Towards a better implementation of accessibility indicators in land use and transport planning practice

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ABSTRACT

With the rapid growth of automobile ownership in the 20th century, transport planning has evolved around mobility-based approaches aiming at easing the movement of vehicles and guided by indicators such as hours of delay, traffic speed and number of cars in congestion. Yet, given the growing awareness toward the negative externalities of car use, the shortcomings of the mobility-centered approach are becoming more and more apparent. In order to address these shortcomings, planning for accessibility is increasingly considered as an essential complementary approach. This approach aims to provide reasonable access to destinations (employment centers, amenities, social and health services, etc.) to the entire population instead of prioritizing the optimization of travel times. Accordingly, planning for accessibility evolves around the integration of land use and transport systems and considers all transport modes.

While accessibility, defined here as the ease of reaching destinations, has been widely discussed in the last decades – starting in the late 1950s –, transport planning is still dominated by mobility goals and indicators. Most, if not all, metropolitan regions lag behind in terms of accessibility planning, with most resources and efforts being oriented towards the mobility of private vehicles. This is not surprising, given that mobility approaches have been strongly rooted in practice for most of the last century.

Although a large body of literature has explored how to conceptualize and measure accessibility, research on how to incorporate accessibility in transport planning is scarce. Knowing that accessibility is currently marginalized in transport planning, the overarching goal of this dissertation is to contribute to the implementation of accessibility measures in land use and transport planning practice, by answering the following research question: *How can accessibility measures be incorporated into current land use and transport planning practice in order to improve our understanding of the performance of land use and transport systems?*

To answer this question, the following objectives will be pursued:

1. To determine **how accessibility is used** in land use and transport planning practice;
2. To identify **appropriate measures** of accessibility to be used in land use and transport planning practice;
3. To **generate measures** of accessibility in a data-challenging context in collaboration with local transport planners.

To reach these objectives, this dissertation follows a manuscript-based approach, with four studies building on one another. Collectively, these manuscripts address both the planning and research realms of transport planning through a multifaceted approach.

Through an analysis of 32 metropolitan transport plans around the world, the first study reveals that, while the concept of accessibility is considered in most planning documents, it is rarely translated into goals and indicators that reflect the ease of reaching destinations. One main reason for this is that accessibility is used as a vague term in most plans and is not adequately discussed or defined. This research highlights the weaknesses in the use of accessibility in planning and identifies best practices to effectively address the ease of reaching destinations in metropolitan transport plans.

The findings of the first study are strengthened by a second study surveying 343 practitioners about accessibility. The results of the study demonstrate that most practitioners, although aware of the concept of accessibility, do not consider the ease of reaching destinations in their work. In addition, the results identify two main barriers to the implementation of accessibility indicators: lack of knowledge and lack of data. Conversely, the presence of clear indicators in planning documents as well as the planners' own initiatives are identified as the main reasons for which accessibility indicators are implemented in various organizations around the world. An increased collaboration between academics and practitioners is also identified as an important contributor to the integration of accessibility indicators in practice.

In light of the knowledge and data barriers, the third study assesses the usability of various accessibility measures from a planning perspective. Three measures of accessibility to jobs by public transport in the Greater Toronto and Hamilton Region are generated and assessed through a mode share regression model. The study concludes that the simplest measure – the number of jobs that can be reached within 45 minutes of travel at 8 am – is the most adequate to assess the performance of land use and transport systems at the regional level. It thereby highlights the relevance of considering the ease of operationalization and communication when selecting a measure.

Using the measure identified in the above study, the last study conducts an equity assessment of public transport services in four large metropolitan areas in Brazil. The study, led in a data-challenging context, proposes a methodology that can be easily applied by any transport agencies and illustrates the relevance of the accessibility indicators to inform planning processes. Conducted in collaboration with local transport planners, the study also contributes to an enhanced collaboration between research and planning.

Overall, this dissertation presents a set of complementary studies to bridge the gap between research and practice and better understand how accessibility indicators can be incorporated into current land use and transport planning practice. More specifically, this dissertation contributes to the knowledge on accessibility research and practice in the following ways:

- **Highlighting the gap** that exists between research and planning;
- Deepening our understanding of the **current state of practice** in accessibility planning and identifying the **main barriers** to the implementation of accessibility indicators in practice;
- Identifying a **set of practices and indicators** that can be implemented by professionals to capture the ease of reaching destinations and evaluate the performance of land use and transport systems;
- Offering a **replicable methodology to evaluate transport equity through accessibility measures**, using data that is accessible to most transport authorities in the Global North, and an increasing number in the Global South.

This dissertation demonstrates the importance of carefully and critically thinking about how to include accessibility indicators in practice, be it with respect to how it is defined or how it is measured, and about how research can better contribute to the current challenges faced by professionals.

RÉSUMÉ

Avec la croissance rapide du parc automobile au 20e siècle, la planification des transports s'est concentrée sur la fluidité de la circulation des véhicules. Elle a ainsi été guidée principalement par des indicateurs de mobilité tels que les temps de délais, les vitesses de déplacements et le nombre de véhicules subissant la congestion. Toutefois, étant donné la prise de conscience face aux externalités négatives de l'utilisation de l'automobile, les lacunes d'une approche centrée sur la mobilité sont de plus en plus apparentes. Dans cette optique, la planification centrée sur l'accessibilité est de plus en plus considérée comme une approche complémentaire à la planification de la mobilité. Cette planification vise à s'assurer que l'ensemble de la population ait un accès raisonnable aux destinations urbaines (lieux d'emplois, commerces, services sociaux et de santé, etc.), plutôt que de privilégier l'optimisation des temps de déplacements. Ainsi, la planification centrée sur l'accessibilité considère l'ensemble des modes de transports, et ce, de façon conjointe avec l'aménagement du territoire.

