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Comparing the application of different justice theories in equity analysis of transit projects: A case study of the Lisbon Metro Circular Line

Julianno de Menezes Amorim
CiTUA, Instituto Superior Técnico
Universidade de Lisboa
julianno.amorim@tecnico.ulisboa.pt

João de Abreu e Silva
CERIS, Instituto Superior Técnico
Universidade de Lisboa
jabreu@tecnico.ulisboa.pt

Abstract: Although issues of equity and accessibility have already been addressed in transportation, especially with regard to the distribution of costs and benefits, there is no consensus on which concept and metric of fairness would be most appropriate for the evaluation of transportation infrastructure proposals. Normally, a utilitarian perspective is adopted, where issues of unequal distribution of costs and benefits are not the main focus. This paper aims to incorporate the assumptions of other justice theories, namely egalitarianism, communitarianism, and Capability Approach (CA), into the equity assessment of transportation infrastructures, and by doing so, pay closer attention to those who are less advantaged or more open to social exclusion. These theories are critically reviewed considering their contribution to the assessment of equity in terms of transportation infrastructure accessibility impacts. Based on the reviewed theories, accessibility indicators are built and used to assess the equity impacts of the Lisbon Metro expansion project. The findings support the importance of adding other justice perspectives to assessing transportation projects. The CA and Maximax support a need to establish minimum or acceptable distribution standards of accessibility. However, the results from the CA are strongly dependent on the assumptions as to the maximum acceptable travel times.

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1 Introduction

The main purpose of Public Transit (PT) is to provide publicly accessible mobility across specific parts of a city, and its efficiency is based on the number of transported passengers. PT is often more affordable than private cars and some social groups (e.g., students, the elderly, and low-income persons) make more use of collective modes (Rodrigue et al., 2017).

Providing access to different goods, services, activities, and employment is a basic requirement in contemporary cities, and may be directly related to social inclusion (Griffin & Sener, 2016; Lucas, 2012). For instance, in peripheral locations residents without access to a private car face isolation, or at the very least more restricted access to

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services and employment opportunities (Rodrigue et al., 2017). Accordingly, accessibility is an important indicator of quality of life.

A fair transportation system provides a sufficient level of accessibility to all in most circumstances (Martens, 2017). This perspective has important implications for equity in transportation provision. Transportation equity refers to the fair distribution of transportation outcomes across a specific space or sociodemographic groups (Di Ciommo & Shiftan, 2017). According to Di Ciommo and Shiftan (2017), the major goal of transportation policy and projects should be to improve access to transportation, as a prerequisite to improving accessibility to key activities.

Although equity is a fundamental concept in transportation policy, it can be relatively vague and, thus, susceptible to different interpretations. The assessment of transportation equity can be difficult because there are several definitions of equity, ways of categorizing people, impacts to consider, and ways to measure these impacts (Litman, 2018). Likewise, just as the concept of equity can be understood in a number of different ways, the same is true of a related concept, that of justice, for which there is no comprehensive definition (Kymlicka, 2001). The relationship between both concepts imply that the adoption of different justice theories will impact the way equity is perceived, measured, and assessed. Thus, both the adopted definition and measurement of equity can significantly affect analysis results (Litman, 2018).

Transportation solutions that, in a broader urban context, represent a global gain for the population, are not necessarily “fair” or “equitable” decisions. Different social groups use the system differently, for different purposes and with varying degrees of dependency. Accordingly, transportation investments do not necessarily mean an equal improvement for all users. One good example is improving transportation services or infrastructure for already favored or wealthy groups, to the detriment of users who have limited modal choices (such as low-income groups, and/or people with disabilities); this increases disparity in terms of the distribution of accessibility, even if the overall coverage provided by the transportation system has improved. Thus, justice theories provide moral justification for distribution concerns with regard to policy interventions (Nahmias-Biran et al., 2017). Also, an ethical perspective could provide different answers about inequalities in terms of accessibility, regardless of how accessibility is measured or conceptualized (Pereira et al., 2017).

The justice theories explored here were chosen because of their notoriety in current academic debates about justice and the application of equity principles to the appraisal of transportation projects (e.g., Di Ciommo & Shiftan, 2017; Golub & Martens, 2014; Martens, 2017; Pereira et al., 2017; Wee & Geurs, 2011).

This paper sets out to explore application of the assumptions of four justice theories: utilitarianism, currently the most widely used theory in assessing transportation investments, Walzer’s communitarianism (Walzer, 1983), Rawls’ egalitarianism (Rawls, 2001, 2003), and Sen’s Capabilities Approach (CA) (Sen, 1992, 2000, 2009) to assessment of the equity impacts of transportation projects.

Through understanding the key principles of these four justice theories, it will be possible to compare their distribution assumptions (see Nahmias-Biran et al., 2017; Pereira et al., 2017), and summarize their insights and restrictions of their application to issues of accessibility and equity. For this specific study, we build gravity-based accessibility indicators, which were adapted based on the assumptions of the above-mentioned justice theories. We then use the new circular line of Lisbon’s Metro (subway network) as a case study to compare the distribution of accessibility and equity outcomes. To the best of our knowledge, this is the first time that equity outcomes resulting from the simultaneous application of different theories of justice have been analyzed and compared.

The rest of this paper is organized as follows. Section 2 offers a review of the literature on accessibility, equity in transportation, and justice theories. Section 3 describes the case study, providing details in terms of local data and the proposed Lisbon Metro circular line, followed by the construction of the indicators. Section 4 discusses the results obtained. The paper ends with the conclusions and a brief discussion on the implications of our results, their limitations and the further research.

