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Analysing space-time accessibility towards the implementation of the light rail system: the case study of Brescia

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Abstract

This paper proposes a methodology for investigation of the space-time relations of accessibility to public services and collective mobility. The paper assesses the space-time efficiency of local public transport facilities and makes an accessibility analysis as a baseline for evaluating future changes. It explains the potential for improvement and the effects on planning paradigms. Public transport accessibility greatly changes during day and night time so they should be assessed through multi-scaled and diachronic maps as a contribution to the timetable plan and overall planning strategies. The case study of Brescia, Italy is used to test the methodology. The new light rail system of Brescia entered into operation in 2013 and could change the entire form of urban mobility.

1. Introduction

Accessibility is one of the oldest prerequisites of a town's shape and natural growth (Mumford, 1961). Accessibility is used as a performance indicator for a well-functioning city (or region). It is also a fundamental element for understanding how much land use and mobility are intertwined (Hull, Silva & Bertolini, 2012). Accessibility describes the interactions between the activities located in a region and the transportation system serving them. Many authors agree that a shift from a mobility-oriented to an accessibility-based planning perspective is the key towards sustainable transport planning (Banister, 2008; Bertolini & Le Clercq, 2003; Handy, 2002, Marshall, 2001; Pulawska & Rossetti, 2014). In particular, Handy defines mobility as the potential for movement, the ability to get from one place to another, and accessibility as the potential for interacting among different and distributed urban activities. In Handy's view, the final aim of

accessibility is planning to increase the number of opportunities, within a fixed time. Accessibility is both an analytical measure and a normative point of view about changing the way people can get closer to people, and enhancing or re-structuring town schemes based on the fulfilment of people's expectations (Handy, 2002).
Services, as fundamental functions of the organization of urban systems, require a very high level of accessibility so they can be reached in an optimal way by all those who need and use them. Therefore, there should be a very strong link between the location of a service and urban mobility facilities.
Urban mobility has been widely described and analysed in the international literature, but the time-spatial correlations influencing the daily use of services and vice versa much less o (Nutley, 1985; Bonfiglioli, 1994). Recently studies have proposed more detailed theoretical assumptions and case studies, as suggested by Hull, Silva and Bertolini (2012). Noteworthy is the case of Ghent in Belgium (Delafontaine et al., 2012) where person-based accessibility measures have been introduced to take into account the opening hours of urban opportunities.
A consideration of accessibility is at the heart of TOD schemes, as mentioned also in the OECD Report "Pedestrian Safety, Urban Space and Health" (OECD-ITF, 2012). Accessibility must be assessed through the mobility patterns and the inter-modal frequent interactions. A promising description of inter-modality trips is that of the "chain model" (O' Sullivan, 2000; Achuthan et al., 2010; Busi & Pezzagno, 2011). According to this model, door-to-door mobility (e.g. from house to the service and back) goes through a combination of different modes, with the pedestrian movement always in the "odd number position".

<Fig. 1 Near here>

The choice among different transport modes complementary to pedestrian movement varies as a function of distance, accessibility, speed and comfort.
Therefore, pedestrian mobility is a "stand-alone" transport mode. Other transport modes must be linked in the chain by short pedestrian sections, getting on and off coaches or trains, until arriving at the final destination.
The entry into operation of a new mobility system, especially of a potentially efficient one such as light rail, imposes the reassessment of all links in the chain.
Last but not least, as walking is the primary and fundamental form of movement in all transport scenarios, and because pedestrians represent a heterogeneous and vulnerable group of people, safety is an important dimension of accessibility and a fundamental parameter to valuing the quality of the whole mobility asset (Tira & Ventura, 2000; Tiboni, 2004; Busi & Pezzagno, 2006; Fleury, 2012).

