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Measure of urban accessibility provided by transport services in Turin: a traveller perspective through a mobility survey

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Abstract

Accessibility is a fundamental aspect for cities and a good degree of connection among different urban areas can be reached by smoothing the travel experience, through the efficient use of public and private transport modes.
On the whole, a variety of methods has been developed for measuring accessibility, based on different kinds of dataset and using various types of metrics and indices. In this paper, accessibility is analysed focusing on travel times, as perceived by travellers, the measured travel distances and the average speed, derived from these two attributes, to connect various areas of the city.
The methodology developed in the paper is tested on a real dataset for the city of Turin (Italy). This comes to be a proper test site through the availability of citizens' mobility data collected through a travel diary survey proposed in three waves in 2016 and 2017. Such dataset provides useful information to measure the accessibility of different areas of the city.
In this way, it is possible to measure how the zones of a city are differently connected, with a strong dependence on the available transport modes and their quality. Results are compared using both active and passive accessibility indicators, to assess the difference between travellers' perception and the scheduled service for the public transport network. The evaluation proposed can provide useful information to estimate the accessibility at city level and map the zones for their ranking assessment.

Keywords: accessibility; urban mobility; transport network; mobility survey; public transport

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1. Introduction

Accessibility is a key concept in transportation planning (Curl et al., 2015), since it allows to evaluate the effectiveness of transport policy measures on a study area, modelling both travel demand and interactions among transportation system and land use (Cascetta et al., 2016; Geurs and van Wee, 2004). Moreover, from a traveller perspective, it influences users' choices at different levels and helps people to carry out their daily activities in the most effective way (Lättman et al., 2018). Despite its importance, starting from the work of Hansen (1959), there is no consensus on a standard definition of accessibility (Cascetta et al., 2016; Curl et al., 2015; Geurs and van Wee, 2004), even if in broad terms it is accepted that the concept is related to the possibility for travellers to reach destinations of activities (Curl et al., 2015; Geurs and van Wee, 2004). Furthermore, several authors distinguished between active and passive accessibility. The former is the ease of a traveller to reach a particular destination, and the latter is the possibility that a specific destination can be reached by potential travellers (Cascetta et al., 2016).

Due to its complexity (Geurs and van Wee, 2004) many indicators to measure accessibility have been proposed, the use of which has increased thanks to the growing availability of detailed data on travel activities (Cascetta et al., 2016). However, each measure is focused on one or few aspects of accessibility (Geurs and van Wee, 2004) and, therefore, each of them has specific limitations (Cascetta et al., 2016; Geurs and van Wee, 2004; Lättman et al., 2018; Ryan et al., 2016). Because of this complexity and limitations, and since one of the main aim of the analysis is to convey clear information to policy makers (Geurs and van Wee, 2004; Ryan et al., 2016; Thomas et al., 2018), this paper adopts a practical indicator that can be easily calculated, applied and understood (Thomas et al., 2018), namely travel speed to move from an origin to a destination, calculated considering the self-assessed travel time and the real distance between trip ends.

By comparing the approach presented in this research with the state of the art in the sector, it can be noted that the majority of papers considers only measured accessibility, rather than perceived accessibility (Lättman et al., 2018), even if the two measures have great differences, which should be taken into account (Curl et al., 2015). In particular, the first one is calculated adopting objective travel characteristics (e.g. travel time, distance and land use), whereas the second one is a subjective measure considering how a traveller perceives the possibility to reach a specific destination (Lättman et al., 2018; Ryan et al., 2016). Perceived accessibility might be different compared to measured accessibility due to individual traveller's constraints and to the lack of perfect knowledge of travel attributes that an individual might have (Curl et al., 2015). The principal added value of this paper is estimating the difference between these two aspects of accessibility, which is important for practical applications to identify critical elements of a transportation system (e.g. zones, transit lines, information services), in which travellers might improve their perceived accessibility, in order to obtain values similar to the objectively evaluated one; in this way, policy measures can be targeted by defining specific interventions to prioritize underperforming scenarios (Curl et al., 2015; Lättman et al., 2018).