2 Mapping equity in terms of justice theories

2.1 Equity, accessibility and public transportation

Equity can be understood as a way of conceiving equality by treating advantageously and fairly groups that are disadvantaged in relation to others (Silva, 2016). With regard to equity in transportation, the key components are the distribution of benefits and costs across members of society and the distributive principle (used to determine whether a distribution is "morally proper" and "socially acceptable") (Di Ciommo & Shiftan, 2017). There is a relationship between social inequalities and the transportation system that results from the unequal distribution of resources, impacts, and access to opportunities (Whitelegg, 1997). Guzman and Oviedo (2018) point out that the need to ensure equitable public transportation is crucially important, as it plays a key role in shaping access to opportunities (e.g., household income can limit people's travel to the strictly essential). Accordingly, a discriminatory distribution of transportation resources may exacerbate the vulnerability of disadvantaged communities and contribute to social exclusion.

The concept of social justice emphasizes a fair distribution of benefits and burdens among all members of society (Pasha, 2018), and its equity dimension recognizes that individuals have different needs, and that resources should be distributed to benefit marginalized populations (Boschmann & Kwan, 2008). Equity in transportation aims to include social and spatial factors in social welfare assessment by introducing the concept of accessibility to key activities (Levitas et al., 2007), focusing on accessibility gains and replacing the traditional measure of travel time savings that favor better-off groups who travel more (Di Ciommo & Shiftan, 2017; Martens & Ciommo, 2017).

In theory, equitable and effective transportation planning should help direct urban areas toward a more just transportation system (Griffin & Sener, 2016). Accordingly, a more promising policy approach is to focus on inequalities in terms of accessibility levels (Pereira et al., 2017). However, accessibility can be measured and conceptualized in many different ways and with specific ethical perspectives (Martens et al., 2012; Martens & Golub, 2012; Pereira et al., 2017; Wee & Geurs, 2011). Thus, a clear definition and understanding of the concepts of accessibility are fundamental for the applicability of accessibility as a comparative parameter. Accessibility can be understood as the potential for interaction with locations dispersed in space (Hansen, 1959). It is related with the potential for individual participation in a given activity in a given location, through the existence of transportation systems (Jones, 1981). This understanding of accessibility stresses that there are variations in accessibility levels that people may experience. Usually the accessibility level experienced will be lower due to limitations in terms of people's ability to overcome distances (Martens, 2017). In other words, intrinsic accessibility for each individual depends on the context: the transportation system, land-use patterns and individual attributes, such as income, gender, place of residence, physical abilities, etc. (Hansen, 1959; Martens, 2017; Pereira et al., 2017). Also, Martens (2017) argues that the question as to a sufficient level of accessibility goes beyond a philosophical approach and can only be answered through a process of democratic deliberation and selection (see Martens, 2017 for further reference to these concepts).

Generally speaking, the distinctions frequently made from a perspective of equity and accessibility are those between income classes and regions. These distinctions can rule out implementation of policies where low-income groups or poor regions "lose" and high-income categories or wealthy regions 'win' (Wee & Geurs, 2011). However, a particular policy may appear equitable or inequitable, depending on the assessment method used. As a result, assessing transportation equity impacts can produce conflicting results, depending on the type of equity definition (Litman, 2018). Herein, the concept of basic accessibility that refers to people's ability to reach activities that society considers basic or essential is applied (Litman, 2018).

2.2 Relationship between justice theories and equity in the transportation system

Transportation equity appraisal can be difficult because various impacts can be taken into consideration, and varying ways of measuring these impacts can be developed (Litman, 2018). There are several options available to reflect distribution effects. In order to report them, important choices have to be made, such as the indicator to be used and the value of each unit to be compared (e.g., accessibility) (Wee & Geurs, 2011).

Transportation equity aims to maximize average accessibility and minimize disparities between the worst-off and better-off groups (Martens et al., 2012). The main challenge to transportation equity analysis is defining the costs, benefits, and the distributive principle (Di Ciommo & Shiftan, 2017). In this respect, the distributive pattern of a specific good, along with the moral justification for distribution thereof is provided by justice theories.

Different justice theories propose different answers as to how policies should be assessed (in an ethical perspective) in the face of questions on equitable transport benefits distribution. These particularities and specificities (Pereira et al., 2017) are summarized in Table 1.

Table 1. Summary of justice theories

Justice Theories	Object of Distribution	Distributive Principle	Distribution Pattern
Utilitarianism	Welfare	The greatest good for the greatest number	Whatever distribution maximizes the mean well-being
Rawls' Egalitarianism	Primary Goods	Difference Principle	Maximin criterion (subject to constraints, based on the least advantaged groups)
Walzer's Communitarianism	Basic Goods and Social Meaning Goods	Distributive Spheres	Free Exchange for Basic Goods and Social Goods within a specific distributive sphere
Sen's Capability Approach (CA)	Basic Capabilities	Human Dignity and Equal Respect	Minimum Threshold (Everyone should be above that threshold)

The utilitarian approach focuses on the instrumental value of travel to facilitate the undertaking of activities from which people derive, regardless of accessibility. Urban and transportation policies should facilitate travel to the activities that maximize aggregate utility (Pereira et al., 2017). As welfare is seen as a whole and equally important, this approach focuses on aggregate transportation performance measures, without paying particular attention to how accessibility is distributed among individuals (Martens, 2011; Wee & Roeser, 2013).

