenarios have been created considering the target distance between the stops. The model gives positive results considering both travel speed and management cost reduction. To evaluate the potential impact of the model in the case study, it is now necessary to analyze the consequences on urban mobility and accessibility. For this, the results obtained in chapter 8 are studied considering mobility demand and the PTALs results.

9.1 Data

The following datasets are used:

1) the stop spacing model results for the three scenarios analyzed (respectively 400, 500 and 600 meters of target distance between the stops)

2) database of Milan mobility demand, which mainly contains the Origin-Destination (OD) matrix of the movements and where it is possible to get information such as the origin and the destination areas of the movements and the number of the trips made during the day. In the Origin-Destination matrix, it is not possible to find the exact origin and destination point of the movements, but just their origin and the destination areas.

3) PTALs results obtained from the accessibility analysis made in chapter 6

4) A network of Milan roads

9.2 Methods

The get to know the impact of the new stop spacing system on urban mobility, the model is studied considering the mobility demand. In particular, the analyses aims to use the Origin-Destination (OD) matrix to compute the multimodal network analysis on about 13% of the movements in the matrix (about 1200 movements). For this, the following workflow is used:

1) Work on the mobility demand database and select the movements that are computed during the peak hour (8.00-9.00) just using the public transport system, the study aims to analyze changes on the public transport service and on the walking paths.

2) Considering the Origin-Destination matrix, network analyses are computed on about 13% of the movements made, using the public transport system, during the peak hour (13% is considered as representative).

   Since in the Origin-Destination matrix it is possible to have information just about the origin and the destination area of the movement, to perform network analyses it is first necessary to find the exact point of origin and destination of the movements. For this, a random point on a street within the origin or destination area is chosen.

   Create a multimodal network dataset to consider both the walking path distance and the public transportation one. The public transport speed differs routes by routes and it is based on the stop spacing system results obtained in the previous chapter. The walk speed is based on PTALs literature (80 meters/min) and also the average waiting time. The network analyses are computed for the current stop spacing system and for the three proposed scenarios.

To study the impact of the stop spacing model on the accessibility, PTALs analyses are made for the three proposed scenarios. The workflow is the same to the one explained in chapter 6.

All the analyses are made for the peak hour (8:00-9:00) and they are done using ArcGIS 10.0.

9.3 Result

Studying the model scenarios considering the OD (Origin-Destination) matrix gives the possibility to evaluate the potential impact of the model on the urban mobility. In particular, it allows to investigate how the pedestrian time and the total travel time change.

Considering the totality of the movements, the total travel time decreases by 1.6%, 1.9% and 2.2% for the three model scenarios (respectively 400, 500 and 600 meters of target distance between the stops). The pedestrian time decreases by 0.4% for the 400m scenario and increases by 2.8% and 5.2% for the other scenarios, while the time spent on the public transport decreases by 2.0%, 3.7% and 5.0% (Table 9.1).

Table 9.1 Changes on total travel time, pedestrian time and time spent on the public transport.

	Δ TOTAL TRAVEL TIME	Δ TOTAL TRAVEL TIME ON PUBLIC TRANSPORT	Δ TOTAL PEDESTRIAN TIME
400 m	-1.6%	-2.0%	-0.4%
500 m	-1.9%	-3.7%	2.8%
600 m	-2.2%	-5.0%	5.2%

The tables below (Table 9.2-9.4) show, for each scenario, the rate of movements which increased, decreased or stayed constant in time.

For the scenario of 400 meters of target distance between the stops (Table 9.2), the travel time decreases by 62.8% of the analyzed movements of the OD matrix, increases by 16.6% and doesn't change for 20.6% of the movements. The time spent on the public transport decreases by 64.6%, increases by 16.8% and doesn't change for 18.7% of the movements. The pedestrian time decreases by 21.7%, increases by 34.5% and is constant for 43.8%.

For the 500 meters scenario, the travel time decreases by 69.9% of the movements, increases by 19.9% and doesn't change for 10.2% of the movements. The time spent on the public transport decreases by 77.2%, increases by 12.8% and doesn't change for 10.0% of the movements. The pedestrian time decreases by 22.5%, increases by 54.5% and doesn't change for 23.0% of the movements.