In this paper both active and passive accessibility are calculated on the basis of travel speed, for both car and public transport (PT) as travel modes in Turin (Italy). The second research contribution is the application of the proposed method to a case study, in which measured accessibility is estimated using data provided by public transport agency which considers detailed scheduled transit service characteristics; whereas, perceived accessibility is evaluated from a local travel survey, analysing subjective perceptions of travel. In the first phase only perceived accessibility is considered (active and passive) for car and public transport, to obtain a general representation of the two measures. Thus the differences between accessibility values on car and public transit are shown to make comparisons for the two modes. In the second phase, perceived and measured accessibility are calculated for public transport. They are compared not only to quantify the difference, but also to identify critical cases in which people might improve their travel experiences, maximizing their accessibility.

2. Datasets description

2.1. Travel survey

Data from a mobility survey carried out in the Turin metropolitan area were used to estimate perceived accessibility. The survey was administered to a representative sample of the population (4466 persons), collecting socio-economic characteristics of the respondents, their travel diary and activities carried out in the 24 hours before the interview. In particular, locations were entered through Google Maps APIs to better estimate covered distances according to the transport mode reported (car as driver, car as passenger, taxi, urban or suburban bus, tram, metro and train). Then, detailed questions were asked about a randomly selected chained trip among those reported, concerning, for example, travel times with all used means, walk and wait times and travel contingencies (such as travelling with children or carrying heavy or bulk items). In the last part of the survey a Stated-Preferences experiment was carried out by contrasting the actual travel mode choice for the chained trip with a series of alternatives. A more detailed description of the survey can be found in Ceccato and Diana (2019).

2.2. Public transport lines GTFS

Measured accessibility was calculated using information available from the General Transit Feed Specification (GTFS) standard. Data about the Turin public transport service are provided by "Gruppo Torinese Trasporti (GTT)" and "5T S.r.l" transportation agencies. Information about stops, routes, scheduled frequency and travel time of all the transport services in Turin, including buses, trams, urban trains and the underground were used to estimate both the average and the maximum speed among zones, considering all the line connections including one or none transfer, consistently with survey data. More details about assumptions and calculations can be found in Deflorio et al. (2017).

3. Method

Travel speed values obtained from the GTFS system and those reported in the travel survey were compared. The formers were considered as measured accessibility, since values were objectively calculated; the latter were considered as perceived accessibility, since travel time used in speed estimation was the one reported and estimated by survey respondents. Measured accessibility between zones *i* and *j* was calculated as the ratio between the minimum distance between the two centroids from the road network ($dist_{i,j}$) and the minimum travel time between the two zones ($time_{i,j}$) (Deflorio et al., 2017) according to Eq. 1, where N is the total number of zones in the study area:

$$\mathrm{Acc}_{\mathrm{i,j}} = \frac{\mathrm{dist}_{\mathrm{i,j}}}{\mathrm{time}_{\mathrm{i,j}}} \qquad \mathrm{i,j} = 1, \dots, \mathrm{N};\ \mathrm{i} \neq \mathrm{j} \tag{1}$$

Measured accessibility was estimated using the planned frequency from GTFS data, assuming a fixed access and egress time, and supposing waiting time at the stops as a function of the scheduled headway (Deflorio et al., 2017). Since public transit frequency changes along with time period and lines, different speed values were obtained, and only the average and the maximum were retained between zones. The former represents a mean value beyond the previous explained variations and the latter represents the accessibility of the fastest route connecting two zones (Deflorio et al., 2017).

Perceived accessibility was estimated considering travel speed registered in the travel survey. In particular, the speed of each trip was calculated as the ratio between the measured distance and the self-assessed duration of the trip. The former was obtained from Google Maps by considering the specific origin, destination and travel mode of the trip, and the latter is reported by respondents, including in-vehicle travel time and walking and waiting time for public transport. In this way travel speed, and therefore accessibility, is affected by subjective perceptions. Since origin and destination (OD) of the trips are points (i.e. specific addresses were provided by respondents), to compare travel speed thus obtained with the values from GTFS, data were aggregated at zonal level, considering 94 Traffic Analysis Zones of the study area. After that, only OD pairs recorded both in the GTFS and the survey were retained. Also in this case, for each pairs, average and maximum speed values were considered. The former allows understanding the accessibility between two zones averaging people perceptions and individual travel experiences of persons travelling between those zones; the latter was used to evaluate and represent the best travel choices (route and schedule) that an individual might adopt maximizing her velocity, i.e. the best accessibility value.