Rawls recognizes freedom of movement as crucial, where accessibility can be related to the concept of an individual's basic rights (Rawls, 2001). However, when Rawls (2001) expands his original understanding of primary goods to include personal goods and services provided by the state, arguing that these must follow the "difference principle" (Rawls, 2003), he ends up allowing accessibility to be understood as a primary good. Briefly put, the difference principle says that inequalities can only be considered fair if they work to the benefit of the least well-off, and thus mitigate inequalities of opportunity and the morally arbitrary effects of social and natural lotteries (Rawls, 2003).

The idea that accessibility should be understood as a primary good and be subject to the difference principle is supported by several authors (Pereira et al. 2017; Wee & Geurs, 2011; Wee & Roeser, 2013), but this doesn't mean that everybody should experience the same level of accessibility. Based on an interpretation of Rawls' theory, Pereira et al. (2017) state that justice is not about whether some people enjoy greater accessibility than others, but how institutions and policies deal with inequalities in order to minimize them (Rawls, 2003). A transportation policy can only be considered fair if it distributes benefits in a particular way, one that reduces inequality of opportunities (Pereira et al., 2017). Furthermore, Rawls works with a basic structure of society, not providing sufficiently clear guidelines for the distribution of transportation benefits and without having to return to a procedural approach to justice (Nahmias-Biran et al., 2017).

Walzer's approach is particularly important to supporting the claim that accessibility is the key social good distributed in the domain of transportation (Martens, 2012; Martens et al., 2012). When meanings are distinct, distributions should be autonomous (Walzer, 1983), setting them apart from other goods and not being subjected to market forces (Nahmias-Biran et al., 2017). Also, the important role played by transportation in achieving these opportunities can justify a different distributive approach (proper sphere) to transportation, where the good (accessibility) has a distinct social meaning (Nahmias-Biran et al., 2017). Walzer's theory therefore raises two key questions regarding transportation and accessibility's social meaning. Firstly, it implies that distributive principles have to be "read" by studying the society, without a need to provide a moral justification. Secondly, and related to the first issue, there is a risk that these principles reflect the interests of dominant groups in society, instead of embodying largely shared meanings (Martens, 2012; Nahmias-Biran et al., 2017).

Walzer's (1983) perspective argues that the principles of a just or unjust distribution must be established by the social meaning that each society ascribes to the good itself, where every issue of distributive justice should be a local account (Nahmias-Biran et al., 2017; Teuber, 1984). Accordingly, the theory fails to provide clear and solid demarcation points for the distribution of accessibility (Nahmias-Biran et al., 2017).

In Sen's theory, mobility, as the ability for moving around, should be considered as a basic capacity on account of its central role in enabling people to reach their primary needs (Sen, 1992, 2000, 2009). The transportation system is a mean for reaching activities that shape a person's capabilities, and accessibility is a prerequisite for performing the related functions (Nahmias-Biran et al., 2017). However, people's ability to convert transportation resources into capabilities is affected by contingencies (e.g., personal characteristics, cultural norms) (Ryan et al., 2015). Accordingly, it is not mandatory that everyone should enjoy exactly the same transport conditions, but a minimum level of access to essential activities to meet basic needs must be ensured (Pereira et al., 2017).

The CA (Sen, 2000), provides two important insights about accessibility distribution: (I) it must ensure that people have a sufficient level of capability—minimum accessibility thresholds; (II) accessibility must be measured taking into account individual particularities as much as the characteristics of transportation and the land-use system (Nahmias-Biran et al., 2017). However, it may not be possible to specify sufficiency in a non-arbitrary way (Nahmias-Biran et al., 2017). The emphasis on sufficient capacities (Sen, 2009) provides a guiding point for the distribution of accessibility: a transportation system should not create barriers to people reaching a sufficient level of capacities. Because the CA is fundamentally concerned with individual freedom of choice and human agency, accessibility must be seen as an individual attribute, taking into account how personal characteristics (e.g., gender, income) shape differences in accessibility levels (Pereira et al., 2017).

Thus, the choice of metric strongly shapes the conclusions that can be drawn from the accessibility analysis (Pereira et al., 2017). Considering everything that has already been said, one can say that assessments based on Utilitarianism can be based on global rates of the benefit's distribution, whereas Rawls and Walzer’s theories should focus on disparities in distribution. CA-based assessments should concentrate on issues related with access to a minimum level of accessibility.

2.3 Accessibility measures and justice theories

Accessibility measures can be built on the basis of four main components: land-use—distribution of opportunities; transportation; time-of-day; and individual—i.e., the needs, abilities and opportunities of individuals (Geurs & Wee, 2004). The interactions between them produce different levels of accessibility. Ideally, an accessibility measure should include all components, but in practice, the focus on different components of accessibility has led to different perspectives for their measurement, such as infrastructure-based, location-based, utility-based and person-based measures (Geurs & Wee, 2004).

The accessibility indicators used for equity analysis must be able to capture the opportunities that impact on people’s lives, namely in terms of employment, education and opportunities for social interactions, (Golub & Martens, 2014; Lucas, 2006). Equity indicators must be operationalized taking into consideration the definition of costs and benefits, the distributive principle and the identification of criteria for determining relevant population groups (Di Ciommo e Shiftan, 2017).

One should note that thereafter, the concepts and assumptions adopted for the interpretation of justice theories and the operationalization of accessibility indicators are influenced by our case study. In practice, this means that some assumptions may be context dependent. Accordingly, we use the concept of Basic Access, which is understood as access to key-activities, such as health care, education and employment, social and recreational activities, basic foodstuffs and clothing, public services and utilities, and emergency services (Litman, 2018). The opportunities (key -activities locations) used in the accessibility indicator are grouped into five areas: education, employment, health, shopping, and leisure. These land-use destinations and areas represent the most common daily destinations, based on the work of Mavoa et al. (2012) as well as the 2017 mobility survey (INE, 2018b).