Bien que le concept d'accessibilité, définie dans cette thèse comme la facilité d'accéder aux destinations, ait été largement discuté dans les dernières décennies – débutant au tournant des années 1950s –, la planification des transports est encore aujourd'hui dominée par des objectifs et indicateurs de mobilité. La plupart des régions métropolitaines sont limitées en ce qui a trait à la planification axée sur l'accessibilité, la grande part des ressources et des efforts étant accordée aux déplacements automobiles. Cette réalité n'est pas surprenante, étant donné que les outils et approches basés sur la mobilité sont depuis longtemps ancrés dans la pratique.

Si de nombreuses études ont exploré comment conceptualiser et mesurer l'accessibilité, la littérature portant sur l'intégration de l'accessibilité dans la planification des transports se fait plus rare. Sachant que l'accessibilité est actuellement marginalisée dans la pratique, cette thèse vise à contribuer à la mise en œuvre des mesures d'accessibilité dans la planification des transports et de l'aménagement du territoire, en répondant à la question de recherche suivante : *Comment les mesures d'accessibilité peuvent-elles être intégrée dans la planification des transports et de l'aménagement du territoire afin d'améliorer notre compréhension de la performance de ceux-ci ?*

Afin de répondre à cette question, les objectifs suivants sont mis de l'avant :

1. Déterminer **de quelle façon l'accessibilité est considérée** dans la planification des transports et de l'aménagement du territoire ;

2. Identifier des **mesures appropriées** d'accessibilité pour la planification des transports et de l'aménagement du territoire ;
3. **Générer** des mesures d'accessibilité en collaboration avec des professionnels en transport dans un contexte où les données sont limitées.

Ces trois objectifs de recherche sont réalisés par le biais d'une série de quatre études qui s'appuient les unes sur les autres, considérant autant le domaine de la recherche que celui de la planification.

La première étude analyse 32 plans de transport de différentes régions du monde et démontre que, bien que le concept d'accessibilité soit présent dans la plupart des plans, celui-ci se traduit rarement par des objectifs et des indicateurs reflétant la facilité d'accéder aux destinations. Cette réalité s'explique, entre autres, par le fait que le terme accessibilité est utilisé de façon vague et n'est pas clairement défini dans la majorité des plans. Cette étude met en lumière les lacunes quant à l'intégration de l'accessibilité dans la planification et identifie un ensemble de meilleures pratiques qui permettent de considérer, de façon efficace, la facilité d'accéder aux destinations dans les plans de transport métropolitains.

Les résultats de cette première étude sont renforcés par une seconde étude ayant sondé 343 professionnels en transport à propos de l'accessibilité. Cette étude démontre que la plupart des professionnels, bien qu'ils soient familiers avec le concept d'accessibilité, ne considèrent pas la facilité d'accéder aux destinations dans leur travail. De plus, l'analyse des résultats révèlent deux barrières principales à l'utilisation d'indicateurs d'accessibilité : le manque de connaissances et le manque de données. Inversement, la présence d'indicateurs clairement définis dans les documents de planification ainsi que la propre initiative des professionnels sont identifiés comme les principales raisons motivant l'utilisation d'indicateurs d'accessibilité. L'étude met également en lumière la nécessité d'une plus grande collaboration entre les chercheurs et les professionnels en transport.

À la lumière des barrières identifiées ci-dessus, la troisième étude compare l'utilité, pour la planification des transports, de différentes mesures d'accessibilité. Trois mesures d'accessibilité à l'emploi en transport en commun dans la Grande Région de Toronto et Hamilton sont générées et comparées à l'aide d'un modèle de régression de part modale. L'étude conclut que la mesure la plus simple – le nombre d'emplois accessibles en moins de 45 minutes à 8h – est la mesure la plus adéquate pour évaluer la performance des systèmes de transport et d'aménagement du territoire au niveau métropolitain.

À l'aide de la mesure d'opportunités cumulatives identifiée ci-dessus, la dernière étude réalise une analyse de l'équité des transports en commun dans quatre régions métropolitaines au Brésil. L'étude propose une méthode accessible à la plupart des agences de transport et illustre la pertinence des indicateurs d'accessibilité pour informer la planification des transports et de l'aménagement du territoire pour atteindre un objectif sociétal plus large. De plus, cette étude contribue aussi à une meilleure collaboration entre chercheurs et professionnels, ayant été réalisée en collaboration avec des professionnels en transport.

En conclusion, cette thèse propose une série d'études complémentaires visant à combler l'écart entre la recherche et la pratique afin de mieux comprendre comment les indicateurs d'accessibilité peuvent être intégrés dans la planification des transports et de l'aménagement du territoire. Plus concrètement, cette thèse contribue au développement des connaissances dans le domaine de l'accessibilité par les moyens suivants :

- **Mettre en lumière l'écart** existant entre la recherche et la pratique ;
- Approfondir notre compréhension des **pratiques actuelles** en matière d'accessibilité et identifier les **barrières** à l'intégration d'indicateurs d'accessibilité en pratique ;
- Identifier **un ensemble de pratiques et d'indicateurs** qui peuvent être mis en œuvre par les professionnels pour prendre en considération la facilité d'accéder aux destinations et évaluer la performance conjointe des systèmes de transport et de l'aménagement du territoire ;
- Offrir une **méthodologie reproductible pour évaluer l'équité des transports par le biais des mesures d'accessibilité** en utilisant des données qui sont accessibles à la majorité des agences de transports du Nord global, et à un nombre croissant de celles-ci dans le Sud global.

Cette thèse démontre l'importance de se questionner sur comment inclure l'accessibilité dans la planification des transports, que ce soit par rapport à sa définition ou à son opérationnalisation en pratique, et de comment la recherche peut contribuer de façon plus significative aux enjeux auxquels les professionnels font face.

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AUTHOR CONTRIBUTIONS

This dissertation consists of four manuscripts that have been submitted to peer-reviewed journals. All manuscripts were completed with a co-author; details of author contribution are given below.

