International Transport Forum

How Equitable is Access to Opportunities and Basic Services Considering the Impact of the Level of Service?

The Case of Santiago, Chile

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OECD

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Acknowledgements

Abstract

Cities face the daily challenge of providing people with access to different activities through their public transport systems. Despite its importance, there is little research on accessibility that focuses on the use of this mode and even less accounting for the impact of level of service (i.e. travel time, waiting time, reliability, comfort and transfers). Thus, the aim of this paper is to propose a methodology to determine how access to opportunities and basic services through public transport systems is distributed in cities, and how the perceived level of service decreases or accentuates the existing gaps.

Three indicators are calculated for Santiago based on data from public transport operations, smart card validations and georeferenced information: walking accessibility to public transport stops considering the quality of urban furniture, safety and environment; connectivity provided by the system in each area to the rest of the city considering the level of service through a measure of generalised time (in-vehicle time); and a measure of attractiveness of the destinations, based on number of trips attracted by purpose. The methodology is applied to a case study in Santiago, a highly unequal and segregated city.

The results show that the accessibility gap between disadvantaged areas and more wealthy neighborhoods of the city increases if the user's perception of level of service for public transport is considered. We show that the three proposed indicators provide different dimensions of accessibility suggesting how and where to intervene to effectively improve equity. Thus, the indicators could be used to assist the prioritisation and focus of investment plans, the design process of urban policies or transport infrastructure and become a key input for planners and decision-makers.

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Introduction

The spatial gap between the activities that people do and their homes generates travel needs and therefore demand for transport, which in turn influences the land use system and activities distribution. Hence, while this distance exists, accessibility, understood as how easily you can reach an activity from one location using a particular transport mode (Dalvi and Martin, 1976), is and will remain as a central focus of transportation research (Martellato and Nijkamp, 1998).

However, conventional transportation planning has generally focused more on mobility and the physical journey, related to number of trips, distance and speed. This approach is more concerned about mass transport (how to move the most people efficiently) than social transport, which focuses on people's accessibility (Betts, 2007). The latter approach is particularly relevant because, in urban settlements, lack of access to transport can mean a lack of opportunities for work, study, recreation and social interaction, which can profoundly impact people's quality of life and development (Lucas, 2006).

The main objective of cities should be smart growth, with emphasis on equity, non-motorised modes and public transport (Litman, 2003), especially considering that the majority of population with the greatest needs is captive of this system by not having a car available. Despite its importance, Martin et al. (2002) and Mavoa et al. (2012) note that there is little and limited research on public transport accessibility.

In addition, Lei and Church (2010) show that most studies on this subject are focused only on proximity to public transport stops (physical accessibility), regardless of quality of urban furniture, urban environment and quality of public transport services. This last point is vital because, as expressed Lucas et al. (2016), there is an urgent need to consider the quality of service in people's travel experience in public transport and non-motorised modes.

Thus, the main objective of this work is to develop accessibility measures accounting for quality of service. We compare traditional accessibility measures – that consider only travel time or an impedance measure composed by different level of service variables with the same weight - with a new approach based on disaggregated indicators that also take into account urban environment and level of service impact in time perception and trip quality. A secondary objective is to use Santiago de Chile as a test field for the proposed measures, i.e. to study how Santiago's public transport system meets the need for access to opportunities and basic services.

The accessibility indicators proposed here could be used to assist the prioritisation and focus of investment plans, the design process of urban policies or transport infrastructure and become a key input for planners and decision-makers. Thus, this work attempts to contribute to the equitable development of the city, achieving the levels of accessibility and connectivity needed for social and economic development and reducing inequality gaps.

The paper is organized as follows: Section 2 provides contextualisation of Santiago in terms of segregation, equity, mobility and access. Section 3 shows a brief literature review about accessibility measures and proposes three accessibility indicators: 1) accessibility to public transport stops taking into account the quality of urban furniture, safety and environment; 2) connectivity provided by the system in each area considering the level of service (travel time, waiting time, reliability, comfort and transfers)

through a measure of generalized (in-vehicle time) and; 3) a measure of attractiveness of the destinations, based on number of trips attracted by purpose. Section 4 show results for the application of these three accessibility indicators to the case study of Santiago. Finally, Section 5 analyses and discusses the results in terms of land use and transport planning and equity, ending with some conclusions and recommendations about project-prioritization and public investment.

Context: Santiago, Chile

Santiago is the capital of Chile and its largest metropolitan region. It has a population of over 6 million people within an area of approximately 640 km^2. This section addresses Santiago's significant social segregation, land use and inequality problems. It also provides an overview of its public transport system and the evolution of its modal share.

Land use, segregation and inequality

Santiago suffers from a high socioeconomic residential segregation and income inequality. This is not surprising since Chile has one of the highest Gini coefficient within OECD countries; the income ratio between the wealthiest and poorest 10% in the country is 26 (OECD, 2015), while 9.2% of the population still lives below the poverty line (MDS, 2013).

The high-income elite in Santiago lives in its north-eastern area (Rodriguez, 2008). In the last decades, this area has grown much faster than the rest of the city, attracting productive activities, commerce and services. As shown in Figure 1 it has become an extension of the historic business district located in the centre of the city. Due to weak planning instruments and a lack of integrated land use and transport planning, the activity centre has moved chasing higher-income households (and their purchase power).

Figure 1. **Activity centre evolution.**
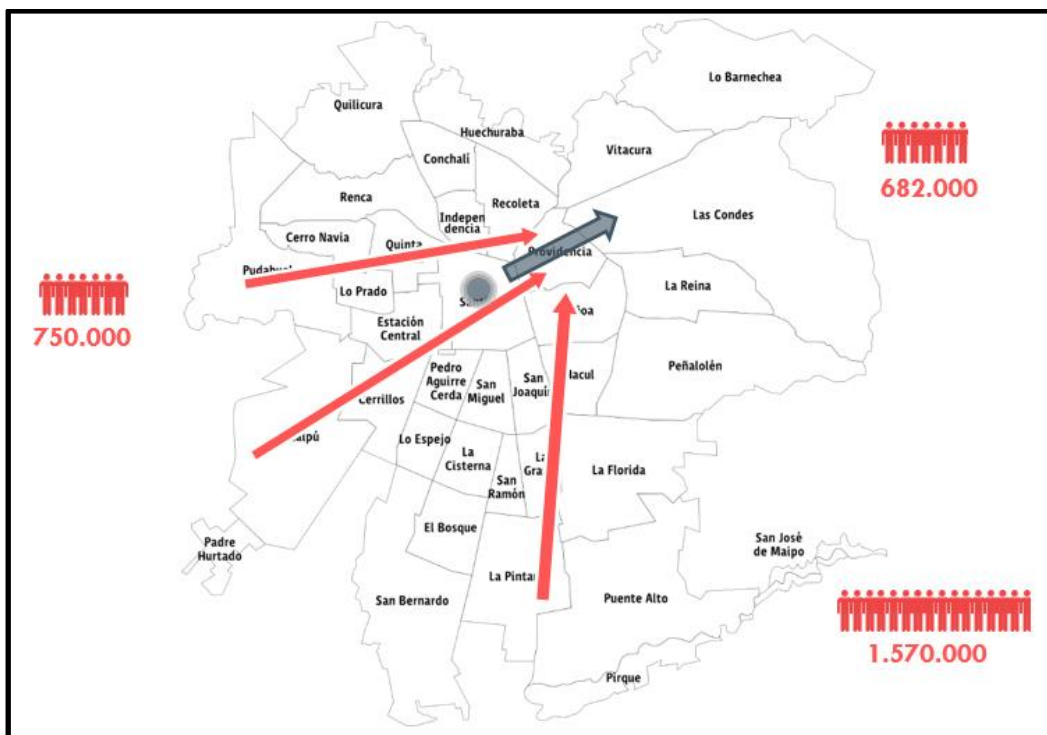
Note: In 1970 it was located in the historical city centre (Santiago) and it has moved towards Providencia and Las Condes. This affects the, much larger, lower-income population by forcing longer trips

This evolution has affected the low-income population, especially those living in the periphery. Until the 1980s, Santiago had several slums, conveniently located near the centre of the city. As a strategy to eliminate slums, their inhabitants were offered social houses, mostly located in the periphery of Santiago. The growth and expansion of the city concentrated in these "bedroom communes" that lacked the diversity and quality of job and study opportunities offered in their former locations. A large part of the low-income population still lives in these areas, which require long commutes. Rodriguez (2008) notes that this pattern of numerous trips from poor communes (usually peripheral) to business centres (downtown and high-income areas) is common in Latin American metropolitan cities

This phenomenon is clearly observable in Santiago forcing a significant portion of the low-income population to travel long distances. Not surprisingly, Santiago has increased its car ownership over time, but this increment is not equally distributed: 59% of households do not have access to a car and are still captive public transport users. Figure 2 shows the evolution of cars per household between 1991 and 2012, and the large car ownership gap between high-income and low-income households.