2.3.1 Utilitarianism

Utilitarianism treats all individuals equally, regardless of their travel patterns or social characteristics. From a utilitarian perspective, transportation projects ought to increase the number of individuals benefiting from a project, regardless of their socioeconomic characteristics. A project will be deemed good if it ends up maximizing the welfare (basic access) of the greatest number of individuals (Hausman et al., 2006). Furthermore, a project also is also accepted if the values of the benefits are greater than the costs (both, weighted by the affected population), which is essentially an application of the compensation principle (De Scitovszky, 1941). As a result there are no concerns about the intermediate distribution of accessibility (Kymlicka, 2001; Pereira et al., 2017).

In contrast, the other three justice theories discussed here have in common that they are particularly concerned with the distribution of accessibility levels and the reduction of inequalities experienced by individuals. Assessing equity using these three theories (Rawls, Walzer and Sen-CA) involves a need to identify those who are disadvantaged in terms of transportation (Karner & Niemeier, 2013; Pereira et al., 2017).

2.3.2 Rawls' Egalitarianism, Walzer's Communitarianism, and the Maximax principle

The Rawls approach argues that a good project should maximize the level of accessibility for people in the worst situation and help mitigate the differences between groups at the opposite ends of the distribution (Rawls, 2003); accordingly, changes to transportation must not exacerbate the differences in accessibility that already exist.

Based on Rawls (2003), accessibility should be subject to the difference principle and the “maximin criterion,” which maximizes the minimum level of primary goods of people in the worst-off situation (Pereira et al., 2017). Thus, a direct relationship can be established between the definitions of primary goods and key activities. Thus, basic access is interpreted as meaning access to primary goods.

Walzer's Communitarianism understands that accessibility must be guided by a proper distributive sphere (Nahmias-Biran et al., 2017). Walzer argues that the distribution parameters of a social good must be assigned locally (Walzer, 1983).

That said, accessibility should be measured by the level of basic access to several opportunities. Also, the unified accessibility indicator should take into consideration the local importance (weighting) of each area of opportunities. These opportunities have different weightings, as they are associated with specific demands and needs (DETR, 2000; Smith et al., 2012). Accordingly, the level of importance for each type of locally defined opportunity should be reflected by travel patterns to access opportunities in each area (Di Ciommo & Shiftan, 2017; Fransen et al., 2015; Mavoa et al., 2012; Smith et al., 2012; Wee & Geurs, 2011).

Assessment proceeds from the assumption that neither the good nor its distribution should harm, or serve as a domination mechanism for, any person (Walzer, 1983). This means that, in a just society, people with different income levels should have similar accessibility outcomes.

However, while Rawls' theoretical approach serves as a source for the debate about equity in transportation, and Walzer's theory is used to establish justification for a distinct distributive approach to transportation benefits, we agree with Nahmias-Biran et al. (2017) that neither Rawls theory nor Walzer's approach can provide a solid footing for a particular distribution of accessibility.

Alternatively, we focus on the “Maximax principle” guidance proposed by Martens et al. (2012), which argues that the application of this principle could assist decision-makers in the selection of transportation projects that maximize average accessibility levels while ensuring that the accessibility gaps between population groups remain within an acceptable range. Briefly put, the criterion combines the goal of maximum average accessibility with a limit as to the maximal gap in accessibility levels allowed between the worst-off and the best-off groups (Martens, 2012; Martens et al., 2012).

The application of the “Maximax principle” implies a systematic assessment of the accessibility gaps between the transportation disadvantaged and those groups in society that experience the highest accessibility levels, ensuring that these gaps do not exceed a pre-defined threshold (Martens, 2012; Martens et al., 2012). Ideally, the “Maximax

Principle" application should use a deliberative process to define the maximum accessibility gap. However, for this work project it was not possible to implement that deliberative process. As an alternative to defining the gap threshold, the existing gap values are used, with the assumption that a transportation project should not exacerbate existing gaps.

2.3.3 Sen's Capability Approach

Sen's approach defends the creation of a minimum threshold of essential activities access, understood here by the minimum threshold of basic access. Accessibility must be distributed in order to guarantee people a sufficient level of capabilities (many of which can be linked to physical destinations) (Nahmias-Biran et al., 2017). The accessibility indicator should be built based on the potential of access to key-activities considered relevant by individuals. However, the assessment demands the definition of a minimum accessibility threshold, which should be established through deliberative processes (see Martens, 2017, for a more elaborate discussion). Thus, the Sen-based equity indicator implies estimating the population below a pre-defined accessibility threshold and compare the different scenarios.

One should note that, for this work, a deliberative process for creating a minimum threshold (as occurred for the Maximax Principle) to establish a sufficient level of accessibility could not be implemented. As an alternative, we propose to build this benchmark describing the minimum level of accessibility to spatially distributed opportunities based on a pre-specified maximum travel time. This threshold could be based on the local average commuting time which is the value used here.

3 Case study

Here we use as a case study the Lisbon Metro Circular Line (LMCL) project (Figure 1). The Lisbon Metro has four lines with 56 stations (yellow line—13 stations; blue line—18, red line—12 and green line—13), over a total length of 44.5 km. The case study if for a circular line that aims to connect the existing stations of Rato (yellow line) and Cais do Sodré (green line) by adding two new stations—Estrela and Santos.