Chapter 2 "How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transport plans" by Geneviève Boisjoly and Ahmed El-Geneidy. Ahmed El-Geneidy contributed intellectually and provided comments and edits to the manuscript. Geneviève Boisjoly was the primary author of the manuscript. She performed all of the statistical analysis, interpretation of the results and writing.

Chapter 3 "The insider: A planners' perspective on accessibility" by Geneviève Boisjoly and Ahmed El-Geneidy. Ahmed El-Geneidy contributed intellectually and provided comments and edits to the manuscript. Geneviève Boisjoly was the primary author of the manuscript. She performed all of the data collection and analysis, interpretation of the results and writing.

Chapter 4 "Daily fluctuations in public transport and job availability: A comparative assessment of time-sensitive accessibility measures" by Geneviève Boisjoly and Ahmed El-Geneidy. Ahmed El-Geneidy contributed intellectually and provided comments and edits to the manuscript. Geneviève Boisjoly was the primary author of the manuscript. She performed all of the analysis, interpretation of the results and writing.

Chapter 5 "Inequity in transit: Evaluating public transport distribution through accessibility measurements in São Paulo, Rio de Janeiro, Curitiba and Recife, Brazil" by Geneviève Boisjoly, Bernardo Serra, Gabriel T. Oliveira, and Ahmed El-Geneidy. Bernardo Serra and Gabriel T. Oliveira and Ahmed El-Geneidy provided help with the data collection, contributed intellectually and provided comments and edits to the manuscript. Geneviève Boisjoly was the primary author of the manuscript. She performed the data collection and all of the analysis, interpretation of the results and writing.

PUBLICATIONS DETAILS AND PERMISSION

Chapter 2 "How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transport plans" is published in Transport Policy, Volume 55: 38-50, 2017 and is included with permission from Elsevier.

Chapter 3 "The insider: A planners' perspective on accessibility" is published in the Journal of Transport Geography, Volume 64: 33-43, 2017 and is included with permission from Elsevier.

Chapter 4 "Daily fluctuations in public transport and job availability: A comparative assessment of time-sensitive accessibility measures" is published in the Journal of Transport Geography, Volume 52: 73-81, 2016 and is included with permission from Elsevier.

Chapter 5 "Inequity in transit: Evaluating public transport distribution through accessibility measurements in São Paulo, Rio de Janeiro, Curitiba and Recife, Brazil" is currently under review for publication in the Journal of Transport Geography.

CHAPTER ONE: INTRODUCTION

1.1 OVERVIEW OF CHAPTER

This dissertation discusses how access to destinations is measured and included in land use and transport planning practice. While transport planning has traditionally focused on mobility, cities around the world are increasingly discussing accessibility goals in an attempt to develop economically, socially and environmentally sustainable communities. Against this background, planners and decision-makers are recognizing the importance of accessibility as a complement to mobility. Yet, since mobility approaches are strongly rooted in practice, the implementation of accessibility-based approaches in planning remains a challenge and this is especially a concern for equity planning. Accordingly, the studies included in this thesis focus on the use of accessibility indicators in land use and transport planning to support the development of accessibility-based practices and how this can be used in equity assessments, especially in data-challenging environments.

To contextualize my work, this introductory chapter discusses the following themes:

- From mobility to accessibility
- What is accessibility and why is it important?
- How is accessibility measured?
- How is accessibility currently considered in land use and transport planning?
- How is accessibility included in equity assessments?

After setting my thesis in the context of the existing literature, I will identify the gaps in the literature that my dissertation aims to address, explain my research question and objectives, present my overarching research design and conclude with a detailed description of the four chapters (manuscripts) included in the dissertation.

1.2 FROM MOBILITY TO ACCESSIBILITY

Transport planning has evolved through the 20th century to accommodate the rise of mass private transport. The growth of automobile ownership in North America and Western Europe in the 1920s, and more significantly after World War II, presented individuals with new opportunities (Muller, 2004). Individuals could travel faster and could thus locate further away from their work, and access activities located further away. The popularity and widespread use of the automobile brought significant challenges for urban planners. The new demand for road space far exceeded the existing supply, which resulted in major congestion issues (Wachs, 1993). In this context, transport planning largely developed with the main aim of facilitating the smooth and safe movement of vehicles, through the expansion of road networks (Levinson & Gillen, 2005). As a result, indicators of mobility such as hours of delay, traffic speed, and number of cars in congestion became dominant in the realm of transport planning (Levinson & Gillen, 2005). Still today, cities in the United States look up to the Urban Mobility Scorecard from the Texas Transportation Institute to see how well they are doing in terms of urban transport.

However, mobility – defined as the ease of moving (Preston & Rajé, 2007) – is a derived demand resulting from individuals' and firms' desire to participate in activities that are spatially distributed across a region. While a few people travel for the joy of travel (circa 0.5% of all trips in the US (Hanson, 2004)), most people undertake trips to accomplish other activities such as working, shopping, visiting friends, etc. Accordingly, travel demand is closely related to the distribution of activities in a region, in addition to the fluidity of the transport system. Inversely, land use developments are largely influenced by transport infrastructures. Given the complex interactions between land use patterns, travel demand and transport infrastructures, increasing road capacity has failed to alleviate congestion (Downs, 2004). Although expanding road infrastructures relieves congestion in the short term, it results in continuous increases in car use in the long run, as a result of induced demand and land development (Downs, 2004; Levinson & Krizek, 2007). Accordingly, and given the growing awareness toward the negative externalities of car use, the shortcomings of the mobility-centered approach are becoming more and more apparent. As a complement, accessibility has been put forward as a central goal for the future of transport planning.