Analyses were carried out at two levels: OD pairs level and zonal level. Moreover, peak period in the morning were considered to calculate accessibility values since it was the relevant time period when most of users travels and, therefore, the performance of the system may be critical (Thomas et al., 2018).

3.1. Active and passive accessibility evaluation on the map

Trip speeds among each OD pair were aggregated for each zone as origin (active accessibility) and destination (passive accessibility) (Cascetta et al., 2016). Eq. 2 reports the active accessibility formula, where *s* is the zone for which accessibility is calculated. Similarly, passive accessibility is evaluated, considering *s* as destination and summing up over the origins:

$$\mathrm{Acc}_{\mathrm{act,s}} = \frac{\sum_{\mathrm{j=1}}^{\mathrm{N}} Acc_{\mathrm{s,j}}}{\mathrm{N}} \qquad \mathrm{s} \neq \mathrm{j} \tag{2}$$

Only zones with at least 10 attracted or generated registered trips were retained, to have more representative speed values. While data from the survey allows estimating speed only between zones reached by some travellers, speeds derived from GTFS data were calculated considering all the possible OD connections among zones, even the ones for which travel demand may be zero. Data were represented on a map to identify critical zones and underperforming scenarios to be prioritized by specific interventions.

3.2. Dispersion diagrams

Dispersion diagrams of measured and perceived accessibility were generated with two main aims. The first one was to obtain an estimation of the bias between the two measures at OD pairs level; the second one was to define a threshold based on the planned performances of the public transport system in normal conditions, to identify critical cases. In particular, each point in those scatterplots represents a trip between two zones that was registered in the travel survey; x- and y-axis values are respectively given by the aggregate travel speed estimated by the travel time reported by respondents and the one calculated by GTFS data. For each OD pair more than one trip, and thus travel speed, can be detected. Therefore, maximum travel speed was used as aggregate value, because it allows to compare the best options related to different distances. Usually people choose the best options, in terms of their perceived utility, which usually includes also the value of waiting and walking time, as well as the number of transfers. Although transfers might affect travel convenience, in this case, they are considered not relevant, because the selected options are limited to only one transit connection, both in travel survey and values obtained from the GTFS data.

Observations below the line of identity are related to possible service criticalities in connecting specific OD pairs. These cases might be due to biased travellers' perceptions of travel time or to an actual speed lower than the one provided by the transit system (because of a decreasing of the service quality). Other reasons might have caused these speed differences, such as a non-familiarity with transit routes. In this case, the analysis reveals a weakness of the service that can be improved with actions oriented to better inform travellers about their options. However, in the present case study, the majority of trips (about 70%) were carried out for systematic purposes (work/school), by travellers who have a consolidated knowledge of transit options, since they daily experience these systematic trips. Furthermore, the anomalies detected in choosing slower options can also derive from their preference in avoiding transfers, or reducing walking distances. This again might highlight a criticality for the transit system in connecting two specific zones, if compared to other OD pairs. Understanding the causes of these potential critical cases is helpful to target policy interventions. In this case, rather than assuming a fixed value of travel speed below which a trip is considered critical, the line of equity ensures that critical cases are identified according to the real possibility of the transportation system to connect zones with a feasible speed.

4. Application results

First, results of the comparison between perceived active and passive accessibility of car and public transport are presented; then, differences between perceived and measured active and passive accessibility on public transport are analysed.