2. The significance of the approach for urban planning

In Italy, starting from the national Planning Act no. 1150/42, services are spatially regulated through the Town Plan (namely *Piano Regolatore Generale* PRG). The following Ministerial Decree 1444/68 introduces the concept of urban standardsthe which includes minimum amount of area to be devoted to services per inhabitant. This was introduced with the objective of halting the Italian post-war urban policy characterised by high density settlements without any allocation of public spaces. The reform of Title V of the Constitution Law (2001) allows the Regions to legislate in the field of urban planning. Lombardy introduced the Plan of Services through the regional law no. 1/2001 as an attachment to the Master Plan. It overcomes the concept of standard quantity and instead promotes service performance: quality, usability and especially accessibility as additional parameters to quantify the level of service of equipment and facilities (art. 7).
Most recently the Lombardy regional law no. 12/2005 elevates the Plan of Services as one of three basic parts that make up the new Town Plan (namely *Piano di Governo del Territorio* - PGT) having a strong connection with land use management.Art. 9, Sec. 3 of the same law confirms quality, usability and accessibility as fundamental factors in the assessment of the provision of services. In case of lack of these factors the Plan must provide corrective actions and quantify the costs for their adaptation.
In the last decade there has been widespread interest shown by local and regional authorities on the organisation of access times for the population to services. The concept of optimization in the use of time and reconciliation between business needs and family care has been present in the Italian legislation since the Act no. 53/2000. It promotes the first substantial step for an efficient development of time policies at urban scale related to the needs of families and most vulnerable citizens (Bonfiglioli, 1994; Bonfilgioli et al., 1995; Bonfilgioli et al., 1997)
The following legislative decree no. 267/2000 identifies the role of the Mayor as the coordinator of the timing of public services. The Regions define the roles of Provinces and Municipalities and provide general criteria for the coordination and administration of the timetables. It is a municipal task, in compliance with national and regional authorities, to adopt a strategic tool to address, from a time-planning point of view, the connections between sectorial planning and land use planning.
The instrument defined for these purposes is the Territorial Timetable Plan (TTP), namely *Piano Territoriale degli Orari*. This plan allows for the setting, implementation and monitoring of time policies as a strategic and land use planning objective (Bonfiglioli, 1994).
The TTP identifies the factors that influence mobility, among others: the ability and independence of movement, the location and the opening hours of services, the distance between residences and services. In order to improve the quality of life of people, the plan promotes the liveability of the city through a better organisation of times and spatial access to goods and services by all citizens, harmonizing the opening hours of offices, schools,

shops and the working hours (Bonfiglioli et al., 1995; Gwiazdzinski, 2003; Delafontaine et al., 2011). Therefore, the TTP focuses on the issues of sustainable mobility, accessibility and temporal usability of public and private services, but also on the redevelopment of public spaces (Mareggi, 2002). The TTP is a strategic document introduced in Lombardy through the regional law no. 28/2004. It is strongly linked to Plan of Services: while the first coordinates time schedules of public transport and services, the second mainly addresses the issue of the spatial distribution of services.
The purpose of the paper is then to propose a methodology to assess the present and future accessibility to public services and to verify the methodology in the case study of Brescia. From the operational point of view, the integration between two fundamental tools has been assessed: TTP and the Plan of Services are quite different from a methodological point of view, the binding effects and competencies involved. Nevertheless, years of solely physical planning of services have shown the limits of the approach. Fostering a growing integration of mobility and urban planning tools include the matter of time management.
Brescia is a city in the North of Italy, with a population of nearly 190,000 and a surrounding metropolitan area growing at a steady rate.
The 'Office of Times' manages the temporal accessibility to services depending on their spatial location and citizens' needs. The present work is a result of an agreement made between the Municipality of Brescia and the Department DICATAM of the University of Brescia to support the revision of a local TTP.

3. Methodological approach

Several data need to be collected to assess accessibility. Precisely, the database required contains the following information:

1. the geographical information about the mobility system;
2. the bus timetable;
3. data sheets of services, both public and of public interest.

The spatial analysis is performed within a GIS environment, using georeferenced information. For this reason, the project involved collection of shapefiles for bus lines and stops, bike sharing stations and light metro line and stations. The data is available obtained through the municipality offices, and the public transport companies. Bus frequencies are obtained from timetables for a typical working day.While spatial and temporal data previously described are necessary for the accessibility analysis related to the whole territory, public service data sheets are needed for the last step of the assessment examining accessibility linked to the opening hours of services. Therefore, the geographical location of the services and opening hours must be known.For this purpose, a data sheet has been elaborated for each service. The sheet contains qualitative and quantitative data, taking into consideration both the boundary conditions (roads, parking capacity, environmental conditions, etc.), as well as those inherent structures