1.3 WHAT IS ACCESSIBILITY AND WHY IS IT IMPORTANT?

As highlighted by Gould (1969), "Accessibility... is a slippery notion . . . one of those common terms that everyone uses until faced with the problem of defining and measuring it" (p. 64). With this in mind, it is essential to define accessibility in the context of this research. In the fields of urban planning, geography and transport planning, accessibility has been widely used to conceptualize the interactions between land use and transport systems. The term accessibility was popularized by Hansen (1959), and following Hansen's work, many researchers have sought to operationalize accessibility, giving rise to a broad variety of definitions. Drawing on key studies that have influenced accessibility research, mainly in the field of transport geography, the main definitions of accessibility are presented in Table 1.

Table 1: Definitions of accessibility

Authors	Definition of accessibility
Hansen (1959)	Potential for opportunities of interaction Measurement of the spatial distribution of activities around a point, adjusted for the ability and the desire of people or firms to overcome spatial interaction
Ingram (1971)	Inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction (for example, time and/or distance)
Wachs and Kumagai (1973)	Ease with which citizens may reach a variety of opportunities for employment and services Physical accessibility as a social indicator
Dalvi and Martin (1976)	The ease with which any land-use activity can be reached from a location using a particular transport system
Ben-Akiva and Lerman (1979)	The benefits provided by land use and transportation systems
Geurs and van Wee (2004)	The extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s) Accessibility measures are seen as indicators for the impact of land-use and transport developments and policy plans on the functioning of the society in general
Preston and Rajé (2007)	Ease of reaching
Levinson and Krizek (2007)	Ease of reaching land use given the transportation system

Although there is no commonly agreed upon definition of accessibility, two main perspectives emerge from the ensemble of the definitions. Firstly, accessibility is about reaching places using the transport system. It hence refers to the geographical access to destinations. Secondly, accessibility is an indicator of the combined performance of the land use and transport systems. Drawing on these common elements, this research uses the following working definition of accessibility:

> Accessibility is defined as the <u>ease of reaching</u> destinations, and reflects the <u>performance</u> of the land use and transport systems in an area.

In line with this definition, it has been well documented in the literature that greater accessibility can help reduce car use, increase social equity, and support economic development. For example, greater accessibility is associated with higher employment rates (Blumenberg & Ong, 2001; Ornati, Whittaker, & Solomon, 1969; Pignatar & Falcocch, 1969; Sanchez, 1999; Sari, 2015; Tyndall, 2015) and land values (Du & Mulley, 2012; El-Geneidy & Levinson, 2006; Koenig, 1980). Furthermore, increased accessibility reduces the risks of social exclusion (Lucas, 2012; Preston & Rajé, 2007) and has the potential to improve individuals' health and overall quality of life (Wachs & Kumagai, 1973; Wasfi, Ross, & El-Geneidy, 2013; Webb, Netuveli, & Millett, 2011; Weinstein Agrawal, Schlossberg, & Irvin, 2008). Finally, accessibility by public transport is associated with greater public transport use and can thus help reduce car use and the resulting greenhouse gas emissions (Handy, 2002; Levinson, 1998).

It is important to note that this dissertation is anchored in the transport geography literature, which is concerned with the geographical access to destinations and the interactions between land use and transport systems. Whereas this research targets geographical accessibility, other, less tangible factors affect one's access to opportunities. These include financial, social and cultural considerations. Furthermore, with the rise of information technologies, access to opportunities can be achieved without geographical consideration in some cases. The spatial dimension of accessibility will nonetheless remain a major determinant of social and economic interactions.

1.4 HOW IS ACCESSIBILITY MEASURED?

Over the past five decades, the measurement of accessibility has remained a major challenge (Dalvi & Martin, 1976; Geurs & van Wee, 2004; Handy & Niemeier, 1997; Koenig, 1980; Morris, Dumble, & Wigan, 1979), largely because the ease of reaching destinations is contingent on a variety of interacting factors. These factors can be grouped into four components, as identified by Geurs and van Wee (2004) in an extensive review of the literature (Figure 1). To start with, access to destinations is largely influenced by the distribution of residential, economic, cultural and social activities (the land use component). Accessibility further depends on the transport network which determines the travel time, costs and convenience from a place (for example, home) to another (for example, work) (the transport component). In addition to the exogenous factors, individual characteristics such as income, level of education, gender and vehicle ownership affect one's abilities and needs to access destinations (the individual component). Finally, time restrictions also play an important role in determining accessibility (the temporal component). These include the availability of opportunities (i.e., opening hours), the personal time constraints, and the schedule of public transport services.

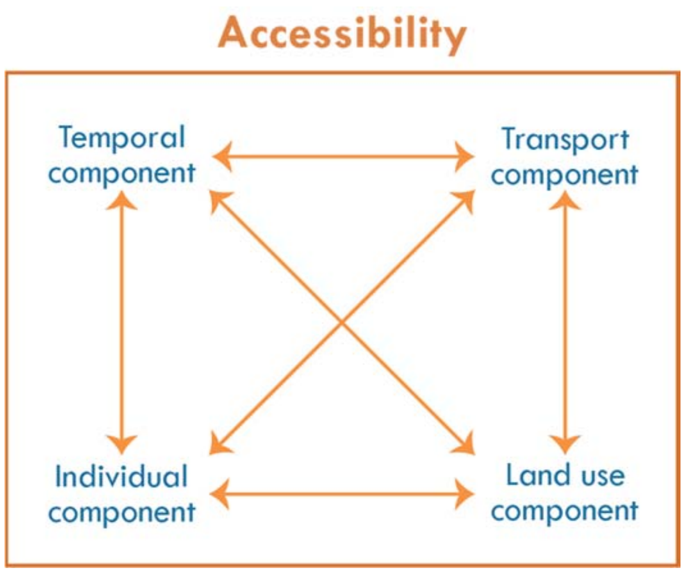

Figure 1: Components of accessibility (inspired from Geurs & van Wee, 2004)