For the 600 meters scenario, the travel time decreases by 70.9% of the movements, increases by 20.5% and doesn't change for 8.6% of the movements. The time spent on the public transport decreases by 80.9%, increases by 10.4% and doesn't change for 8.7% of the movements. The pedestrian time decreases by 19.9%, increases by 62.7% and doesn't change for 17.4% of the movements.

Table 9.2 Proposed scenarios: changes on travel time, pedestrian time and time spent on the public transport.

	Less time	More time	Same time
TRAVEL TIME – 400 m –	62.8 %	16.6 %	20.6 %
TRAVEL TIME – 500 m –	69.9 %	19.9 %	10.2 %
TRAVEL TIME – 600 m –	70.9 %	20.5 %	8.6 %
PEDESTRIAN TIME – 400 m –	21.7 %	34.5 %	43.8 %
PEDESTRIAN TIME – 500 m –	22.5 %	54.5 %	23.0 %
PEDESTRIAN TIME – 600 m –	19.9 %	62.7 %	17.4 %
TRAVEL TIME ON PUBLIC TRANSPORT – 400 m –	64.6 %	16.8 %	18.7 %
TRAVEL TIME ON PUBLIC TRANSPORT – 500 m –	77.2 %	12.8 %	10.0 %
TRAVEL TIME ON PUBLIC TRANSPORT – 600 m –	80.9 %	10.4 %	8.7 %

The figures below (Figure 9.1-9.3) show the distribution of the travel time variation (in percentage) for each mode and for each scenario.

Figure 9.1 shows the distribution of the total travel time variation and from this it is possible to observe that, for all scenarios, the travel time generally decreases for the majority of the movements. In particular, the modal value is within class -1 (> -2% - < 0%). Particularly relevant appears class -5/-9 (>-10% - <=-5%) for the 500 and 600 meters scenario and class 0 (0%) for the 400 meters scenario.

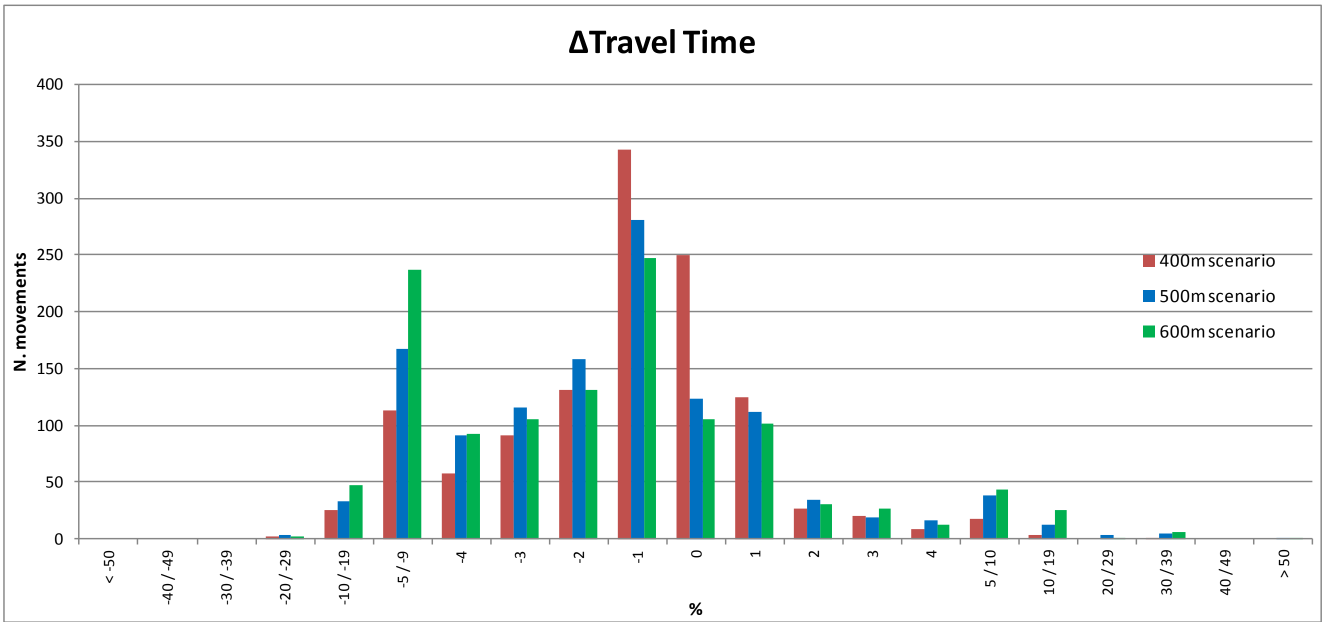


Figure 9.1 Travel Time – distribution of travel time variation (in %) – 400-500-600m scenario.