(compliance with minimum dimensional standards, maintenance and security conditions, minimum support structures, etc.). As well as quantitative parameters, the degree of quality of environmental parameters has been ranked.
The crucial role of GIS-based analysis to assess and manage accessibility issues is well-established, at least within the scientific community, and the dependence on GIS techniques for accessibility analysis has significantly risen in the last decade (see, i.a., Hull, Silva & Bertolini, 2012). Focusing on public transport accessibility, two scenarios have been considered for the case study of Brescia: before and after the entry into operation of a new light rail system. Furthermore, the temporal changes in accessibility during the day are represented. Lastly, the accessibility maps are overlaid with the representation of service location and opening hours.

4. The case study of Brescia: some relevant features of the traffic schemes in Brescia

The largest part of the downtown Brescia is a "restricted traffic area" (ZTL), where access and circulation are limited to few time slots and to particular categories of users and vehicles. Within the ZTL, a smaller area with more restrictive rules is the "privileged pedestrian zone". That is an area where the ZTL is in force 24-hours and where parking is restricted to residents and authorized people. The city of Brescia and the entire Province of Brescia are characterized by a very high motorization rate (593 passengers cars per 1,000 inhabitants): so the modal share is overbalanced toward cars. In Brescia and in the 17 surrounding municipalities, more than 75% of home-work daily trips take place by car; considering the non-systematic mobility, car use is even bigger (ISTAT, 2011).
Local policies are not focused on the limitation of car usage and instead are promoting solutions to increase parking places, since the late '90s in new structures, and to change the regulation of parking on the road (Bonotti et al., 2014). From the point of view of sustainable mobility, the local "cycling plan" dates back to 2000 and it has helped to expand the network during the last decade. A "cycling office" has been established in June 2011, in the frame of the European project "CIVITAS" (2008-2012).
In 2008 Brescia a bike sharing system called "Bicimia" has been set up. Bicimia connects 39 stations located within the municipality. The entry into operation of this service has had a wide success and an extension of the service has been designed with the installation of further stations near the metro stations. The local public transport system in Brescia consists of 18 bus lines with 1,832 bus stops spread over the town and in 13 surrounding municipalities. The fleet is made of 236 buses, travelling at an average speed of 17.52 km/h, operating during working days all year round from 5:00 a.m. to 0:45 a.m..

The scenario is bound to highly change over the next few years, due to the entry into operation of the automatic light metro, so that the level of accessibility of a significant part of the city should reap the benefits.

<Fig. 2 Near here>

The automatic light metro links the northern quarters, where the university and the main hospital are located, to the south-east urban district of San Polino, through city centre, the train central station and the business district of "Brescia Due". The quarter of San Polino has been conceived after the project of the light railway, following some transit oriented development concepts (Tiboni & Rossetti, 2013). The metro line presents 17 stations (see Fig. 2).
The new infrastructure will certainly have a powerful effect by changing significantly the urban mobility patterns and even the environment in which it operates (Tiboni & Tira, 1997). At a detailed level, the neighbouring areas of the metro stations should be designed with particular attention to pedestrian mobility, as the tertiary activities can be expected to concentrate around the stops. At a wider scale, the light railway may foster a radical change in the use of private vehicles and it could be an incentive to the use of public transport even at the suburban scale.

5. Collective and non-motorised transport accessibility

5.1 Spatial accessibility

The collective and non-motorised means, including walking, cycling and collective public transport (buses and light metro), are more sustainable and climate-friendly than the individual motorised modes (Tolley, 2003; Bertolini et al., 2005; Tiboni & Rossetti, 2011). As widely shown in the international literature, non-motorised mobility plays a substantial role in the organization of the whole urban system and the level of service of public transport highly depends on spatial and temporal accessibility (see, for example, Tira & Lombardi, 2009, and the studies conducted in the cities of Birmingham - Nettleton et al., 2006 - and Bromsgrove - Drew & Rowe 2010 - in order to incorporate an "accessibility planning" through the "Local Transport Plan" process as required by the UK Department for Transport).
Based on accessibility maps of the city, the accessibility of the collective transport in Brescia and the changes after the entry into force of the new light railway have been assessed. Actually, two accessibility maps have been drawn: the ex-ante scenario, made of bus stops and bike sharing stations, and the ex-post scenario, with the addition of the new light metro system and its stops.