Figure 2. **Car ownership in Santiago**
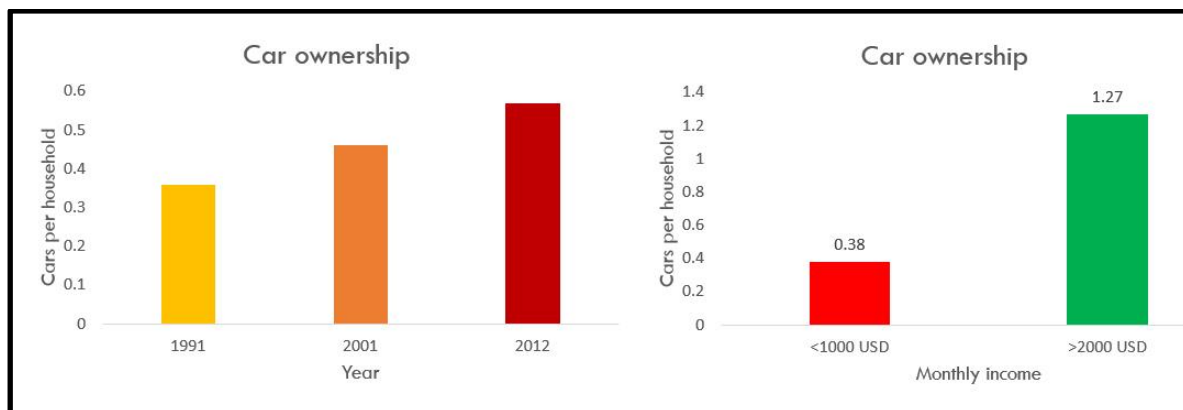
Note: Evolution (left) and current distribution according to income (right). 16% of households have monthly household income above USD 2 000 while 23% is below USD 1 000

Source: Own elaboration, based on SECTRA (2015).

This urban context has important consequences in accessibility and mobility. Travel time from low-income communes has increased due to their peripheral location (Sabatini et al., 2001; Rodriguez, 2008) and due to trips that have grown in length. This impoverishes the accessibility of this group to activities and urban services. As an important example, take accessibility to employment: the eastern sector of the city is privileged due to a high concentration of jobs. A clear correlation between income and proximity between workplaces and homes becomes evident (Figure 3). This generates a big impact in terms of equity and social exclusion (Hidalgo, 2007; Rivera, 2012) and a situation that is hard to overcome just by improving the transport system.

Figure 3. **Income distribution in Santiago (left) and accessibility to employment using public transport (2012) (right).**
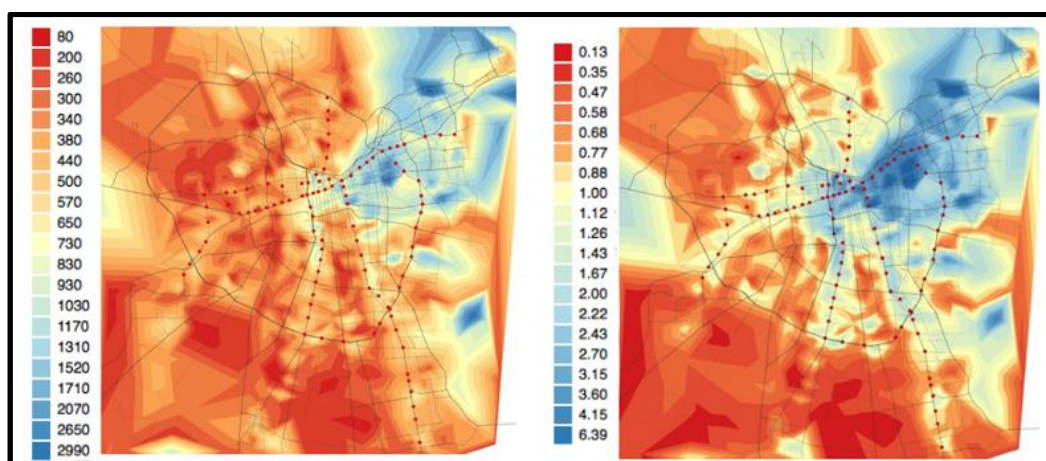
Note: The map uses a standard measure, which depends on the number of opportunities and the generalised travel cost

Source: Niehaus et al. (2015).

Since Santiago does not have a metropolitan authority to ensure a coherent development of the city, the prospect is not promising. Actually, each of the 37 communes has its own mayor, budget and regulations, making land use regulation something than can be easily changed and creating incentives to

attract business activities to its niche. Also, this has consequences in transport infrastructure, as public transport users do not necessarily vote in their destination communes, generating little continuity of the basic transport structure (such as bike paths or public transport corridors).Additionally, there are loose requirements for new real estate developments in general and social housing in particular. Table 1 describes the set of accessibility conditions a housing units project must fulfil to benefit from social housing subsidies. These conditions not only ignore access to job opportunities, but also are insensitive to the quality and capacity of the services being considered (e.g. a school within 1 000 metres becomes useless for the new inhabitants if it is already at its capacity).

Table 1. **Conditions for a housing units project to benefit from social housing subsidies**

Basic service	Condition
Education	Less than 1 000 meters
Health	Less than 2 500 meters
Public transport	Less than 500 meters
Work, public spaces and other services	No conditions

Source: MINVU (2012).

Thus, the regulation in Santiago is quite weak in terms of integrating land use and transport needs. As will be shown in this paper, this gap affects accessibility to different types of opportunities in different areas of the city. To provide a context of the transport system in Santiago, the next section describes the evolution of its public transport system and modal split.

Transantiago and modal share evolution

Public transport in Santiago experienced significant changes during the last decade. Until 2007 the bus system consisted in the semi-formal "Micros Amarillas" (Yellow Buses), with atomised bus property, no fare integration, intense service overlap on the main arteries of the city (meaning more congestion), high accident rates and being overall perceived as one of the worst city services by the population (Diaz et al., 2006).

In 2007 a new city-wide public transport system was implemented, named Transantiago, which aimed to improve operator regulation, eliminate competition for passengers on the streets and reduce the number of accidents and environmental externalities, among other goals.

However, after its inauguration, the system had very serious problems affecting users directly in the quality of their trips. In addition, a significant financial deficit started to grow. Even though quality of service later improved, most citizens in Santiago consider Transantiago a failure (Muñoz and Gschwender, 2008; Muñoz et al., 2014). An important part of this failure had to do with the overnight operational start for the whole system (or "big bang" implementation), not leaving enough time to allow users to adapt to the new smart-card payment and trunk-feeder structure. There were also poorly designed contracts for the operators, who did not have strong enough incentives to comply with the required frequencies and headway regularity. Additionally, a significant part of the infrastructure (mainly BRT-type corridors and exclusive lanes) was not built at the time the system started operating.