Figure 9.2 shows the pedestrian time distribution which appears really heterogenic. The modal value, for the 400 meters scenario is within class 0 (0%) while for the other two scenarios it belongs to class 1 (values from > 0% to < 2%). For the 500 and 600 meters scenarios, the pedestrian time generally seems to increase while for the 400 meters one it looks to be constant. In particular, for the 400 meters scenario, Table 9.2 shows that the pedestrian travel time doesn't change for the majority of the movements (43.8%). Even if the pedestrian time increases by 34.5% of the movements and decreases by 21.7% (Table 9.2), Table 9.1 shows that, considering the totality of the movements, the total pedestrian time decreases by 0.4%. This is explained by the fact that, the total pedestrian time difference for movements where the time variation is < 0% is greater than the one for movements with a time variation > 0%.

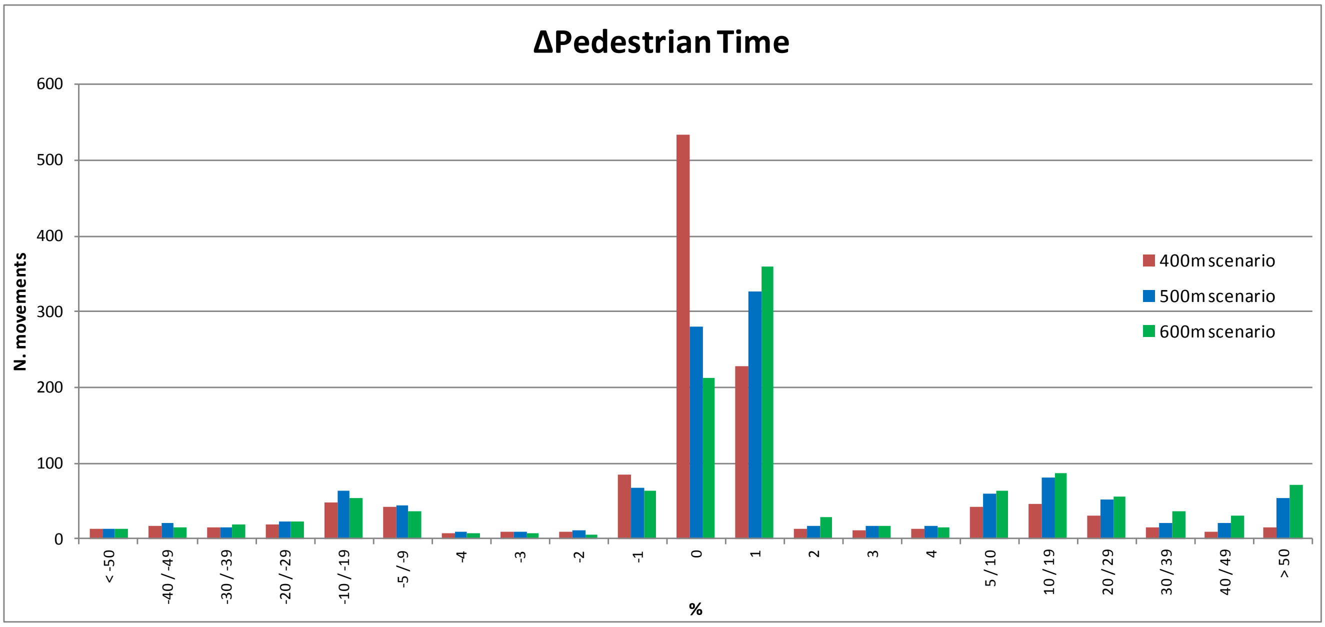


Figure 9.2 Pedestrian time – distribution of travel time variation (in %) – 400-500-600m scenario.

Figure 9.3 shows the distribution of the transportation time variation and from this it is possible to observe that, for all scenarios, the time spent on the service generally decreases for the majority of the movements. In particular, for the 400 meters scenario, the modal value is within class -1 (> -2% - < 0%) while for the other two scenarios it belongs to class -5/-9 (> - 10% - < = -5%).