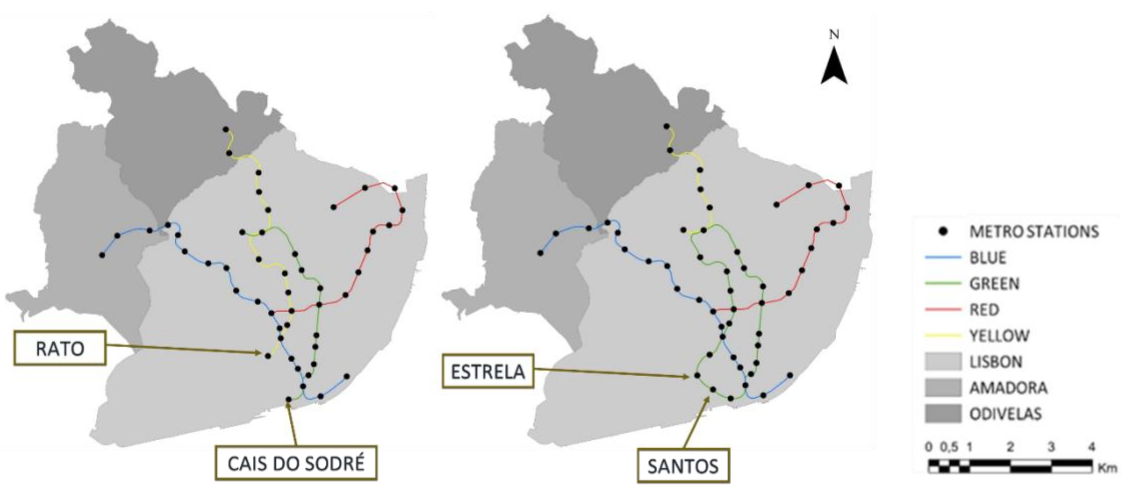

Figure 1. Lisbon metro circular line project

Hence, the green and yellow lines (already in existence and operation) will undergo considerable changes: the yellow line will be reduced to only 7 stations and the green line will be transformed into a circular line, becoming the largest metro line in terms of the number of stations. As of 2017, public transport accounts for about 21% of all trips made by Lisbon residents, with the metro accounting for about 8% (INE, 2018a, 2018b).

3.1 Accessibility indicators

To enable assessment according to each justice theory, accessibility indicators based on the gravity model were constructed. Also, because the assessment focuses on the distribution of accessibility to a specific transport project intervention (LMCL), only those opportunities within a 400 m radius around each metro station are taken into consideration; this metric corresponds to the common walking distances to access and egress public transportation systems (Aultman-Hall et al., 1997). This approach allows for direct comparison between the two metro network configurations, isolating them as much as possible from other PT modes. The same radius is used to define the area for which the disadvantaged population groups are estimated.

Travel times are estimated using the General Transit Feed Specification (GTFS), which provides travel time estimates based on average travel speeds, and distances (Farber et al., 2014; Farber & Grandez, 2017; Fransen et al., 2015). The final travel times were estimated for both scenarios (current and LMCL). The former scenario (current situation) considered the existing metro lines and stations, and for future metro stations, the bus lines with stops within 400 meters of these new stations are used to estimate the travel times. The latter scenario (LMCL) takes into consideration only the metro lines and stations for the travel time estimation. To account for time penalties for transfers and waiting times (Deboosere & El-Geneidy, 2018; Farber et al., 2014; Karner, 2018), five minutes for each penalty is used, which corresponds to the average waiting time (about one half of the headway time).

Opportunities are estimated as follows: employment—as in Portugal there is no available information about jobs below the municipal level, the number of jobs was estimated using the 2017 mobility survey (INE, 2018b), taking into account the number of work-related commuting trips ending within 400 meters around each metro station; education—the schools and universities surrounding each metro station were identified and their number of students was collected; health—number of health centers and hospitals, both private and public; shopping—number of retail establishments; and leisure—urban parks and gardens, cinemas, theaters, bars, cafés and restaurants; all data collected is open data provided by Lisbon City Council (Câmara Municipal Lisboa - Geodados, 2018).

For the Sen-based indicator, we assume that, in an ideal scenario, the maximum travel time threshold should be 30 min. This threshold is based on Bertolini's work that recommends considering a 30 min. time limit where journeys to work are concerned (Bertolini et al., 2005). This value is also close to the Lisbon average one-way commuting time which is 26 min. (INE, 2018b). The above assumptions are applicable to this case study or to similar contexts; however, other values and mechanisms to define travel time and accessibility thresholds could also be taken into consideration. To calculate the accessibility indicators resulting from the travel time threshold, it was necessary to assume that all available opportunities within a radius of 400 m from each station were accessible within the established maximum travel time (i.e., 30 min.). The accessibility indicators and assessment process for each justice theory are presented in Table 2.

Table 2. Accessibility indicator

Utilitarianism

The assessment is based on:

The difference between the average weighted (weighted in terms of the population of each zone) accessibility and the number and percentage of population experiencing an increase in their accessibility. The average weighted accessibility is expressed by:

$$\bar{A} = \frac{\sum_i \left(\sum_j (\sum_k Op_{ik} w_k) e^{\beta T_{ij}}\right) Pop_i}{Pop} \quad (1)$$

Where:

$\bar{A}$ is the average weighted (weighted in terms of the population living around each metro station) accessibility*;*

Opjk are the travel opportunities in zone *j* of a specific type *k;*

Wk is the weighting of the observed travel by purpose *K* (commuting to work, commuting to school, health, leisure, and shopping)*;*

T is the travel time between *i* and *j*, and *β* the travel cost sensitivity parameter (in the present case travel time).

The value of *β*, -0.056, is based on previous research in the Lisbon Metropolitan Area and was estimated considering public transportation travel times (in minutes)(de Abreu e Silva, 2007).