In the first scenario, each area within a range of 350 m from the bus stops and within 250 m from each bike sharing station has been taken into account. This influence radius has been estimated considering an "optimal" pedestrian access time to the bus stop of 5 minutes, at a 3 km/h speed. The 5 minutes for the access are taken from the literature (see Columbo, 1966; O' Sullivan & Morrall, 1996; Yigitcanlar et al., 2007; Festa, 2009) where the definition of daily duties was based on some basic sociological assumptions. The pedestrian speed is generally described as 4,8 km/h, here reduced to 3 to take into consideration average pedestrian conditions (like the elderly). Using a GIS Spatial Analyst tool, the accessibility value of every 20x20 m^2 cell of the area has been calculated through a linear function. This function varies between the value 1 (maximum accessibility), at the stop, and 0 (minimum accessibility) at the border of the circle designed by the influence radius.
The accessibility by bus and by bike has been summed up giving different weights to the two transportation modes in order to consider the rate of use of the two systems: 0.9 for bus and 0.1 for "Bicimia". These are not absolute values but they are consistent with the number of passengers of the two means of transport, considering that in 2009 the public transport service in Brescia carried 42,668,471 passengers while the number of trips by Bicimia has been of 108,040.
The result is the accessibility map (Fig. 3) that gives to each cell a value.

<Fig. 3 Near here>

The second map shows the accessibility values in the new scenario: for the light metro stations the minimum accessibility value is zero (if the walking distance is more than 500 m). That is due to the fact that pedestrians are keen to walk more (about 10 minutes) to reach a faster and/or more frequent collective transport system as the light rail (O' Sullivan & Morrall, 1996). Like in the previous map, the different level of service of the transportation means has been weighted: 0.6 for the light rail, 0.3 for buses and 0.1 for bike. The new weight distribution is due to the fact that the light metro system has an estimated hourly capacity of 17,000 passengers/hour (in its initial configuration of 16 trains), that is the double of the passengers that are currently using the bus network. Fig. 4 shows the results in terms of current accessibility.

<Fig. 4 Near here>

Both maps (past and new scenario) show how the space is not homogeneously accessible: that is more evident in the new scenario where the accessibility is much higher along the metro axis than close to the bus stops. But this is just a first step of the analysis that doesn't take into account the frequency of the public transport service. In order to better

perform the analysis, this first assessment level must be integrated with the temporal dimension.

5.2 Diachronic accessibility

Regarding temporal changes in accessibility by public transport, only the ex-ante scenario has been considered, as many variables of the future public transport system are still unknown.

Looking at buses, the frequency changes consistently during the day and most services do not work during the night. An analysis of the timetable and of the daily frequency of each bus line has been conducted. There are three main frequency slots during the day:

- rush hours (from 7.00 to 9.00 a.m. and from 11.30 a.m. to 2.00 p.m.);
- soft hours (from 9.00 to 11.30 a.m. and from 2.00 to 7.00 p.m.);
- low frequency hours (from 5.00 to 7.00 a.m. and from 7.00 to 11.00 p.m.).

Focusing on spatial location of bus stops in the whole municipality, it is possible to link every stop with the average waiting time of the bus at the stop. The average waiting time has been added to the walking access time starting from each point within the radius of 350 m from the stop itself.

<Fig. 5 Near here>

The following maps (Figs. 5 – 6 – 7) show the results in terms of total access time from a fixed point to get on the bus, the so called "local accessibility" (Hillman and Pool, 1997) given by the walking time to the stop and the average waiting time at the stop), for the different frequency slots of the day. When the cell is light green it means that the access time to the bus is less than 5 minutes, while a dark red cell represents an access time of 60 minutes or more.

Looking at the three maps it is possible to assess how much the access time changes during the day: it is very short in the rush hours while it becomes much longer (in some points even longer than 60 minutes) late in the evening and at early morning.

<Fig. 6 Near here> <Fig. 7 Near here>

After the entering into force of the light metro system, the time accessibility scenario changed, but at the moment it's not clear how the current mobility system will be modified to better integrate the new transportation mode.

The automatic light metro can have a maximum frequency of 90 seconds, so, by using this as rush-hour frequency data, the following map has been implemented. Fig. 8 shows that the temporal accessibility to the automatic metro, considering its walking distance time and the maximum frequency, is at most 10 minutes.