This brought important consequences. Between 2001 and 2012, the use of public transport in Santiago decreased (even though public transport share has been declining systematically for decades). Although some of this drop probably happened before 2007, it is reasonable to associate it to Transantiago not providing the level of service necessary to attract users and to the bad image acquired during its first months of operation. The share of walking trips decreased while car trips increased by 5% (see Figure 4), although it is hard to tell if this is a direct consequence of Transantiago's implementation. Cycling increased significantly, mostly in high-income areas where it was almost non-existent. This increment is probably due to the low service of Transantiago and the increasing congestion in that part of the city where car ownership is the highest.

Figure 4. **Modal share evolution in Santiago, Chile**
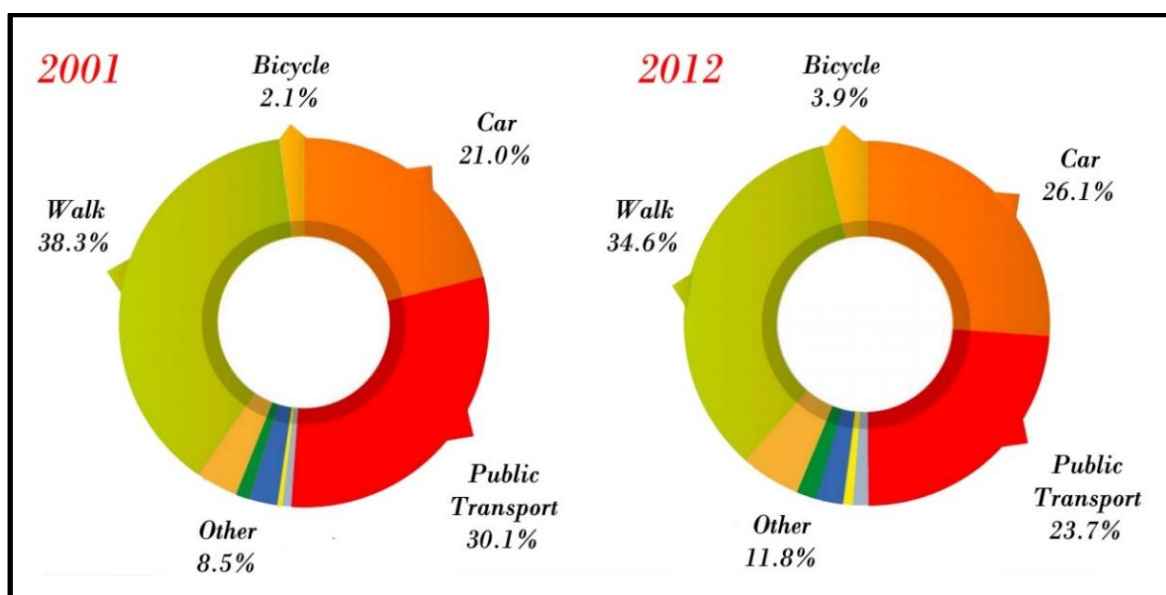
Source: SECTRA (2015).

Nevertheless, not everything brought by the new system was bad. Before Transantiago, Metro (the subway system) was underutilised, serving mainly those living next to Metro stations or those who could pay double fares (mainly middle and high-income segments). Currently, Santiago's Metro network has 103 km, and is used intensively thanks to the integrated fare and a bus system that feeds it, which has allowed greater coverage (see Figure 5). In the following sections, we review accessibility measures used in the literature and propose ways to translate this coverage into an index accounting for urban space quality and the level of service of public transport.

Figure 5. **Santiago's public transport network**
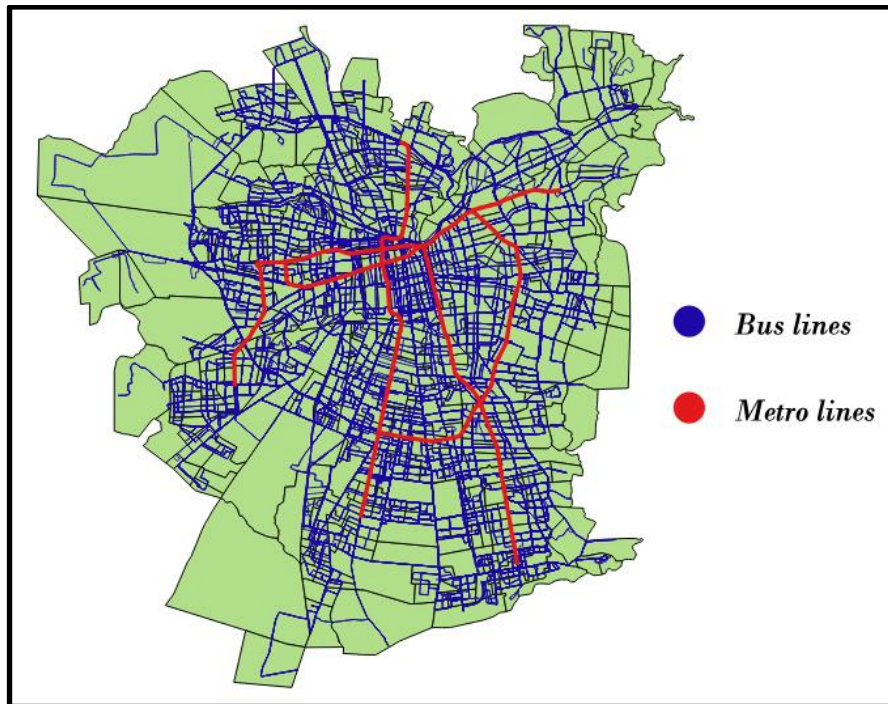
Source: Own elaboration, based on DTPM (2016).

Accessibility measures

A large number of different measures for accessibility, defined as the potential to reach opportunities that are spatially dispersed, have been proposed in the literature and used to address important questions of policy and planning (Páez et al., 2012). According to Geurs and Van Wee (2004), there are four types of accessibility measures:

- based on infrastructure, where infrastructure level of service is analysed (e.g., congestion and average speed in a transport network) (AVV, 2000; DETR, 2000);

- based on location, which describes accessibility to activities from given locations (e.g., potential, isochrones, adapted-potential) (Ingram, 1971; Van Wee et al., 2001);

- based on the person, taking into account personal differences and time restrictions (based on Hägerstraand's space-time geography) (Kwan, 1998; Neutens et al., 2008);

- based on utility, related to economic benefits from accessibility (e.g. balancing factor benefit and logsum benefit measures) (Martinez, 1995; De Jong et al., 2007).

Most of these accessibility measures have two parts: a transport component depending on distance, travel time and/or cost, and a component related to activities, which should describe how attractive each destination is for performing an activity like, for example, the quantity or quality of the opportunities or facilities to perform the activity (Burns, 1979; Koenig, 1980; Handy and Niemeier, 1997).

We propose using a measure based on location, specifically Potential Accessibility measures, also known as Gravitational Accessibility, proposed originally by Hansen (1959) and Ingram (1971). These measurements consider all possible destinations (weighted by their importance) and use an "impedance function" within the indicator, making the accessibility decay with the distance, cost or travel time. Despite not being as easy to interpret and communicate as the (much more popular) isochronous measures, they allow to evaluate the combined effects of transportation and land use, without imposing an arbitrary threshold for distance or time in which all destinations are equally attractive. Furthermore, this type of accessibility measure is appropriate as a social indicator when used to analyse the level of access for different socioeconomic groups (Geurs and van Wee, 2004).

Despite the abundant research in accessibility measures, there is little literature evaluating accessibility, mobility and connectivity by public transport considering the perspective of the users (Cheng and Chen, 2015). One of the most relevant elements to consider should be user perceptions regarding quality of service. Therefore, we propose to build three indicators to analyse access by public transport on an unbundled basis.

- Physical Accessibility Index (PAI): Access to public transport stops taking into account a proxy of walking quality (Cheng and Chen, 2015). We analyse the quality of urban furniture, safety and environment.

- Public Transport Index (PTI): Connectivity provided by the system based on public transport zonification of the city accounting for perception of travel time, waiting time, reliability, comfort and transfers, i.e., different weights for each variable within generalised travel time.