4.1. Active and passive accessibility through car and public transport

The greatest accessibility values on car are shown for the most external zones, since they are zones with less congestion and high free flow speed infrastructure. In particular, for active accessibility (Fig. 1a), in zone 77, 65 and

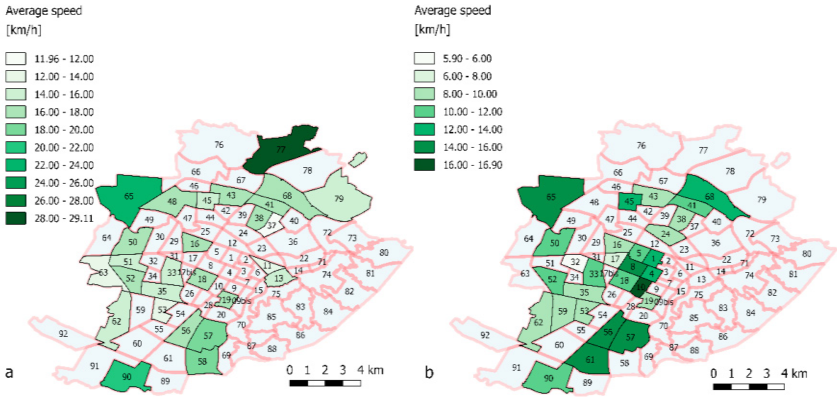

Fig. 1 (a) active perceived accessibility on car; (b) active perceived accessibility on PT

90 there are entrances to a high speed road surrounding the city, which allows to reach several destinations with short travel time. On the contrary, internal zones denote low accessibility values due to congestion delays.

Concerning the accessibility on public transport, the highest active accessibility values (Fig. 1b) are obtained for zone 8, 10, 56, 57 and 61 where there are the three main train stations of Turin; in these zones there are many transit stops of different lines including metro, providing a range of possibilities to public transport users, who can therefore easily choose the best path to reach her destination. Furthermore, in zone 45 there is a train station with a urban railway line, linking several part of the city using the railroad infrastructure, with a speed usually higher than the one on road. Virtually aggregating the zones with the highest accessibility values in Fig. 1b one can note two main corridors. The first one is a central corridor along a north-south direction, which is supplied by transit lines (tram, in particular), with reserved lanes and traffic light priority systems, increasing public transport speed. The second one starts form the western part of the city and it ends in the southern areas, passing through central zones; this corridor is supplied by a metro line, which increases travel speed on average. The analysis of passive accessibility for public transport (whose map is not reported here for the sake of briefness) denotes high values of speed for the north-south corridor, indicating the effectiveness of interventions in these zones for both accessibility indexes.

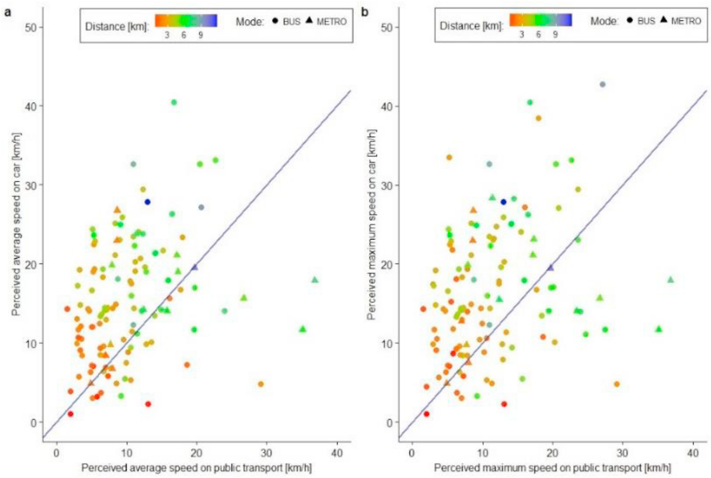

Fig. 2 (a) average speed on car and PT; (b) maximum speed on car and PT

Fig. 2 shows average and maximum speeds reported by respondents in the survey for trips on car and public transport. Trips are coloured according to the distance evaluated by car. As expected Fig. 2a indicates that the average speeds of the trips performed on car are greater than the ones performed on public transport. The difference is about

4.9 km/h on average (t-test, p-value <0.001). Observing the graph one can note that metro often provides higher speed rather than the one of car, suggesting that this mode might be competitive respect to private mode in terms of travel speed, like in active and passive accessibility maps. Moreover Fig. 2b shows that the points are slightly farther from the equity line suggesting that the difference in terms of the maximum speed is greater than the average one; however the mean difference is about the same (4.9 km/h, t-test with p-value <0.001).