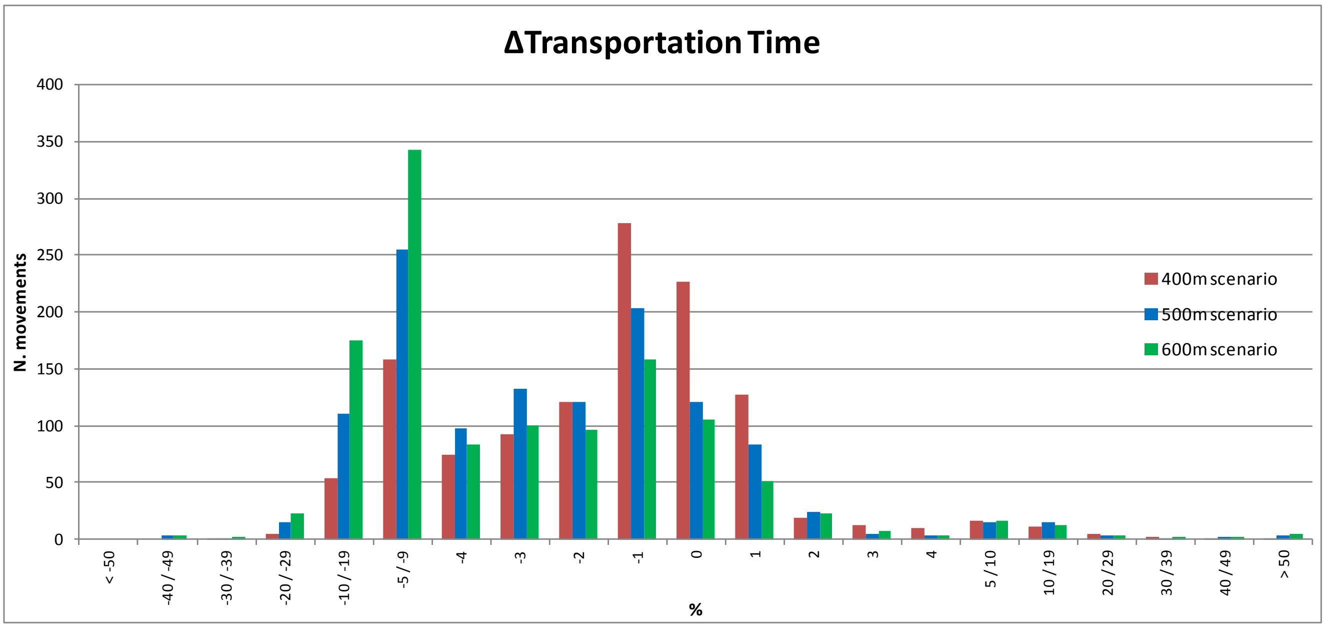


Figure 9.3 Transportation time – distribution of travel time variation (in %) – 400-500-600m scenario.

Studying the model scenarios considering PTALs model gives the possibility to evaluate the potential impact of the model on the urban accessibility.

The figures below (Figure 9.10-9.16) show the accessibility map for each of the proposed scenario and show where the accessibility increased, decreased or stayed constant.