As accessibility research has emerged to explain the interactions between land use and transport, the first measures of accessibility have typically focused on these two components (Hansen, 1959). Later research has built on these location-based measures to account, to a certain extent, for the individual and temporal components. For example, recent studies have included in their measures the daily fluctuations in public transport services (Anderson, Owen, & Levinson, 2012; El-Geneidy et al., 2015; Farber, Morang, & Widener, 2014). Other studies have developed measures of accessibility specific to an income group or accounting for the income profile of the workers residing at the origin (Karner, 2018; Legrain, Buliung, & El-Geneidy, 2016). Nevertheless, these measures remain aggregated measures of accessibility. In contrast, temporal and individual factors are predominant in studies of person-based accessibility (Miller, 2005). These studies are largely based on the space-time prism, developed by Hagerstrand (1970), and focus on the accessibility constraints experienced by a specific individual. Similarly, utility-based measures assess the valuation of accessibility by individuals, but from an economic perspective (Ben-Akiva & Lerman, 1985). While person-based measures provide an in-depth assessment of individuals' accessibility, they are difficult to communicate and to operationalize at the regional level. In this regard, location-based accessibility is generally more useful in providing a regional assessment of land use and transport systems' performance. Overall, this brief overview of accessibility measures highlights the variety of measures that have emerged in the last decades in an attempt to balance between the specificity of the measure, and its operationalization in practice.

Yet, despite the recent rise in the development of accessibility measures, few studies have assessed the usability of these measures for planning purposes. From a planning perspective, the usability of a measure depends on multiple criteria that are often in conflict with each other. On the one hand, measures must be theoretically sound, sensitive to the multiple accessibility components (Geurs & van Wee, 2004). On the other hand, measures should be easy to operationalize, and easily interpretable and communicable (Geurs & van Wee, 2004; Handy & Niemeier, 1997). While a few studies have discussed the theoretical implications of different measures, no empirical study has to my knowledge compared the usability of different accessibility measures in practice.

1.5 HOW IS ACCESSIBILITY CONSIDERED IN LAND USE AND TRANSPORT PLANNING?

Whereas transport has emerged as an isolated field, researchers started in the second half of the 20th century to emphasize the need to include accessibility as a performance indicator in land use and transport plans as an alternative approach to mobility-based transport planning (Koenig, 1980; Morris et al., 1979; Wachs & Kumagai, 1973). They argued that accessibility better reflected the economic and social benefits of the network, namely in terms of land values and quality of life (Koenig, 1980; Wachs & Kumagai, 1973). More recently, accessibility has been put forward as a central theme of research, namely with respect to social equity, economic development and environmental protection (Handy, 2002; Lucas, 2012; Preston & Rajé, 2007).

However, although accessibility has been a central theme of research in the last decades and has recently gained attention in the planning sector, transport planning is still dominated by a mobility-oriented paradigm. In an assessment of four metropolitan plans in California, Handy (2005) found that plans were developed around mobility although they addressed some concerns with accessibility. These concerns were, however, not defined as accessibility issues. More recently, Proffitt, Bartholomew, Ewing, and Miller (2017) found that accessibility is increasingly incorporated in American transport plans, especially in larger metropolitan areas, but is still marginally addressed compared to mobility. For example, increasing road capacity or traffic speed was the most commonly recommended intervention in the plans assessed. Also, only 23% of the plans included access-to-destination indicators, compared to 45% for vehicle-miles-traveled indicators. Furthermore, accessibility is often not clearly defined in the plans and thus often used as a buzzword. While almost all plans included the word accessibility, only 10% defined the term. In the United Kingdom (UK) context, the concept of accessibility has been widely used, mainly due to the establishment of accessibility planning requirements by the national government

(Halden, 2011). However, given the broad and flexible guidelines, accessibility is often “misused” and “abused in practice” (Halden, 2011). Furthermore, there is no consensus about which accessibility indicators and metrics should be used in planning practice (Halden, 2011).

Overall, research has shown that the paradigm shift from mobility to accessibility is far from complete. Accessibility is not yet a mature concept in planning and is accordingly not being used effectively. In fact, although transport issues are increasingly framed in terms of access to opportunities (Geurs, Krizek, & Reggiani, 2012; Handy, 2008; Lucas, 2012; Manaugh, Badami, & El-Geneidy, 2015; Preston & Rajé, 2007), the implementation of accessibility in policy and practice is generally limited (Halden, 2011; Levinson & Gillen, 2005; Proffitt et al., 2017). It is important to mention that, while most studies focus on the Global North, this gap in practice is even more significant in the Global South, where data collection represents a significant challenge.

1.6 ACCESSIBILITY AND EQUITY IN RESEARCH AND PRACTICE

Equity issues are inherent to the provision of transport infrastructures and services. Transport agencies are increasingly concerned with equity due to a variety of reasons including, but not limited to, the increasing number of funding bodies and policies requiring equity assessments (Golub & Martens, 2014; Karner, 2016; Manaugh et al., 2015). Whereas there is a lack of guidance on how to define and assess equity in the distribution of transport investments (Golub & Martens, 2014; Lucas & Jones, 2012; Pereira, Schwanen, & Banister, 2017), accessibility is increasingly presented as a key concept and indicator for transport equity analyses (Karner, 2018; Lucas, van Wee, & Maat, 2016; Manaugh et al., 2015; van Wee & Geurs, 2011).