Maximax Principle

The assessment is based on the distribution of average accessibility with a range constrict.

→Accessibility is expressed by:

$$A_i = \sum_j (Op_{jk} WG_{n_k}) e^{\beta T_{ij}} \quad (2)$$

Where:

Ai is the accessibility for zone *i*;

Opjk are the travel opportunities in zone *j* of a specific type *k*;

WGnk is the weighting of the observed travel by purpose *k* (commuting to work, commuting to school, health, leisure, and shopping);

T is the travel time between *i* and *j*, and *β* the travel time sensitivity parameter.

→The Gap is expressed by:

$$Gap = \bar{A}_g - \bar{A}_d \quad (3)$$

Where:

$$\bar{A}_g = \frac{\sum_i (A_i) Pop_{ig}}{Pop_g} \quad (4)$$

$$\bar{A}_d = \frac{\sum_i (A_i) Pop_{id}}{Pop_d} \quad (5)$$

Where:

$\bar{A}_g$ is the average accessibility weighted in terms of the general population (Pop_{ig}) around each metro station;

$\bar{A}_d$ is the average accessibility weighted in terms of the disadvantaged population (Pop_{id}) around each metro station.

The disadvantaged population is defined by means of their income levels, that is, population groups that are below a minimum income threshold set previously and ideally by the same deliberative process used to establish the Gap.

Sen's Capability Approach

This estimates the population that is below a minimum level of accessibility.

→Accessibility is expressed by:

$$A_i = \sum_j (Op_{jk} WG_{n_k}) f(T_{ij}) \quad (6)$$

Where:

$$f(T_{ij}) \begin{cases} 0 & if\ T_{ij} > 30\ min \\ e^{\beta T_{ij}} & if\ T_{ij} \leq 30\ min \end{cases} \quad (7)$$

Where:
Ai is the accessibility for zone i;
$Opjk$ are the travel opportunities in zone j of a specific type related with travel purpose k;
$WGnk$ is the is the weighting of the observed travel by purpose k (commuting to work, commuting to school, health, leisure, and shopping);
T is the travel time between i and j, and β the travel time sensitivity parameter.

→The Threshold is expressed by:

$$A_{Ti} = \sum_j (Op_{jk} WG_{n_k}) e^{\beta T_{ij}} \quad (8)$$

Where:

$$T_{ij} \begin{cases} 30\ min \quad if\ T_{ij} > 30\ min \\ T_{ij} \quad\quad if\ T_{ij} \leq 30\ min \end{cases} \quad (9)$$

This time standard is the minimum that meets the threshold standard. Note that the urban configuration remains constant.

Where:
A_{Ti} is the accessibility for zone i;
T is the travel time between i and j.

→The population below the Threshold is expressed by:

$$Pop_i \begin{cases} 0\ if\ A_{Ti} > A_i \\ Pop_i\ if\ A_{Ti} \leq A_i \end{cases} \quad (10)$$

$$Q_{BT} = \frac{\sum_i Pop_i}{Pop_T} \quad (11)$$

Where:
Q_{BT} is the percentage of the population that is below the Threshold;
Pop_i is the population living around each metro station that is below the Threshold;
Pop_T is the entire population living around all metro stations.

This indicator can either be estimated for the global population or for different socioeconomic groups (e.g., disadvantaged population).

It is possible to assign different levels of importance to different types of opportunities based on local observed travel behavior (Di Ciommo & Shiftan, 2017; Fransen et al., 2015; Mavoa et al., 2012; Smith et al., 2012; Wee & Geurs, 2011). Thus, such weighting factors (Table 3) were defined by means of the proportion of daily trips by purpose related with each opportunity type. The weighting factors reflecting the current local reality are taken from the Lisbon Mobility Survey (INE, 2018b).

Table 3. Travel purpose weightings

Travel purpose weightings—Observed in Lisbon					
	Employment	Health	Education	Leisure	Shopping
GLOBAL	0.39	0.02	0.13	0.19	0.27

4 Results

Table 4 summarizes the variation in accessibility values for the two scenarios (current and LMCL), calculated for all opportunity types and for the general population for each metro station.

Table 4. Summarizes the accessibility variation between the current situation and the circular line

Variation in Accessibility					
Station	Future line	(%)	Station	Future line	(%)
Aeroporto	R	-0.28	Lumiar	Y	-10.60
Alameda	GC/R	3.69	Marques de Pombal	GC/B	4.41
Alfornelos	B	0.74	Martim Moniz	GC	2.98
Alto dos Moinhos	B	0.77	Moscavide	R	-0.28
Alvalade	GC	8.06	Odivelas	Y	-10.58
Amadora este	B	0.74	Olaias	R	-0.31
Ameixoeira	Y	-10.58	Olivais	R	-0.29
Anjos	GC	1.59	Oriente	R	-0.28
Areeiro	GC	1.42	Parque	B	0.88
Avenida	B	0.58	Picoas	GC	8.13
Baixa Chiado	GC/B	9.16	Pontinha	B	0.74
Bela vista	R	-0.30	Praça de Espanha	B	0.80
Cabo ruivo	R	-0.28	Quinta das Conchas	Y	-10.68
Cais do Sodré	GC	9.19	Rato	GC	18.52
Campo Grande	GC/Y	2.78	Reboleira	B	0.74
Campo Pequeno	GC	7.90	Restauradores	GC	0.51
Carnide	B	0.74	Roma	GC	2.94
Chelas	R	-0.29	Rossio	B	3.91
Cidade Universitária	GC	8.69	Saldanha	GC/R	7.41
Colégio Militar/Luz	B	0.75	Santa Apolónia	B	0.37
Encarnação	R	-0.28	Santos	GC	29.64
Entrecampos	GC	8.06	São Sebastião	B/R	2.20
Estrela	GC	42.06	Senhor Roubado	Y	-10.58
Intendente	GC	2.25	Telheiras	Y	-16.77
Jardim Zoológico	B	0.79	Terreiro do Paço	B	0.37
Laranjeiras	B	0.78	Total	All lines	3.08