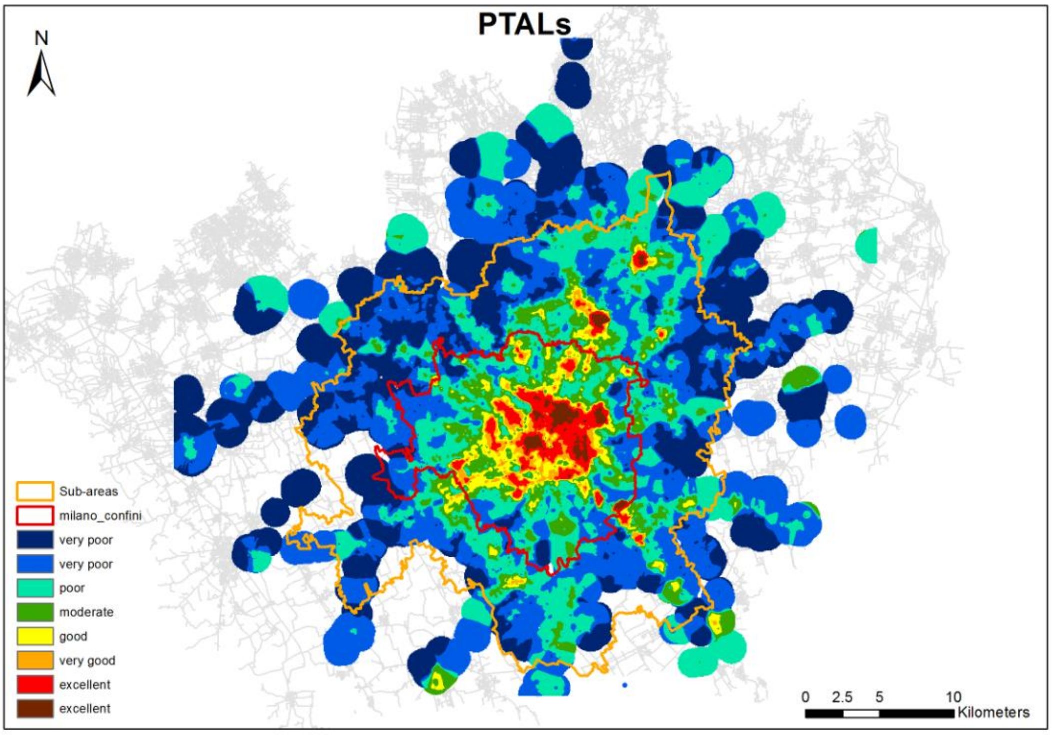


Figure 9.4 Accessibility map – present condition.

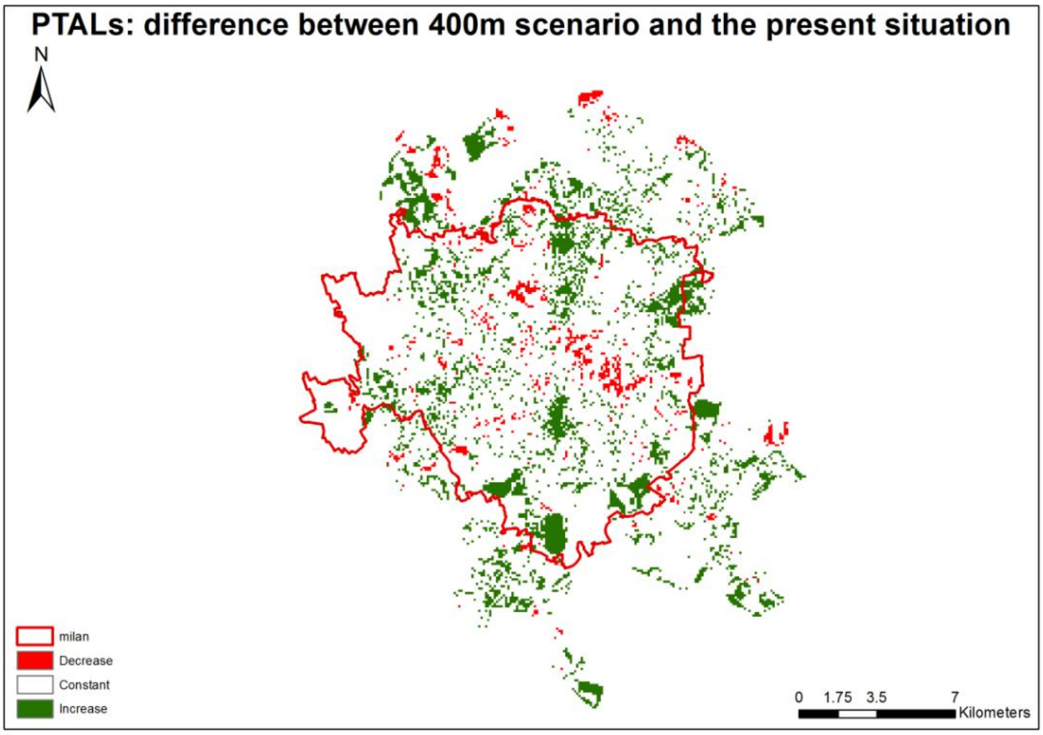


Figure 9.5 Difference between the accessibility levels: 400 m scenario - present condition.

From Figure 9.5 it is possible to observe when the accessibility level changed. The accessibility level was lowered by 1.0% (red areas), raised and then improved for 4.8% of cells (green areas) and it didn't change for 94.2% of the cells (white areas) (Table 9.5).