1.6.1 Theories of justice and transport

From a theoretical perspective, researchers argue that accessibility, broadly understood as the level of access to opportunities, should be considered to assess the distribution of benefits provided by transport systems (Lucas et al., 2016; Martens, 2016; Martens, Golub, & Robinson, 2012; Pereira et al., 2017; van Wee & Geurs, 2011). Several authors build on Rawls' theory of justice to support the idea that accessibility is central to transport justice (Martens, 2016; Martens et al., 2012; Pereira et al., 2017; van Wee & Geurs, 2011). Rawls' theory of justice identifies a set of *primary goods* that are essential to every citizen, and argues that institutions should play a role in the distribution of these goods to ensure that all citizens are equal (Martens, 2016; Pereira et al., 2017). Although Rawls does not identify accessibility as *a primary good*, Martens (2016) provides a strong argument for considering accessibility as such. Whereas Rawls defines *primary goods* as the set of goods that enable individuals to pursue their own life plans, Martens (2016) demonstrates that accessibility is essential to enable individuals to meet their needs, as it allows them to reach activities and opportunities. Accordingly, given that accessibility is argued to be a basic good in the sense of Rawls' theory of justice, it should be distributed according to the principles of justice (Martens, 2016; Pereira et al., 2017). In other words, the literature suggests that transport planners and policy-makers wanting to consider equity in the distribution of transport benefits should be primarily concerned with the level of accessibility that is provided to individuals.

Another principle of justice discussed in the context of transport refers to the equity of infrastructure and service distribution. Egalitarian theories, such as Rawls' theory of justice, stipulate that all people should be treated equally (Lucas et al., 2016). Similarly, the capability approach suggests that all individuals should be provided with equal opportunities (Pereira et al., 2017). While this could suggest that the benefits of transport systems should be equally distributed to all individuals, researchers emphasize that what matters is equality of opportunities. Since individuals inevitably have unequal opportunities in a society, given internal and external constraints, egalitarian theories suggest that an unequal distribution of transport benefits should be considered to minimize inequality of opportunities (Martens, 2016; Pereira et al., 2017). In other words, it is argued that individuals who are more likely to have limited opportunities, due to financial, cultural, physical, or cognitive constraints, should be provided with higher levels of accessibility.

1.6.2 Accessibility and equity in the distribution of public transport services

Against this theoretical background, a number of studies have used accessibility indicators to measure equity, especially with respect to public transport. Furthermore, most of these studies adopt the concept of vertical equity, which is in line with the theories of justice discussed above (Bocarejo & Oviedo, 2012; Delmelle & Casas, 2012; El-Geneidy et al., 2015; Foth, Manaugh, & El-Geneidy, 2013; Golub & Martens, 2014; Grengs, 2001, 2010; Kaplan, Popoks, Prato, & Ceder, 2014; Karner, 2018; Paez, Mercado, Farber, Morency, & Roorda, 2010a, 2010b; Welch, 2013). More specifically, vertical equity is defined in transport planning as providing greater benefits to the populations that are potentially the most in needs (Stanley & Lucas, 2008), which we refer to in this dissertation as disadvantaged or vulnerable groups. In the context of transport, this includes low-income individuals, low-skilled workers, children and youth, elderly people and minority groups, as these individuals are more likely to suffer from lack of accessibility, due to either transport or location constraints (Clifton, 2004; Currie, 2010; Delmelle & Casas, 2012; Dodson, Buchanan, Gleeson, & Sipe, 2006; Foth et al., 2013; Jaramillo, Lizarraga, & Luis Grindlay, 2012; Kawabata, 2003).

A common approach to measuring vertical equity in accessibility studies compares the level of accessibility provided to different socio-economic groups in a region. To do so, researchers typically measure the level of accessibility for every zone (census tract, traffic analysis zone, neighborhood) in a region and combine these measures with socio-economic data (Bocarejo &

Oviedo, 2012; Delmelle & Casas, 2012; Foth et al., 2013; Grengs, 2001; Kaplan et al., 2014; Lucas et al., 2016; Paez et al., 2010a, 2010b; Welch, 2013). Such analysis is typically conducted in an aggregated manner, by considering the socio-economic characteristics at the zonal level (Bocarejo & Oviedo, 2012; Delmelle & Casas, 2012; El-Geneidy et al., 2015; Foth et al., 2013; Grengs, 2001; Kaplan et al., 2014). For example, El-Geneidy et al. (2015) grouped the census tracts of Toronto, Canada into ten socio-economic decile (based on income, unemployment, immigration and rent data) and then compared the average accessibility to jobs of each decile. By doing so, the authors determined that, while the lowest decile (most vulnerable) had a high level of accessibility relative to the rest of the region, the second and third lowest decile had a lower than average accessibility and therefore required attention in terms of land use and transport interventions. Kaplan et al. (2014) adopted a similar approach and visually compared the level of accessibility to employment opportunities and the median income of each zone in Copenhagen, Denmark. The study led to the identification of specific low-income zones with a low level of accessibility, which are to be targeted from a vertical equity standpoint. While the first study (average accessibility by socio-economic decile) allows quantifying the discrepancies between groups, the second study (visual comparison) is a useful tool to specifically identify areas that are disadvantaged in terms of opportunities. In both cases, the comparison of accessibility across socio-economic neighbourhoods contributes to assessing the level of accessibility provided to vulnerable neighborhoods compared to the rest of the region. From a land use and transport perspective, this provides a better understanding of the performance of land use and transport systems relative to the localization of vulnerable populations.

Another approach to assessing accessibility from a vertical standpoint is to generate accessibility indicators specific to each socio-economic group of interest. For example, Paez et al. (2010b) generated a distinct cumulative-opportunity accessibility measure for four different personal profiles (senior with vehicle, senior without vehicle, non-senior with vehicle, non-senior without vehicle). To do so, they calculated a specific distance threshold for each profile based on individual socio-economic characteristics (age, income, etc.) and vehicle ownership. They then used the distance thresholds of each profile to calculate a measure accessibility specific to each profile. The results illustrate the level of accessibility in each zone, for each profile, and thus allow directly comparing the level of accessibility provided to the different profiles. This approach is not widely used in research or practice, likely because it is more complex to operationalize and communicate and requires access to more data sources. The approach is nonetheless relevant to investigate accessibility issues specific to certain groups.