Legend
Chromatic Scale: Darker red shades represent higher losses and darker greens represent higher gains. Acronyms: GC=Green Circular Line; R=Red Line; Y=Yellow Line; B=Blue Lineß

Of the 58 metro stations (the 56 current and two new stations), only in 15 of the areas around them is there a reduction in overall accessibility levels. It is still possible to see an increase in the weighted average accessibility of approximately 3%. The number of people experiencing increases to their accessibility levels is also up; about 70% of the 334,000 people living near the current and future metro stations (Table 7). The areas around the metro stations that have suffered a reduction in their accessibility levels are in both the red line (with very small reductions) and the future yellow line (with reductions close to and above 10%). These two lines have in common the fact that they are both peripheral to the center of Lisbon. As expected, those stations that experience higher increases in accessibility are the two new stations (with increases close to or above 30%).

From a utilitarian perspective, these results justify the implementation of the new circular subway line.

The analysis based on the "Maximax criterion" assumes that transport interventions should ensure that average accessibility is maximized with a range constrict (Martens, 2012). This means ensuring an acceptable level of accessibility for all population groups, regardless of location.

In addition, a focus is also placed on the distribution of this average accessibility across disadvantaged population groups. In an ideal case, these groups would be defined by income. However, in Portugal income data is not collected by the census. Geurs & Wee (2004) argued that some characteristics can influence a person's level of access to transport, such as education level for instance. By deeming the education levels to be a proxy for income, the data on education level (available in the Census) is used to define the disadvantaged groups. In this particular case, the number of people with no formal education or only elementary schooling is deemed to be a proxy for the low-income population.

Table 5. Accessibility values and the gap for the current line and circular line

	Average Accessibility		
	General Population	Disadvantaged Population	Gap
Current Line	15835.2	15413.2	422
Circular Line	16359.4	15898.4	461

Note: The gap is the difference between the average accessibility values for both the general population and the disadvantaged population.

The data presented in Table 5 shows that the average accessibility values show a similar upward trend for both the general and the disadvantaged population, with an increase in accessibility levels above 3% for the LMCL (specifically 3.31% for general population and 3.15% for disadvantaged population). However, the "Maximax criterion" is not exclusively about increasing average accessibility but combines that goal with a constrain on the gap of accessibility levels. Accordingly, in order to allow for comparability, the choice for the GAP calculation was the value obtained as the difference between the average accessibility for the two population groups (general population and disadvantaged population). Table 5 shows that for the LMCL the Gap increases by 9%, thus exacerbating the disparities already found.

One should point out that this assessment is based on the premise (established above herein) that any transportation project must not exacerbate the already existing disparity levels. Accordingly, it is assumed that the already existing disparity levels of should be deemed to be the maximum acceptable level. One conceivable way to mitigate this caveat would be to conduct a deliberative process with the local population to define the maximum accepted disparity level in terms of accessibility.

The analysis based on CA focuses on people below a minimum accessibility threshold (Table 6). The global values show that currently around 233,000 people experience accessibility levels below the defined travel time threshold of 30 min., representing 70% of the people living within 400 meters of each station. For the LMCL, this number is reduced to around 156,000 people below the defined threshold (47% of the population). It also means that about 77,000 people will experience an increase in their accessibility to values above the established threshold. Looking at the disadvantaged population, the results show that in the current situation around 104,000 people or 73% are below the accessibility threshold, and for the circular line, the values are around 75,000 people or 52% of the population. This means that around 29,000 disadvantaged people will benefit from the project as their accessibility levels are lifted beyond the defined threshold.

Table 6. Change in population living below the minimum accessibility threshold between the current situation and the circular line

	Population below the Accessibility Threshold						
	Maximum Travel Time Threshold (min)						
	30	35	36	37	38	39	40
General Population							
Current Line	**232628**	158308	139921	117674	91507	65481	49259
Circular Line	**155861**	137454	134355	125936	113434	113434	113434
Q_{BT} (Current | Circular)	**70 | 47**	47 | 41	42 | 40	35 | 38	27 | 34	20 | 34	15 | 34
Disadvantaged Population							
Current Line	**103872**	71832	64046	55302	45269	34183	26389
Circular Line	**74523**	67206	65976	61373	55744	55744	55744
Q_{BT} (Current| Circular)	**73 | 52**	51 | 47	45 | 46	39 | 43	32 | 39	24 | 39	19 | 39

Note: Table units - Q_BT (%); Current and Circular Line (No. of people).

The results from the CA are strongly dependent on the assumptions as to the maximum acceptable travel times, which in his case, are based on the observed travel behavior, with the implicit assumption that the observed behavior reflects the basic needs of the population. This assumption is not necessarily true, and different maximum acceptable travel time thresholds may lead to opposite conclusions. Special care should be taken in defining them and, whenever possible perform a sensitivity analysis of their values. In this case, a sensitivity analysis is carried out, and its results are also presented in Table 6. One should note that, for maximum travel time thresholds above 35 minutes (or 36 minutes if one takes only the general population into consideration), the recommendations drawn from the CA are inverted. This shows that the assessment using the CA approach is highly sensitive toward the travel time variable, thus identifying a possible caveat for this approach. Besides performing a sensitivity analysis, another possible way to mitigate this caveat would be to conduct a deliberative process with the population to define the maximum accepted travel times and the minimum accessibility thresholds. This was unfortunately beyond our resources, and it could be considered a limitation of this work.