Table 9.3 Accessibility changes: 400 m scenario.

400 m scenario	
Decreased	1.0 %
Constant	94.2 %
Increased	4.8 %

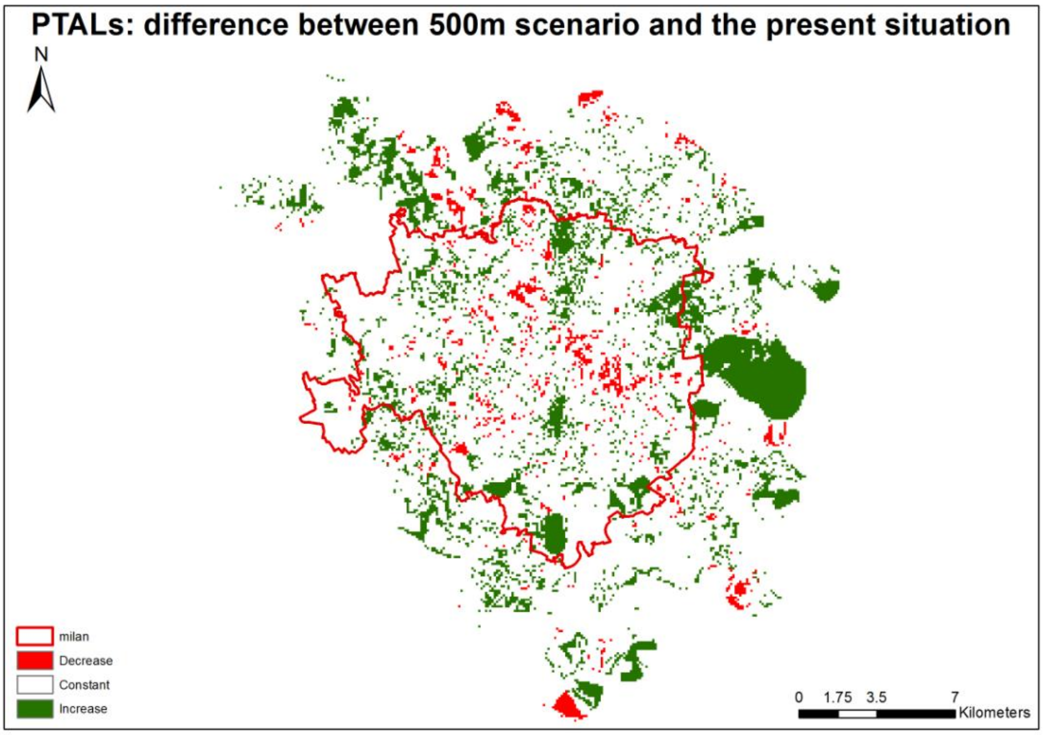


Figure 9.6 Difference between the accessibility levels: 500 m scenario - present condition.

The accessibility level was lowered by 1.5%, raised 7.4% of cells and it didn't change for 91.1% of the cells (Figure 9.6 and Table 9.6).

Table 9.4 Accessibility changes: 500 m scenario.