- Attractiveness Land Use Index (ALUI): Attractiveness of the destinations, based on number of trips that each area attracts by basic purposes, i.e., work, education, health, recreation and shopping (SECTRA, 2015).

The methodological details of each indicator are described next, including a discussion on how they contribute to a better and more complete analysis of city fairness in terms of access to opportunities and basic services.

Physical Accessibility Index (PAI)

Calculating walking accessibility to public transport stops requires defining various elements: accessibility functional form, level of disaggregation of the city, walking speed and finally, how to measure the travel quality during this stage.

As we pointed out before, this paper uses measures based on location, specifically based on potential or gravity. These measurements use the decay of accessibility based on a parameter of resistance and can overcome the arbitrariness of the isochronous measures where there are no objective conventions to define neither thresholds nor the ability to assess the opportunity based on their proximity, since everything located within the isochrones limits is considered equally attractive and accessible (Geurs and van Wee, 2004). We propose to use the indicator described in equation (1):

$$A_i = \sum_{j \in \varphi} F\left(\frac{d_{ij}}{v}\right) \qquad (1)$$

Where i is localisation (origin) and j corresponds to public transport stops. Meanwhile, φ is the set of 10 public transport stops closest to i and $F\left(\frac{d_{ij}}{v}\right)$ corresponds to impedance function, which depends on the distance d_{ij} and average walking speed v. For simplicity, we use Euclidean distances and a conservative value for the speed of 3.6 km/hr v. Since the actual distance that users experience when walking through the network is greater than the Euclidean distance, a correction factor that varies between 1.2 and 1.35 based on five values reported by Gonçalves et al. (2014) is applied to d_{ij}.

Most studies use Power, Gaussian, Logistic or Negative Exponential impedance functions (Handy and Niemeier, 1997). However, the literature generally puts little attention on the functional form and on how it relates to actual human behaviour. In this work, we use the Richards Function, tested by Martinez and Viegas (2013), similar to a Logistic function (see equation 2).

$$F\left(\frac{d_{ij}}{v}\right) = \frac{1}{\left(1 + Qe^{-B\left(\frac{d_{ij}}{v}-M\right)}\right)^{\frac{1}{V}}} \qquad (2)$$

where B is the growth rate,

V affects near which asymptote growth occurs,

Q depends on the value F(0),

M is the time of the maximum growth

Figure 6 displays graphs of the Negative Exponential and Richard functions. Martínez and Viegas (2013) argue that the second one represent better people's perceptions by softening accessibility decay for low travel times. To calibrate and set the maximum threshold walk to public transport we use information from origin destination surveys in Santiago (SECTRA, 2015).

Figure 6. **Differences between accessibility impedance functions: Richards and Negative Exponential**
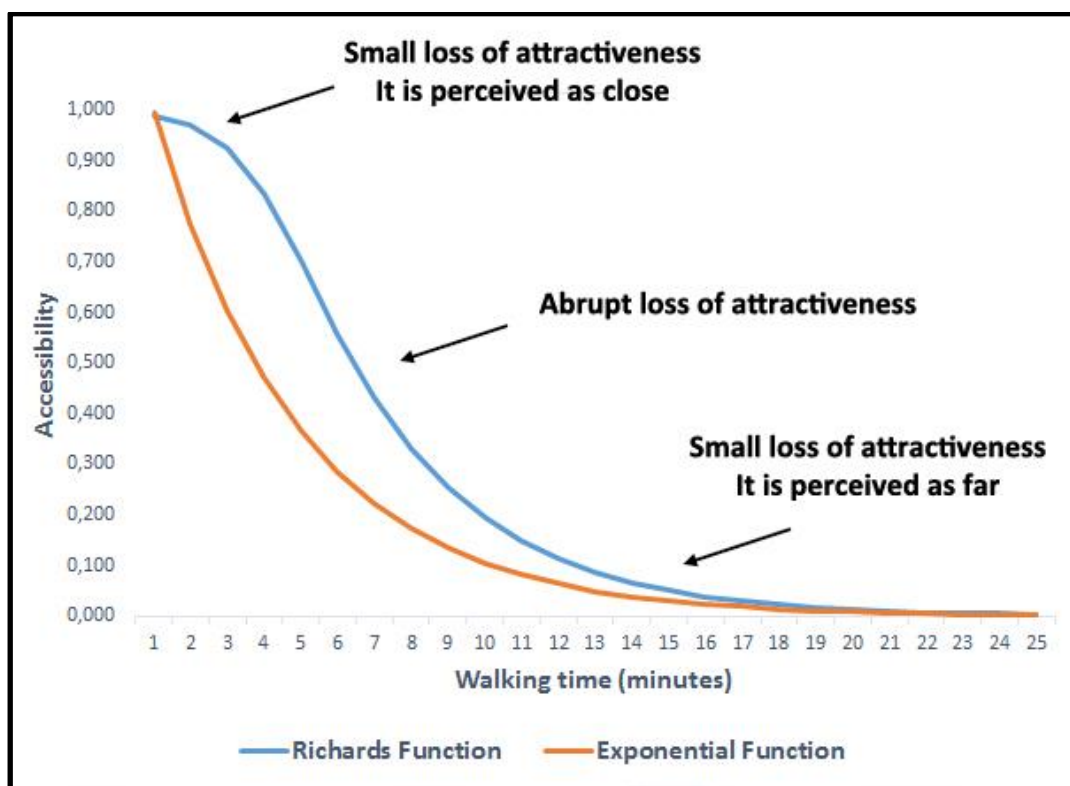
Source: Own elaboration, based on Martinez and Viegas (2013).

PAI has its maximum value (1) when travel time is 0-1 minutes because the opportunity or service is adjacent to the origin. Using the proposed method by Mamun et al. (2013), we observe that 95% of public transport users walk less than 15 minutes to their initial stop, so we define an access value of 0.05 for 15-minute walk. Using the same methodology, we define an access value of 0.2 and 0.7 for 10-minute and 5-minute walk respectively. The parameters obtained based on this calibration are shown in Table 1.

Table 1. **Estimated parameters of Richard impedance function**

Parameters
Q = 5,49 E-05
B = -1,09
M = -5,09
v = 4,02

Regarding disaggregation of the city, we use 804 zones that the Metropolitan Public Transport Directory (the entity that manages and regulates Transantiago) regularly works with. These zones are small enough to avoid spatial aggregation errors and to allow us to calculate accessibility based on relatively homogeneous locations.

To obtain a measure of the level of service while walking, we used georeferenced information of Santiago pre-census (INE, 2011). In this data, each city block is evaluated by a group of trained surveyors who rate several aspects of public space using a binary scale with 1 meaning the presence of the element and 0 meaning lack of the element.

Two particular aspects (sidewalk and street quality) are rated with a scale of 1 to 5, with 1 meaning poor conditions and 5 meaning excellent conditions. Based on this, and grouping elements according to their similarity or affinity, four indexes were created, which together form the Environment and Urban Quality Index (EUQI) described in Table 2.

The aggregate EUQI values range between 2 and 19 and are analysed as a complementary indicator of accessibility. Traditional accessibility indicators only considering walking time between locations and public transport stops seems insufficient since it ignores, for example, how safe or comfortable this walk may be.

Table 2. **Components of EUQI and his values**

Index	Components	Range of values
Security/safety	Luminary, road signs and roofed bus stops	0 to 3
Environment	Gardens, seats, sport fields and playground	0 to 4
Cleanness	Garbage bins and rubble	0 to 2
Infrastructure	Sidewalks and streets quality	2 to 10

Public Transport Index (PTI)

To calculate this component, we use the same functional form from the Physical Accessibility Index (see equation 1), but instead of considering just the walking time from each origin to the closest bus stops and/or subway stations, we account for the total (perceived) generalised travel time experienced by the user from the initial station or stop to the final one. Thus, to calculate the connectivity and level of service provided by public transport, we incorporate frequency, regularity, travel time, transfers and comfort experienced on the trip. This requires information about system operation and data from smart card validations.