Observing the map of the difference between maximum travel speed on car and public transport for active accessibility (Fig. 3a) one can note that car provides higher velocities than public transport. Similar values are shown for zones in which there are metro (zone 56) and train stations (zones 56, 45 and 68) where travellers can use a service of local urban train, crossing the city through the railroad system. Furthermore, external zones (such as 65 and 90) have higher values of active accessibility on car rather than on public transport; this might be one of the cause of the low use of park and ride parking, where people coming from outside the city might leave their car near high speed road and take public transport; to increase the use of such infrastructures, improving public transport speed is a key factor. On the contrary Fig. 3b shows that most of the zones with high active accessibility on car have also high values of passive accessibility (Fig. 3a), indicating that in this zone pubic transport service should be effectively improved, increasing transit speed; interventions such as reserved lanes and traffic light priority systems could be adopted. Zone 3 is the only zone with a passive accessibility value on public transport greater than the one on car, since it is a central zone where low speed limits are adopted for cars. Similar values of passive accessibility are reported for zones along a north-south direction, since this corridor is supplied by transit lines (tram, in particular), with reserved lanes and traffic light priority systems, as shown in Fig. 1b. These results suggest that such interventions to increase public transport speed could be a factor to make this mode more attractive and competitive with private car.

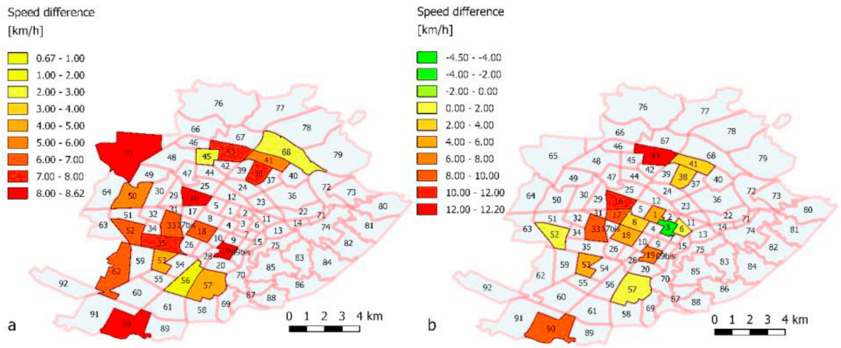

Fig. 3 (a) active perceived accessibility: difference between car and PT; (b) passive perceived accessibility: difference between car and PT

4.2. Measured and perceived accessibility by public transport

Observing Fig. 5a one can note that, for most of the observations, the average speed perceived by survey respondents is greater than the one derived from GTFS data. Moreover, trips performed on metro are set above the identity line. Indeed the average speed from GTFS considers also bus lines that decreases the mean values of speed, due to their low velcity respect to the speed on metro. Therefore, the corresponding values of speed from GTFS are lower than the perceived ones that are carried out only using metro. On average, the difference between the two speed is about 6.6 km/h (t-test, p-value <0.001)

Fig. 5 indicates that the difference between the two speed values does not depend on trip distances, since points with different distance are mixed; however it shows that both the survey and GTFS data report low speed for short distances, since the effect of waiting and walking time respect to the in-vehicle travel time is greater for short trips than for long ones. On the other hand, points below the identity line in Fig. 5a indicate trips that have a perceived average speed lower than the average speed provided by the public transport system (GTFS). This means that, from a user perspective, these persons might improve their travel performances by adopting other solutions (e.g. changing transit lines), and, from a provider perspective, the actual quality provided is different from that scheduled. This