500 m scenario	
Decreased	1.5 %
Constant	91.1 %
Increased	7.4 %

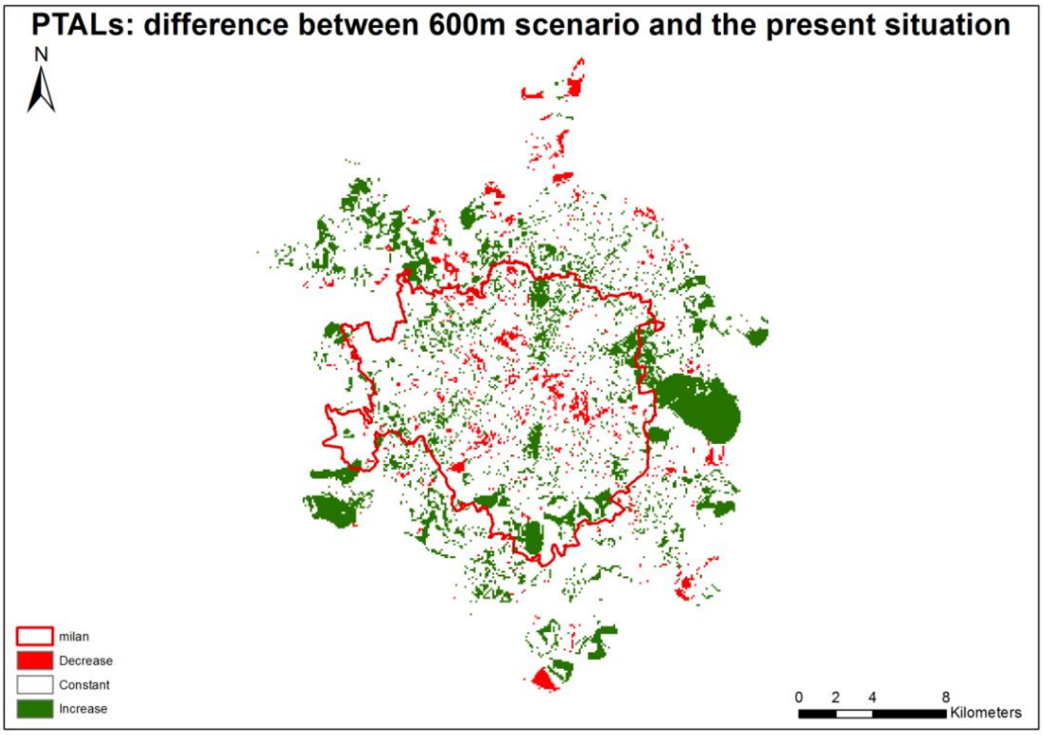


Figure 9.7 Difference between the accessibility levels: 600 m scenario - present condition.

The accessibility level was lowered by 1.9%, raised 8.3% of cells and it didn't change for 89.9% of the cells (Figure 9.7 and Table 9.7).

Table 9.5 Accessibility changes: 600 m scenario.

500 m scenario	
Decreased	1.9 %
Constant	89.9 %
Increased	8.3 %

9.4 Discussion

The analyses made to evaluate the impact of the stop spacing model on mobility and accessibility give two different results:

- the study made on the mobility demand gives several results: considering the totality of the movements (Table 9.1), the total travel time and the time spent on the public transport decreases for each scenario while, for the scenario with 500 and 600 meters of target distance between the stops, the pedestrian time increases.

  The figure related to the pedestrian time (Figure 9.2), which appears really heterogenic, has to be read considering the average of the pedestrian time, which is about 5.44 minutes for the original state, 5.41, 5.59 and 5.72 minutes for the model scenarios (400, 500, 600 meters). The pedestrian time difference is then generally little and this is can be acceptable.

It is also important to say that, when the distance between stops increases the pedestrian time does the same while both the total travel time and the service time decreases. This means that the disadvantage coming from a longer pedestrian time is balanced by an advantage in a service that is more efficient. This is particularly evident from Table 9.2 – 9.4: for 400 meters scenario, the pedestrian time increases by 34.5% of the movements while the transportation time decreases by 64.6% of the movements. The same happens for the scenarios with 500 and 600 meters of target distance between the stops where the pedestrian time increases respectively by 54.4% and 62.7% and the time spent on the public transport decreases by 77.2% and 80.9% of the movements.

The transportation time decreases for each scenario. From Figure 9.3 it is possible to observe that, when it increases, it averagely increases by values lower than 2%. It is also important to underline that the aim of the network analysis was to compute the fastest total travel time without considering the service used. For this reason, comparing the service time can, sometimes, be misleading since it is not said that the service used is the same one. This can explain the movements with a high increased travel time.

- the analysis made on the PTALs model gives good results since the accessibility level doesn’t change for about the 90% of the totality of the cells for each scenarios. Furthermore, there are more cells that increase their accessibility level than cells which decrease it.

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10 Conclusions

This study aimed at making a contribution to the studies on the public transport efficien-cy, to propose potential changes to the surface public transport stop spacing system and to propose a framework to study the public transport as a whole system investigating the mobility demand and the accessibility.

Analyzing the urban mobility demand allows to examine, on a macro level, some of the factors that influence people's choice of travel mode. In particular, the results obtained studying the Origin-Destination matrix highlight that the use of public transport is preferred in the areas where the service efficiency is higher, while the use of car is preferred where the public transport system is less efficient. From the analysis of the mobility demand, it results that the number of car movements is higher in the hinterland region and it is lower in City centre; the opposite happens on the public transport which has its higher values in the central urban area and the lower ones in the urban suburbs. This reinforces the idea that the more a system is efficient and easy to access the more the use of public transport likely increases.