To analyse what is the impact of using this type of accessibility measure compared to traditional indicators (which usually ignore different travel components such as walking and waiting time or do not distinguish it from in-vehicle travel time), we use a generalised time function to account for different dimensions of the level of service, disaggregating trip components and transforming them into equivalent

in-vehicle time (IVT) units (Wardman, 2001). Each component has a different weight based on user's perception.

For example, it is not the same to travel for 20 minutes sitting than to do so standing in a context of five passengers per square meter, and it is not equivalent to wait and walk 10 minutes in a 20-minute trip than to spend the whole 20 minutes travelling in the vehicle. Table 3 shows travel components considered in this study, how we measure them and the IVT equivalence we give them.

Table 3. **Level of service attributes considered in the accessibility indicator.**

Component	Measure	Equivalency (IVT)	Source
Waiting time (for a frequency f_c and a headway coefficient of variation CV)	$\frac{1}{2f_c}(1 + CV^2)$: expected waiting time including regularity	Multiplicator: 1.6 times (average in UK studies)	Marguier and Ceder, 1984; Wardman, 2001
Travel time	Tv_{p90}: 90th percentile travel time to introduce reliability impacts.	Unit of measurement is IVT	Chen et al., 2003; Pu (2011)
Transfers	Number of transfers	Penalty: 2 to 22 minutes depending on transfer conditions	Currie, 2005; Raveau et al., 2014
Comfort	$\frac{pax}{m^2}$: passenger density inside Metro/bus	Travel time is multiplied by a value between 1 and 2.2, depending on crowding level	Whelan and Crockett, 2009; Tirachini et al., 2013; Batarce et al., 2015

Reported values show that crowding, unreliability and transfers are highly penalised by users. The multipliers and penalties from Table 3 are used to calculate an equivalent in vehicle time (IVT) between each origin destination pair of stops, t_{ij}. We use them to build a functional form for the proposed access measure as follows:

$$C_i = \sum_{j \,\in\, \varphi} \sum_{l \,\in\, \emptyset} F_{ij}(t_{ij}) \cdot C_{ijl} \qquad (3)$$

In which:

ij corresponds to each origin destination pair of public transport stops

φ is the set of all public transport stops

$\emptyset$ is the set of all bus services, subway services or combination of both

$C_{ijl}: \begin{cases} 1 \text{ if there is a bus service, subway line or combination l that connects i with j} \\ 0 \text{ otherwise} \end{cases}$

and $F_{ij}(t_{ij})$ corresponds to the impedance function introduced in Equation 2.

Attractiveness Land Use Index (ALUI)

Finally, we want to identify the quantity and quality of opportunities and services that can be accessed from a given location. For this we use a methodology inspired on London's case (Cooper et al., 2009), which develops an indicator that measures access to opportunities and essential services (ATOS) by public transport or walk. For this work, we use the number of trips that attracts each transport area by travel purpose (work, education, health, personal visits, recreation and shopping, represented by W_j, E_j, H_j, R_j, V_j and S_j divided by the maximum number of trips attracted by a zone to generate a relative attractiveness measure (Equation 4).

$$ALUI_j = \frac{O_j}{max(O_{j\in\varphi})} \quad j \in \varphi \tag{4}$$

$$O_j = W_j, E_j, H_j, R_j, S_j \text{ or } V_j$$

This indicator complements the indicators presented before. Furthermore, we use it as a weight in (Equation 3) representing the attractiveness per purpose of each area to visit (Equation 5). If an area has basic services and valuable opportunities, its accessibility indicator should have more weight, while accessibility to a place that has no major attractions, should have no utility for the user.

$$C'_i = \sum_{j \in \varphi} \sum_{l \in \emptyset} F_{ij}(t_{ij}) \cdot C_{ijl} \cdot ALUI_j \tag{5}$$

Case study

The motivation for this exercise is to show the impact of considering the level of service and walking quality on accessibility analysis. Traditional accessibility analysis usually considers only physical accessibility, or equal weight for on-board, waiting and walking time, and does not consider comfort, reliability, regularity and number of transfers.

To show the differences in terms of accessibility and level of service, we analysed a trip to a destination in Santiago's CBD attracting 17.3% of the trips (SECTRA, 2015), concentrating employment, study, health and shopping opportunities. The idea is to compare the three proposed indicators for trips to this destination coming from two communes of different income levels: Las Condes (USD 3 260 per month per household on average) and San Miguel (USD 1 480 per month per household). Both trips include an initial walk and involve the Metro, as described in Figure 7.

Figure 7. **Route from San Miguel (left) and from Las Condes (right) to Santiago Centro through walk and Metro (Line 2 and Line 1, respectively)**
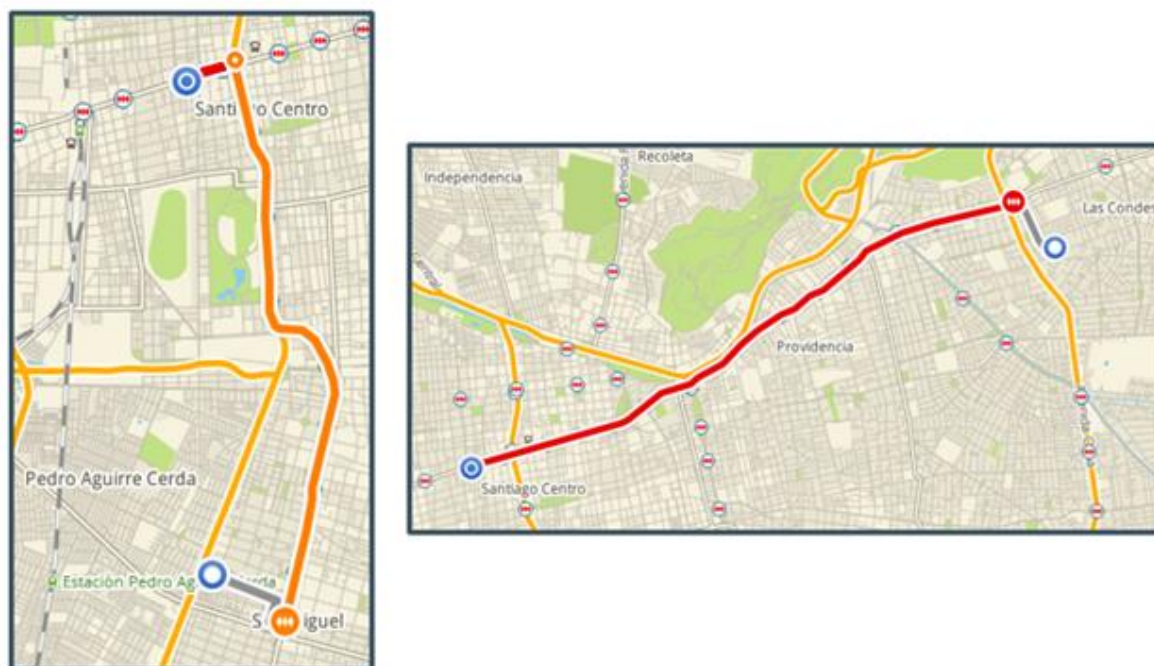
Source: 2GIS (2016))

PAI results

Santiago offers short walking times to public transport stops for most parts of the city. This is consistent with the perception of closeness to public transport reported by 85% of the population of the 35 communes analysed in this study (MINVU, 2010). The nearly 12 000 bus stops in Santiago are part of an extensive network that achieves wide coverage in various sectors, especially in the downtown area.

Figures 8 shows PAI values for Santiago and the case study communes of San Miguel, Santiago and Las Condes. As we can see, better PAI is concentrated on the city centre. Las Condes, one of the richest parts of the city, does not have great coverage of public transport despite concentrating a large number of service jobs that are usually performed by captive public transport users who live far from this commune.