A third approach, proposed by Golub and Martens (2014) in a case study of the San Francisco Bay Area, consists in comparing accessibility to jobs by car and by public transport to assess modal equity. In this study, the authors generate an access ratio for each zone, dividing the level of accessibility via public transport by the level of accessibility by car. A ratio of 1 means that individuals using public transport have the same level of accessibility as individuals using a private vehicle, while a ratio below 1 reflects a lower level of accessibility by public transport. This approach addresses vertical equity from a modal perspective, but could be combined with socio-economic data to identify areas with the greater needs.

Overall, different approaches have been proposed in the literature to evaluate equity through accessibility measures. As highlighted above, equity issues are increasingly considered in transport planning, often as part of a requirement from an overseeing institution. Equity is generally linked to the concept of accessibility in metropolitan transport planning (Karner, 2016; Manaugh et al., 2015), yet accessibility to transport, rather than destinations, is still predominant in practice

(Atlanta Regional Commission, 2016; Leadership Council of the Sustainable Development Solutions Network, 2015; Marks, Mason, & Oliveria, 2016; Metrolinx, 2008; Singapore Land Transport Authority, 2013). As a result, many agencies rely on simple indicators of proximity in their plans, and little attention is given to robust accessibility indicators in equity analyses (Karner, 2016).

1.7 GAPS IN KNOWLEDGE

This dissertation stems from the increased interest in accessibility planning and the challenges related to its implementation in practice. As a key land use and transport performance measure, accessibility has been extensively researched with the ultimate purpose of informing decision-making and influencing land use and transport planning. Academics have demonstrated the multiple benefits of accessibility in various regional contexts and have explored multiple ways of measuring of accessibility. Yet, accessibility is still marginalized in land use and transport planning, and little is known on the use of accessibility measures in practice. Furthermore, whereas a plethora of accessibility measures have been developed, there is little research assessing the usability of the various measures and significant gaps remain in the implementation of accessibility measures to evaluate transport equity, especially in the Global South.

1.8 RESEARCH OBJECTIVES

With this in mind, the ultimate goal of this research is to contribute to the implementation of accessibility measures[1] in land use and transport planning practice. To do so, this research will answer the following overarching research question:

How can accessibility measures be incorporated into current land use and transport planning practice in order to improve our understanding of the performance of land use and transport systems?

To answer this question, the following objectives will be pursued:

1. To determine **how accessibility is used** in land use and transport planning practice;
2. To identify **appropriate measures** of accessibility to be used in land use and transport planning practice;
3. To **generate measures** of accessibility in a data-challenging context in collaboration with local transport planners.

The first objective acknowledges that it is essential to first evaluate the current use of accessibility in practice in order to identify the challenges and opportunities associated with the incorporation of accessibility in land use and transport practice (objective 1). Secondly, these challenges and opportunities need to be addressed in research. To do so, this thesis will assess, from a planning perspective, the various measures of accessibility that have been presented in the academic literature, with a focus on public transport systems (objective 2). It will then demonstrate how such

[1] Note on accessibility indicators, accessibility measures and accessibility metrics: In this dissertation, the terms "accessibility indicators", "accessibility measures" and "accessibility metrics" are used interchangeably and refer to the primarily quantitative measurement of the level of accessibility provided by land use and transportation systems.

measures can be developed to address planning objectives in a data-challenging context, in collaboration with local transport planners, in order to increase research applicability and knowledge transfer (objective 3). This last study will focus on public transport equity in Brazilian metropolitan regions, as the Global South has received less attention in research and in practice, and where the lack of accessibility by public transport is a growing concern, especially with respect to low-income areas. It is important to mention that all three objectives focus on metropolitan (also referred to as regional) land use and transport planning.

The research design consists of a combination of qualitative and quantitative methods and is divided into four studies (Figure 2). Each study corresponds to a chapter of the dissertation, in addition to the introduction and conclusion chapters.