To study the urban accessibility allows to understand the accessible level of different urban areas. In the study, it was decided to use the PTALs model to analyze the urban accessibility. PTALs measure reflects: 1) the walking time from the point of interest to the public transport access points; 2) the reliability of the service modes available; 3) the number of services available within the catchment; 4) the level of service at the public transport access points. This model gives the possibility to measure the accessibility level of each urban area in a detailed and accurate way, taking into account walk access time and service availability. The results obtained highlight that the accessibility level is on average poor in the hinterland area, where the density of the public transport stops and the service frequency is lower. In the City instead, the accessibility level goes from good to excellent in the Bastioni and Filoviaria Ring and it is very heterogeneous in the City Boundary region, where the accessibility level varies from very poor to excellent.

To study the relationship between accessibility and population density gives insight to where the accessibility should improve considering where people live. The results obtained from the study of the population density allows to understand which are the most populated areas: Milan centre is not highly populated; the Filoviaria Ring is highly populated; and the density in the Municipal Boundary is variable. By intersecting the population density analysis with the PTALs results, it is possible, first, to overcome the limits of the place-based analyses including a people-based perspective that focuses on individuals in space and time and, second, to understand where the accessibility level should improve. The results obtained highlight that the suitable areas represent about the 72% of the intersected areas.

In the study, a new stop spacing model has been developed with the aim of improving the surface public transport efficiency and minimizing the operating costs. The new stop spacing model is created working on the distance between consecutive stops, which is one of the aspects that affects more the quality of the service. The distance between the stops has been increased creating three different scenarios: 400, 500 and 600 meters of target distance between consecutive stops.

According to the study and to the proposed model on the stop spacing system of the City of Milan, eliminating some of the stops could have a positive effect on travel times and operating costs reduction. In particular, changing the stop spacing system eliminating an average of 1.7, 2.5 and 3.4 stops per route for the three model scenarios (respectively 400, 500 and 600 meters of target distance between the stops), would decrease the travel time by, respectively, 3.0%, 4.4% and 5.7%. The results also highlight that with a higher cruising speed, possible for example in an optimal situation with traffic light priority and public transport fast tracks for public transport vehicles, the travel time could decrease by 3.9%, 5.8% and 7.6%.

The results obtained from the operating costs analysis show that it could be possible to have an annual cost reduction per km by about 0.5%, 1% and 2% for the for the three scenarios analyzed (respectively 400, 500 and 600 meters of target distance). This results could have positive consequences on the public transportation use, which could likely increase, and on the public transport management, which could have more money to invest in the improvement of other aspects of the service. The study doesn’t focus on the possible environmental benefits.

The model is merely based on theory. It has some limitations, such as to not consider the traffic congestion and to consider that the public transport vehicles doesn’t skip any stop. The study also, doesn’t take into consideration the tradeoff of lost ridership due to the elimination of more accessible bus stops.

Another limitation of the study is related on the stops location. In the model, stops are located without considering the reality. The model is based on a broad scale and its intent is to show some of the possible positive effects coming from the stops elimination.
The analyses made on the mobility demand and on the accessibility are also important to evaluate the effects of potential changes to the surface public transport stop spacing system. In particular, the analysis made on the mobility demand, computing network analyses on about 13% of the Origin-Destination matrix movements, shows that that the travel time averagely decreases by 1.6%, 1.9% and

2.2%, the transportation time decreases by 2.0%, 3.7% and 5.0% and the pedestrian time changes by -0.4%, +2.8% and +5.2% for the three model scenarios (respectively 400, 500 and 600 meters of target distance between the stops). In terms of minutes, the results show that the increased pedestrian time is balanced by a more efficient surface public transport system. Walking distances for accessing the transport vary among the different population groups and in this study it is not investigated the effect of distance deterrence on different population groups.

The model scenarios have a good impact on the accessibility as well. The accessibility level didn't change for 94.2%, 91.1%, 89.9% of the cells (respectively 400, 500 and 600 meters of target distance between the stops), was lowered by 1.0%, 1.5% and 1.9% and increased by 4.8%, 7.4% and 8.3%.

To conclude, the model developed in the study generally gives good and interesting results. The model is based on a broad scale and it has some limitations. To understand its real efficiency, it is necessary to make other studies on a closer scale.

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