Table 7 summarizes the results of the assessments based on Utilitarianism, the Maximax Principle and Sen (CA). The results based on CA (30-minute threshold) corroborate the results of the utilitarianism-based analysis and go against the analysis based on the “Maximax Principle.”

Table 7. Assessment standards by justice theory

Justice theories	Distribution Pattern	Assessment Standards	Recommendations
Utilitarianism	Whatever distribution maximizes the accessibility levels	Overall Figures: →Total Population Favored: 234 194 people →Total Average Accessibility: Increase of 3.31%	Supports construction of the Circular Line
Maximax Principle	Maximizing the average accessibility while observing a Maximum Gap	Average Accessibility considering: →General Population: Increase of 3.31%, →Disadvantaged Population: Increase of 3.15%, →Gap (between general and disadvantaged population): Increase of 9%.	Doesn't support construction of the Circular Line
Sen's Capability Approach	Minimum Basic Level (Everyone should be above)	Population below the minimum accessibility threshold (for 30 min), considering: →General Population: Decrease of 23% (76,767 people) in a comparison between the two lines. →Disadvantaged Population: Decrease of 21% (29 349 people) in a comparison between the two lines.	Supports the Circular Line, for the adopted values, but is also sensitive to the travel time threshold. Above 36 minutes, it doesn't support construction of the Circular Line.

The results obtained may reflect the fact that utilitarianism does not consider possible increases in the levels of inequality as well as possible reductions in accessibility to which some areas, and the people who live in them, are subject.

An analysis of the indicators based on Sen and the "Maximax principle" also provides (through the intermediate data) relevant complementary information, indicating whether the increases in inequality are only because accessibility grows differently around stations or whether there are actually people who lose out in this process (i.e., areas and the population living in them that actually see a reduction in their accessibility). The different results for Sen's CA-based indicator highlight the role that assumptions may have in equity analysis, indicating a need for transparency in these assessments.

5 Conclusions

This paper explores the application of equity analysis based on four different justice theories (Rawls' Utilitarianism, Rawls' Egalitarianism, Walzer's Communitarianism and Sen's Capabilities Approach), and their influence on assessment of the distribution of transportation project impacts (namely, in defining the metric and assessment system used). The focus herein is on the new circular line project for the Lisbon Metro network as a case study. Utilitarianism understands welfare (taken into consideration herein as basic access) in a uniform way, while not paying due attention into its distribution throughout different social strata, and also not providing parameters to assess its distribution levels. Given this limitation, the other two theoretical approaches (Maximax and Sen) are able to encompass dimensions of vertical equity, assessing distribution patterns in terms of both benefits and impacts between different social groups. In this article, the benefits are materialized through the accessibility indicator, since, as a potential facilitator of access to different opportunities, it is directly related to social inclusion.

An equitable investment in transportation is expected to bring more benefits to disadvantaged population groups. However, each justice perspective defines particular assessment parameters based on its own criteria. Equitable distribution ought to minimize disparities between lower and higher-placed groups (Litman, 2018; Martens et al., 2012) and this assumption finds some support in the theories of Rawls, Walzer and Sen. The findings support the importance of including justice perspectives other than utilitarianism in the assessment of transportation projects, in order to assess and ensure more equitable transportation. More importantly, the other approaches indicate the areas and social groups that will be negatively affected by the transportation changes proposed by the projects, and these are issues that are not adequately covered by utilitarianism.

In contrast to the other justice theories, the CA relies extensively on the definition of a minimum or sufficient threshold. Yet even by means of the sufficiency principle or democratic deliberative procedure, it may not be possible to define the threshold in completely non-arbitrary ways; a deliberative process would give this a higher level of legitimacy.

Another relevant point are the limitations that have to do with data quality and detail level. On account of data availability or lack thereof, travel opportunities had to be aggregated and treated uniformly. Despite the fact that not all jobs are accessible to everyone. Also, there is no distinction between universities and other schools, and neither the retail establishments, nor health facilities, were differentiated by type. This is an important limitation because the assumption is that all the travel opportunities within the areas around each metro station were available for everyone. Regarding this case study, the segregation of opportunities may be more important in terms of the accessibility indicator, including different impedance factors (used here uniformly for all travel opportunities) for each travel opportunity in the gravity model. However, this would add another level of complexity to the assessments by increasing the number of variables, as well as the need for, and volume of, available data to support this breakdown level.

The lack of available income data is another example of a major limitation found in the study; this data would allow a better framing of the distribution of benefits and burdens across the population, providing more solid data for equity assessments based on the Maximax principle. Another limitation and possible future research topic is the construction of the two new stations, given that changes to the accessibility levels of the areas can influence the attractiveness of each of them, leading to possible changes in the social make-up of the residents in the areas around the stations. This process could lead to gentrification, as well as encourage the exodus of residents with greater economic power from the areas around stations that experience a reduction to their accessibility. Studying these effects and how they could be incorporated into a transportation equity analysis is a relevant research topic.

Planning for transportation improvements inexorably involves benefits and burdens that vary depending on the different social groups and communities. This study initiates a discussion about different perspectives for measuring and assessing the distribution of benefits and burdens of transportation system change projects, based on equity parameters established by different justice theories. Lastly, the equity assessment proposed herein also lends some support to the need to establish minimum standards or acceptable distribution standards of accessibility to basic opportunities, which should be used in the assessment of transportation investments.

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