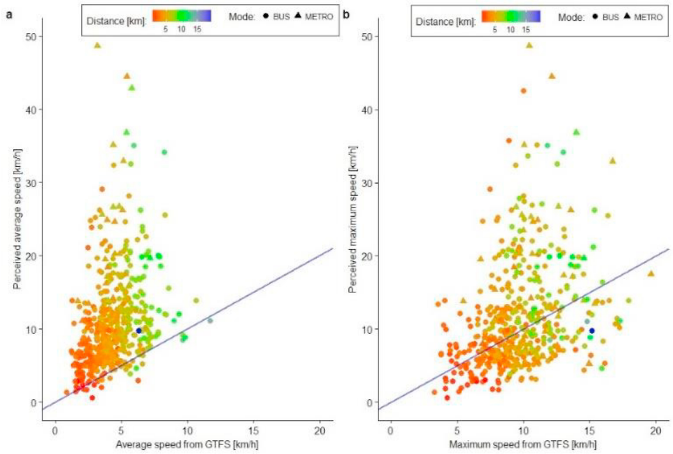

Fig. 4 (a) average speed from the survey and GTFS; (b) maximum speed from the survey and GTFS

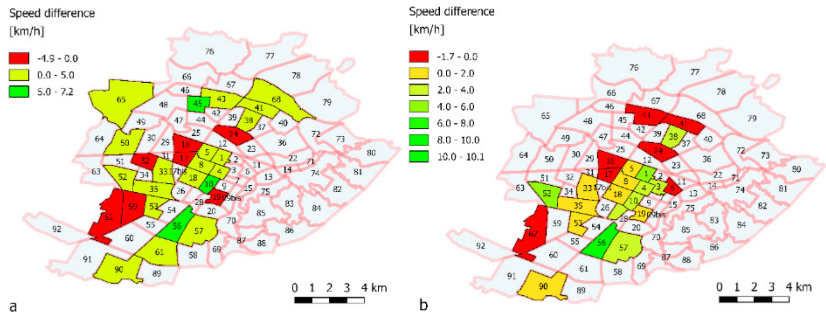

Fig. 5 (a) difference between perceived and measured active accessibility; (b) difference between perceived and measured passive accessibility

analysis allows to identify critical trips without assuming fixed values of travel speed as a threshold; on the contrary it considers a threshold that is derived from the scheduled performance of the public transport system, obtaining results that are reliable since they are based on sound and real data. In particular, these critical cases were analysed by observing details about trip characteristics that were collected in the survey; the analysis shows that the reported reductions of average speed reported, compared to the ones from GTFS, are due to a higher number of transit lines considered as feasible and/or a greater waiting or walking time towards transit stops.

Unlike Fig. 5a, Fig. 5b shows that perceived and GTFS maximum speeds are about the same, since points are closer to the identity line, even if the speed from survey data is greater of about 2 km/h on average (t-test, p-value <0.001). This might indicate that people tend to adopt travel solutions (e.g. the best bus/tram line, transit stop near the destination, the shortest path to reach a transit stop) that minimize their travel time and, therefore, maximize the speed of their trips. Points associated to metro system are closer to the equity line rather than in the average case, since they are usually associated to high travel speeds. Moreover, also in this case, larger distances are associated with higher speeds both from survey data and GTFS data.

The analysis of critical cases at a spatial level are carried out considering the best travel solution that passengers might adopt, i.e. the connection with the maximum speeds. Differences between the maximum speed perceived on public transport and the one from GTFS are respectively mapped in Fig. 4a and Fig. 4b, where red colours show critical cases in which the real travel speed is less than the speed provided by the public transport system GTFS. By observing these two figures one can note that most of the zones have similar values of perceived and measured speed, indicating that in these frequent cases, people are able to plan their trip minimizing their travel time or they have a correct perception of travel time. This confirms that questions about daily trips in the survey were posed in such a way that users reported real travel time, not biased by their perception. In particular, respondents were asked to report their daily activities; therefore, instead of focusing on their trips, travel time was estimated as period between two subsequent activities, obtaining objective values not affected by travellers' perceptions. However observing Fig. 4, some zones are identified as critical. That might be caused by several factors. Respondents might have reported wrong time period of their activities. On the other hand, current local conditions (e.g. congestion) might reduce the speed with respect to the scheduled values by the public transport service. Otherwise travellers were unable to plan their trips on public transport (e.g. without adopting the transit line that minimize the travel time); this is more likely to happen when travellers have to connect among different transit lines (or modes, e.g. bus, metro and tram) missing some transits and, therefore, decreasing travel speed; because of that, zone 16, 17 (Fig. 4a and Fig. 4b) and 32 (Fig. 4b), which are along metro line, show low values of perceived accessibility.