Figure 8. **PAI results.**
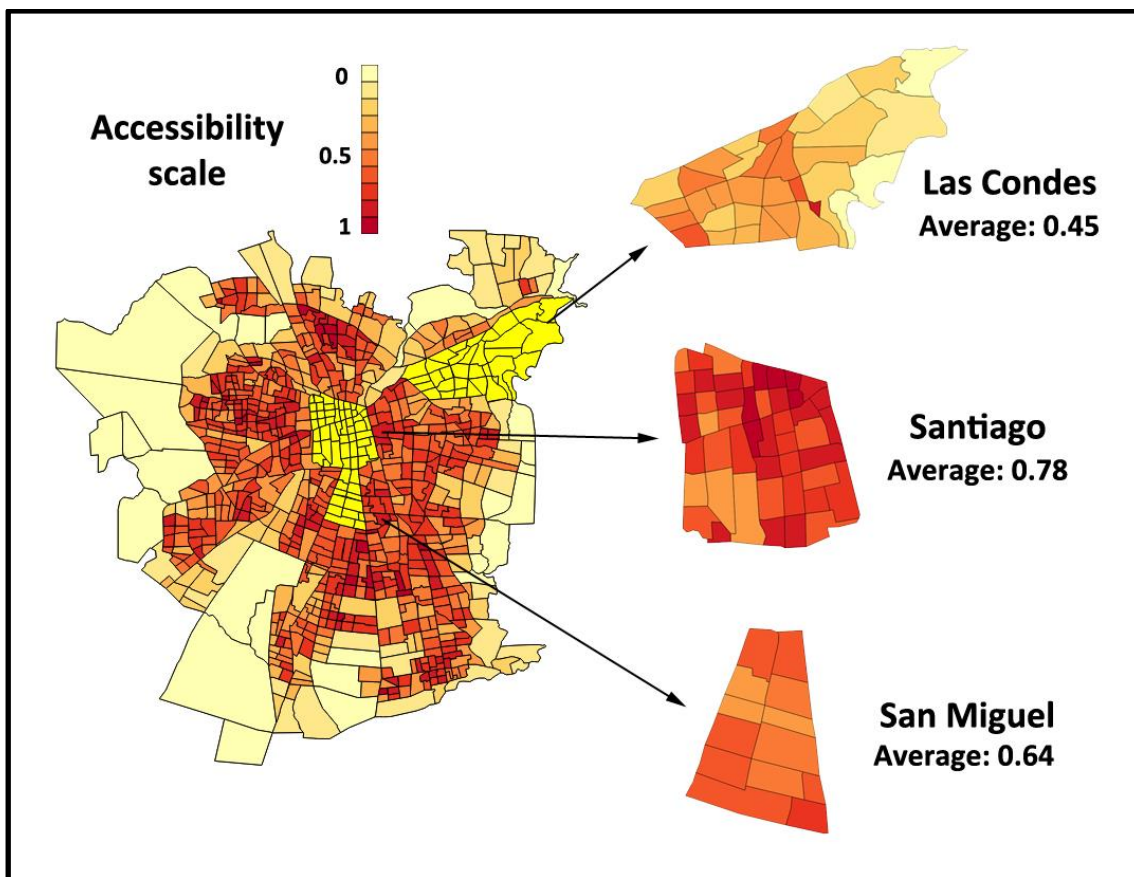
Note: Richards function and v = 3.6 km / hr are used. Scale: 0 (35 minutes on average to 10 nearest stops) to 1 (4 minutes on average to 10 nearest stops). The values are normalized based on the maximum value of access (8.53 of a possible 10 if the location had accessibility 1 to 10 stops nearest).

Meanwhile, Figure 9 shows EUQI values for Santiago and case study communes. As expected, better EUQI is concentrated in the eastern sector of the city, corresponding to the high-income area. Thus, although San Miguel has better accessibility and greater public transport modal share than Las Condes (27% vs. 18% based on SECTRA (2015)), the latter has a better standard of urban environment (EUQI) access on the walk. One of the main reasons for this gap is the municipal expenditure per inhabitant per year (USD 562.8 in Las Condes and USD 182.9 in San Miguel) and the financial independence of each commune.

Figure 9. **EUQI results.**
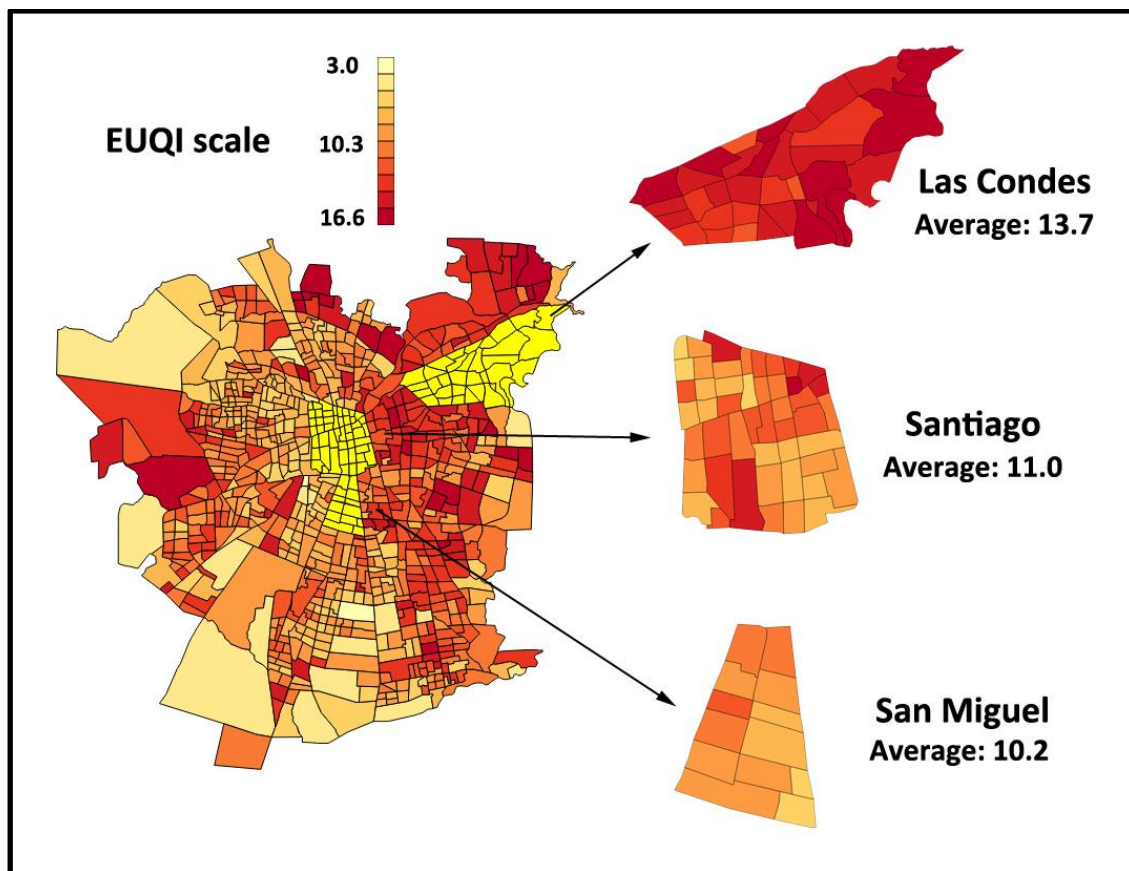
Note: Map is constructed using information from INE (2011), with a maximum value of 19 (see Table 2 for more details). We observed that north-eastern areas of the city have a better environment and urban quality, follow by city centre (12.05 score on average, compared to 10.07 from north, south and west sectors).

It is possible to observe that inequality does not only occur between the communes of the case study. Santiago's north-west and south-west sectors have low levels of accessibility to public transport stops and, at the same time, an inferior EUQI. This shows that despite the significant increment in the number of bus stops in Santiago in recent years, this may not be enough. Focus should be placed not only on quantity but also on quality of public spaces around public transport stops.

PTI results

To compute this indicator we calculate a generalised time measure. We want this measure to account not only for travel time, but also transfers, comfort, reliability and regularity. For example, if we account only for in-vehicle travel time, trips to the centre of Santiago look like Figure 10.