<Fig. 8 Near here>

5.3 Interactions with services

The final step of the proposed methodology is the assessment of the relationship between the space-time accessibility previously described and the services. In the case study, the analysis focuses on a sample of services: public and private sport facilities and municipal offices, among other categories that may be considered in order to extend the analysis and assess the interactions. This type of analysis should be repeated from time to time, in order to evaluate the evolution of the asset.

To investigate the spatial relationship between public transport system and the services, it is possible to overlap the two informative layers of the location of the stops (see Figs. 3 - 4) and the location of services, in order to obtain the results shown in Fig. 9, for the new scenario.

<Fig. 9 Near here>

From a spatial point of view, those services with higher accessibility levels, should have a better chance of being reached using a collective passengers' means of transport in comparison to private car.

The above described maps, showing temporal accessibility, have been overlapped with the timetable of services. Public transport accessibility maps (Figs. 10, 11, 12) allow us to evaluate how long it takes to walk to the bus stop and to wait for a bus after leaving the public service. At 9.30 p.m. (Fig. 12) there are still open sport facilities, but the map shows that they are not easily accessible by bus, due to the low frequencies of the service.

<Fig. 10 Near here>

<Fig. 11 Near here>

<Fig. 12 Near here>

6. Conclusions

The paper shows the first outcomes of an analytical method designed to investigate the space-time accessibility of a region (in general) or, in more detail, to public services located in an urban environment. In particular, the accessibility assessment has been lead looking at the different public transport access modes.

The methodology has been tested on the case study of the city of Brescia where new transport infrastructure has been implemented (Bonotti et al. 2012). The time issue was considered also during this second step and a further analysis was performed considering the frequencies of the bus service during the day. The effects of the new transport infrastructure can

be assessed in order to influence the planning choices, i.e. the location of services, or the surface transport facilities (namely bus lines). The new opening of the metro in Brescia, which lead to new methods of accessing the city, is an opportunity to achieve previously unattainable or unmanageable interventions.
The proposed methodology may then be implemented, both in an analytical and operational approach. The final goal is the increased accessibility for a sustainable mobility pattern: this kind of analysis is therefore required within the territorial timetable plan. Furthermore, the methodology can be transferred to similar case studies that take into consideration the improvement of public transport. The analysis can be easily adapted on the basis of different mode of public transport and different structure and type of services. The crucial information needed is time schedules of public transport and opening and closing hours of services. The influence radius of every specific means of public transport that may be available in a city (e.g. trolleybuses, streetcars...) can be easily found in scientific literature.
A further development of the analysis should also address the urban environment in which the bus stops are located (and the light metro line stops too), with particular regard to pedestrian needs. The interactions between pedestrian mobility and the collective transit systems must be evaluated as basically pedestrians are the main collective transport users. Therefore, particular attention should be paid to the pathways and to the urban spaces used by the passengers (Tyler, 1999; Hillman & Pool, 1997; Tira, 2001), looking at the most vulnerable road users like children, elderly and people with reduced mobility (Busi, 1997) developing accessibility maps.
Furthermore, a collective transport system can be competitive with the private vehicle when attractive and integrated (Busi and Tiboni, 2003). Emblematic is the survey about individual and collective transport in four European cities (Wickham J, 2006). Cities with better quality of public transport system like Bologna or Helsinki are less car-dependent than other cities with lacks of an integrated transport system (e.g. Athens and Dublin), even when car usage by citizens seems to rise over time. This is especially true for non-work journeys, usually dedicated to access to public services.
Transport planning and location of attraction points, like public services, should take into account the whole sequence of movements that constitute the journey, identifying appropriate solutions in close collaboration with urban planners: transport and urban planning must proceed together (Yigitcanlar et al. 2007; Tiboni & Rossetti, 2011). As suggested by Bertolini et al. (2005), through test-applications in the Rotterdam-The Hague region and Delta Metropolis in Holland, the integration of transport and land use planning is essential to the achievement of sustainable development. Again in Randstad Holland (Geertman & Ritsema Van Eck, 1995) accessibility analysis is used to determine the

location of possible building sites: "potential surfaces" where public transport is a good alternative to car-usage.

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