5. Conclusions

In this paper active and passive accessibility are calculated using travel speed for both car and public transport, as selected travel modes for relevant urban trips. As principal research contribution, measured and perceived accessibility are estimated and compared. Measured accessibility is evaluated elaborating data of the scheduled public transport service (in GTFS standard), such as routes, stops and timetables. Perceived accessibility is estimated from attributes of real trips reported by respondents in a mobility survey, which are affected by subjective perceptions of travel. Results are aggregated at zonal level considering both average and maximum speed from zones.

The comparison is then performed for the case study of Turin using both dispersion diagrams at OD pairs level, and on the map, at zonal level (attraction and generation). In both the procedures, critical cases are evaluated without using a fixed threshold in terms of travel speed, because more tailored reference values can be estimated for the different zones, using the scheduled service. In particular, a trip is identified as critical if the perceived accessibility is lower than the measured one, because, users might improve their choice. Critical cases are pointed out also on the maps and this comparison indicates that travellers are usually able to perform their trip maximizing their speed. However, critical cases are identified also when travellers reported a biased travel time. In this case, they have no awareness of a better available travel alternative, or there is an experienced decreasing of the service provided by public transport. The proposed analysis is useful for practical applications to policy makers, who can evaluate accessibility though clear indicators and identify critical cases to target specific interventions. These cases are defined though real data, providing sound basis to improve underperforming scenarios.

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References

Cascetta, E., Cartenì, A., Montanino, M., 2016. A behavioral model of accessibility based on the number of available opportunities. J. Transp. Geogr. 51, 45–58. doi:10.1016/j.jtrangeo.2015.11.002

Ceccato, R., Diana, M., 2019. Substitution and complementarity patterns between traditional transport means and car sharing: a person and trip level analysis. Transportation (Amst). doi:10.1007/s11116-018-9901-8

Curl, A., Nelson, J.D., Anable, J., 2015. Same question, different answer: A comparison of GIS-based journey time accessibility with self-reported measures from the National Travel Survey in England. Comput. Environ. Urban Syst. 49, 86–97. doi:10.1016/j.compenvurbsys.2013.10.006

Deflorio, F., Zapata, H.D.G., Diana, M., 2017. Public transport resilience during emergency: A simulated case in torino. Transp. Infrastruct. Syst. - Proc. AIIT Int. Congr. Transp. Infrastruct. Syst. TIS 2017 689–696. doi:10.1201/9781315281896-90

Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: Review and research directions. J. Transp. Geogr. 12, 127–140. doi:10.1016/j.jtrangeo.2003.10.005

Hansen, W.G., 1959. How Accessibility Shapes Land Use. J. Am. Plan. Assoc. 25, 73–76. doi:10.1080/01944365908978307

Lättman, K., Olsson, L.E., Friman, M., 2018. A new approach to accessibility – Examining perceived accessibility in contrast to objectively measured accessibility in daily travel. Res. Transp. Econ. 69, 501–511. doi:10.1016/j.retrec.2018.06.002

Ryan, M., Lin, T. (Grace), Xia, J. (Cecilia), Robinson, T., 2016. Comparison of perceived and measured accessibility between different age groups and travel modes at Greenwood Station, Perth, Australia. Eur. J. Transp. Infrastruct. Res. 16, 406–423. doi:10.18757/ejtir.2016.16.2.3145

Thomas, T., Mondschein, A., Osman, T., Taylor, B.D., 2018. Not so fast? Examining neighborhood-level effects of traffic congestion on job access. Transp. Res. Part A Policy Pract. 113, 529–541. doi:10.1016/j.tra.2018.04.015