Figure 10. **Total travel times (not including walking, transfers and waiting times) to Santiago Centro (Morning peak, April 2013).**
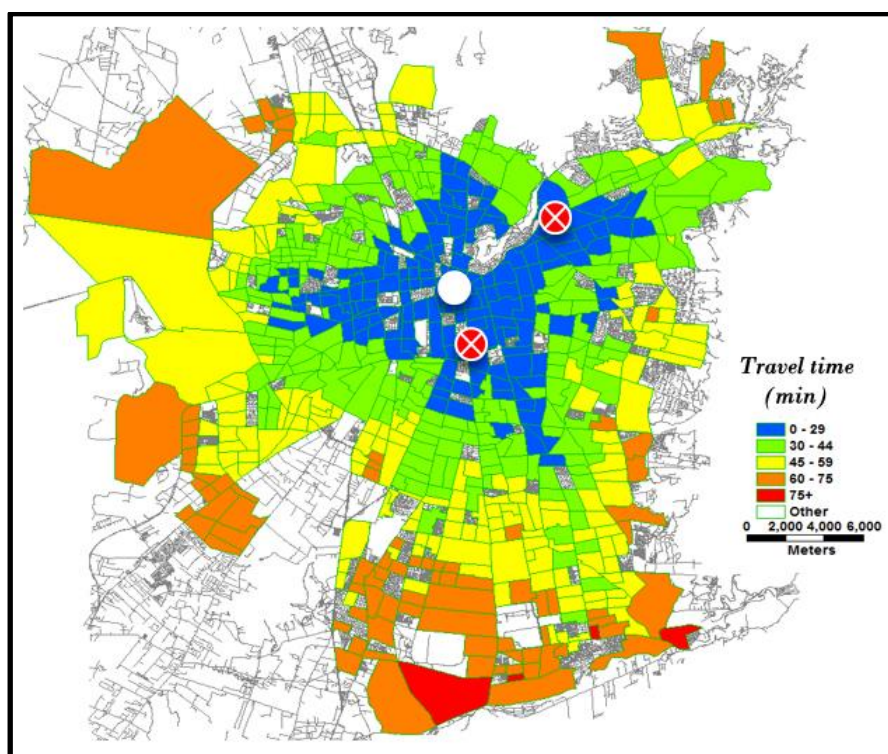
Note: Red circles with crosses represent starting locations for the case study trips to Santiago Centro (white dot).

Source: DTPM (2013)

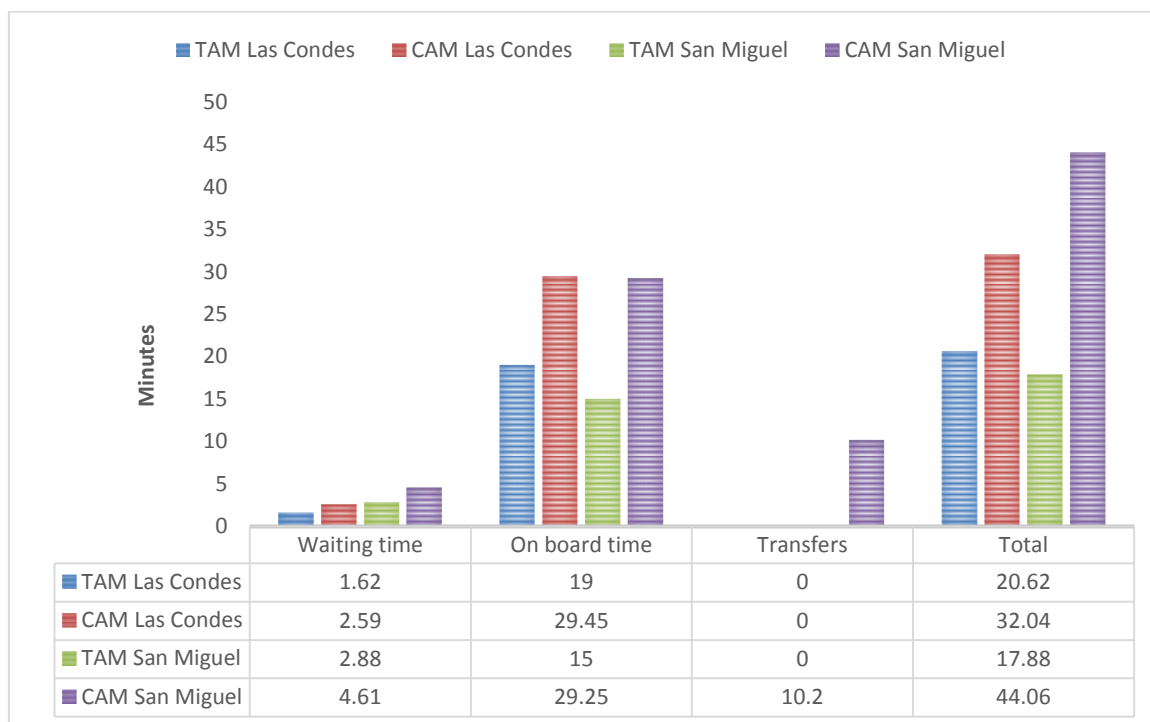To account for comfort we need a measurement of crowding. Available data (Metro S.A., 2015) describes observed in-vehicle passenger density for trains in each metro line at rush hour (8:15 and 8:30 a.m.). In the case of the trip from Las Condes, the user must travel 14 stations experimenting an average density of 3.28 pax/m^2, meanwhile the trip from San Miguel must travel seven stations on Line 2, experimenting a density of 5.68 pax/m^2. Using crowding multipliers from Tirachini (2015) for standing conditions on the Metro subway system, on board travel time must be multiplied by 1.55 and 1.95 respectively to incorporate user perception.

Regarding waiting time, we used headway information from April 2015 (Metro S.A., 2015). Thus, it was possible to incorporate the headway regularity on user's average waiting time. We used a 1.6 factor from Wardman (2001) to transform waiting time to IVT. In addition, we consider a transfer penalisation from Raveau et al. (2014) for Metro subway system equivalent to 10.2 minutes with average conditions.

Figure 11 shows door-to-door time for our case study, comparing the Corrected Accessibility Measure (CAM) with a Traditional Accessibility Measure (TAM) based only on total travel time (formulation on Equation 3 is not calibrated for the entire city yet). The difference in the traditional measure between San Miguel and Las Condes is just 3.26 minutes but, if we account for the level of service, the difference increases to 22.3 minutes. This suggests that the real differences in accessibility levels of different locations can be significantly different when the new attributes are considered, negatively affecting lower income areas therefore having an important impact in equity of travel conditions.

Figure 11. **Door-to-door time in our case study**

	Waiting time	On board time	Transfers	Total
■ TAM Las Condes	1.62	19	0	20.62
■ CAM Las Condes	2.59	29.45	0	32.04
■ TAM San Miguel	2.88	15	0	17.88
■ CAM San Miguel	4.61	29.25	10.2	44.06

Note: If we consider the level of service perception Corrected Accessibility Measure (CAM), San Miguel increases their access time by 146% regarding Traditional Accessibility Measure (TAM), unlike the 55% from Las Condes. The difference lies mainly in transfer penalty and trip comfort, which has a bad perception from users and affects San Miguel's population.

ALUI results

Since this is just one case study, this example does not reveal the full accessibility to work or study from each starting point, as access to each transport zone is not considered. Since the case study focuses on morning peak hours of a working day, we will focus our analysis on accessibility to work and education, because more than 95% of trips made in this period have these purposes (SECTRA, 2015).

Employment and education attractiveness maps are shown on Figure 12. It is important to note that the maps only considers the number of trips attracted by purpose (SECTRA, 2015) and not the travel density, i.e. they are not corrected by the surface of each zone. We note that most attractive zones in terms of education and work are around the centre-east axis called "Alameda-Providencia", the most important avenue of Santiago. We observe that some peripheral locations also have high attractiveness to work, mainly due to industrial activity.

Figure 12. **Work attractiveness (left) and education attractiveness (right) using a normalised scale**
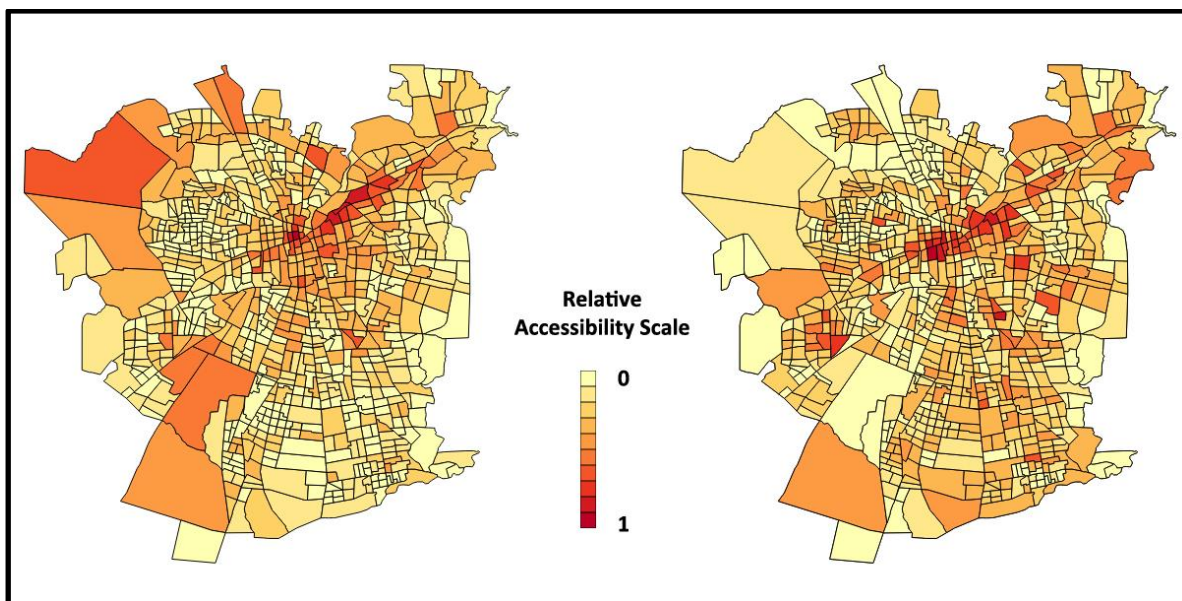
The República Metro station, the final location of our case study, is located on the city centre. The specific zone that includes this subway station has a 0.264 relative work attractiveness score, corresponding to the 26th most attractive area between a total of 804 transport zones. Meanwhile, this area corresponds to the largest attractor of study trips across the city, so good accessibility to this sector is crucial to increase educational opportunities given the existence of educational institutes, technical and training centres, universities and schools.

If we want to know how diverse this is zone in terms of opportunities, Shannon's equitability index is an option (TIEM, 2016) (between 0 and 1, with 1 being complete evenness). Although the predominant purposes are work and study with 83.5% of trips, visiting someone and make purchases account for more than 11.5% of the trips, resulting in a 0.645 index value.

It is clear that San Miguel needs to enhance comfort and transfer conditions during the trip, and walk quality in order to improve their access level. Meanwhile, Las Condes needs to increase their access to public transportation stops, because the commune has good public transport level of service and great walk quality. Therefore, this case study is useful to know what kind of measures apply for each particular area given their needs, which it is the main advantage of analysing each indicator separately.

Discussion, conclusions and future work

Santiago has developed and grown without strong land use policies during the last four decades. Lack of integrated land use and transport planning has generated urban segregation that has brought obvious inequalities in terms of access to services. High-income communes have greater proximity to sub-centres that concentrate activities and opportunities, and can provide better infrastructure and public

spaces given their budget. This, in turn, makes these communes even more attractive for the location of new activities (mostly commerce and services) and high-quality real estate developments, thus creating a vicious spiral of segregation and concentration of opportunities around high-income areas. One of the main problems with this urban development pattern is the increase in travel time for lower income people, who are usually located in the periphery and are more likely to be captive public transport users.

There is a clear need to improve this situation in Santiago, although this is not a simple problem to tackle. The issue can be approached from two main dimensions: land use and transportation. First, land use policies should focus on avoiding the excessive concentration of activities in high-income areas and on promoting the development of sub-centres that are well distributed across the territory. To achieve this, a metropolitan authority with a large-scale (and long-term) vision for the city and with attributions to define zonings and distribute communal budgets is needed. In addition, social housing policies should have stronger (and clearer) requirements in terms of accessibility to basic services and opportunities in order to improve the inequality gap. This is, however, not easy to define because excessive requirements, that would discourage development of social housing, should also be avoided.

Second, level of service of public transport and a walking quality to public transport stops should be improved. This paper addresses the aforementioned problem by proposing new and more detailed accessibility indicators and exploring their use as tools to inform decision-making and public transport planning.

Through three proposed indicators, we analyse walking distance to public transport links, the quality of the urban environment, the connectivity of the transport system, the level of service offered by it and the attractiveness of land use. The indicators allow us to identify areas that have greater needs and show where to focus policy efforts and/or infrastructure.

Therefore, the greatest challenge of this work is how to achieve integration and transition to public policy. It is urgent for urban planners and authorities to take care of the transport inequality problem in Santiago and to acknowledge that lack of access to opportunities can intensify this inequality, closely related to social exclusion. In addition to generating robust and rigorous accessibility indicators, these indexes must be able to be easily communicated to relevant authorities and stakeholders. Only in this way, planners and decision makers can use it as an input in transport plans, projects or policies.

In most welfare policies, efficiency and equity appear simultaneously as main objectives. However, there is a clear trade-off between these two objectives, therefore triggering lengthy discussions about how to integrate them in public policy (Le Grand, 1990; Thomopoulos et al., 2009). Murray and Davis (2001) suggest that there is a tendency to focus on issues of economic efficiency in spite of equity. This tendency is why investment and infrastructure priorities are usually determined using CBA methodologies rather than other methodologies, able to account for wider impacts. We suggest that in the case of transport policy and infrastructure projects, CBA is not enough and should be complemented with indicators of accessibility and equity, such as those proposed in this work.

One way to approach this was proposed by Martens et al. (2012), who suggests that the objective of the authorities should be to maximise the average individual accessibility of users, setting a minimum value, sufficient to ensure basic needs. Thus, we should prioritise projects that ensure vertical equity, defined by Litman (2015) as compensation for other social inequalities from different areas of life.

Accessibility and equity indicators should consider the quality of service of public transport and the environment, road network and street furniture. These variables allow us to measure real differences in terms of unequal access to opportunities. For this, we should consider these elements through a corrected measure as proposed, which takes into account the perception of transport users over traditional accessibility measures.

Future work will extend this case study to the entire city of Santiago, in particular the Public Transport Indicator, and analyse what kind of measure is advisable to perform first. This is an interesting question that needs to be addressed from two perspectives: impact and feasibility. It is important to identify which variables, if improved, will have the greatest impact and which are easier to implement. In other words, we propose to identify the actions with the best cost-to-effectiveness ratio. For example, improving transfer conditions of users could be a simpler measure to implement than reducing in-vehicle travel time and, maybe, perceived travel time can be greatly reduced with a relatively small investment in better transfer conditions.

Finally, it is important to address the issue of increase in car use, observable across several cities in Latin America. More and more people leave public transport and become car users, which is worrying from a sustainability point of view. This brings several challenges: first, investigate how to discourage car use to reduce negative externalities and, second, analyse the impact of this trend on the affordability of housing and transportation.

A low level of service in public transport and poor quality of public spaces may trigger a shift from public transport and walking towards the car. Focusing on improving access by public transport and discouraging car use should be a priority in public policy if we want to achieve more equitable cities in terms of access.

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