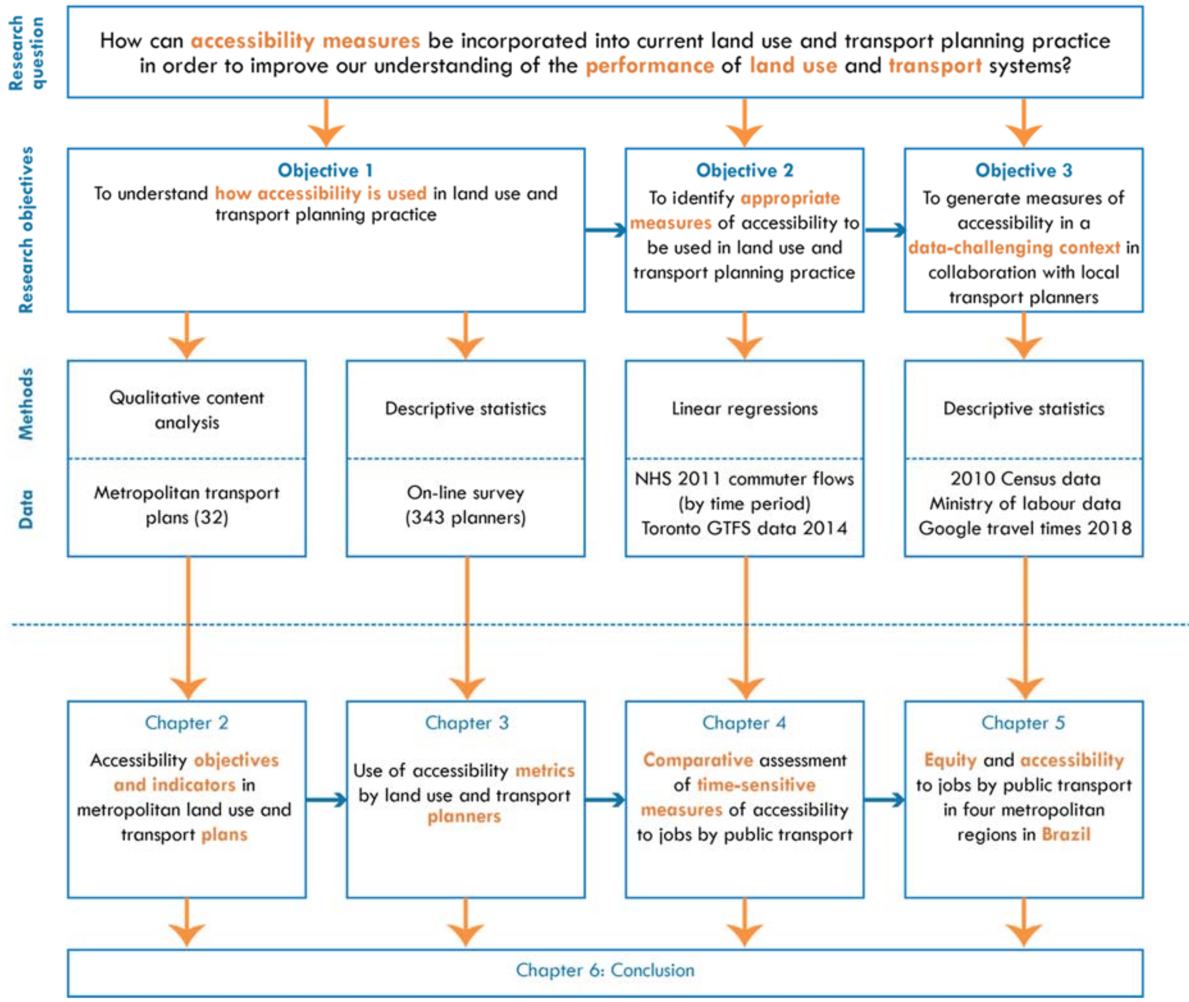

Figure 2: Research design of the proposed research

1.9 DISSERTATION STRUCTURE AND OVERVIEW OF CHAPTERS

This dissertation is structured in accordance with the guidelines of McGill University for a manuscript-based doctoral thesis. It is comprised of four manuscripts that collectively address the research question and objectives presented in the previous section. Chapters 2 to 5 each correspond to a manuscript. They include a brief overview of the study prior to the manuscript as well as distinct introduction, literature review, methodology, results and conclusion sections. Chapter 6 concludes the dissertation by linking together the findings of the four manuscripts. This chapter also summarizes the contribution of the research in the context of broader research objectives and provides recommendations for the implementation of accessibility measures in planning practice as well as avenues for future research. The four manuscripts are briefly introduced below.

Chapters 2 and 3 complementarily address the first objective of determining how accessibility is used around the world. Chapter 2 critically assesses how accessibility is considered in metropolitan transport plans, through a qualitative assessment of planning documents. Chapter 3 then identifies how accessibility metrics are deployed by land use and transport planners, through descriptive statistics of data obtained via an on-line survey. As part of the first objective, these studies highlight the main barriers and opportunities for implementing accessibility-based tools in planning.

Building on the results of these studies, Chapter 4 seeks to identify appropriate measures of accessibility from a planning perspective, by considering the trade-offs between theoretical and empirical soundness on one hand, and ease of communication and data requirements on the other hand. The study thus examines various measures of accessibility and adds to the literature by empirically comparing them. To do so, three types of measures are generated using the same dataset, and included in mode choice models. The accuracy of the measures is then assessed based on the fit of the models. Based on predefined usability criteria, the study concludes by identifying the most appropriate measure of accessibility among the selected ones.

Building on this study, Chapter 5 aims to demonstrate the relevance of the identified accessibility measure to achieve planning objectives. As a case study, accessibility to jobs by public transport is measured for four metropolitan regions in Brazil to assess equity in the distribution of public transport services using data sources that are available to most planners and policy makers. The study provides a comprehensive view of the socio-spatial distribution of public transport services in four large metropolitan areas in Brazil and highlights the importance of quantifying accessibility by public transport, in addition to proximity to rapid transit.

The thesis concludes by providing improved insights on the use of accessibility in practice, and on how to address the current challenges and opportunities.

CHAPTER TWO: HOW TO GET THERE? A CRITICAL ASSESSMENT OF ACCESSIBILITY OBJECTIVES AND INDICATORS IN METROPOLITAN TRANSPORT PLANS[2]

2.1 OVERVIEW OF CHAPTER

Accessibility, the ease of reaching destinations, is increasingly seen as a complimentary and in some cases alternative to the mobility oriented planning paradigm, as it allows capturing the complex interactions between land use and transport systems while providing a social perspective on transport planning. However, although accessibility has been extensively researched in the last decades, it is still largely marginalized in transport planning practice. Accordingly, the aim of this chapter is to critically assess how accessibility is incorporated into metropolitan transport plans and translated into performance indicators around the world, to ultimately derive policy recommendations. This research assesses 32 recent metropolitan transport plans from North America, Europe, Australia and Asia with respect to their goals, objectives and performance indicators. The results suggest that there is a trend toward a greater integration of accessibility objectives in transport plans, yet few plans have accessibility-based indicators that can guide their decision-making processes. The findings show that in order to foster accessibility-based approaches to transport planning, plans need to have clearly defined accessibility goals with a distinction between accessibility and mobility. Furthermore, multi-criteria analysis approaches including accessibility indicators need to guide the decision-making process. This study contributes to a greater understanding of the challenges and successes associated with implementing accessibility in transport planning.

[2] Boisjoly, G., & El-Geneidy, A. (2017). How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transportation plans. *Transport Policy, 55*, 38-50.

2.2 INTRODUCTION

Accessibility is increasingly seen as an alternative to mobility oriented planning paradigm (Geurs et al., 2012), as it allows capturing the complex interactions between land use and transport systems (Hansen, 1959) and provides a social perspective on transport planning (Banister, 2008; Lucas, 2012). While mobility merely reflects the ease of moving, accessibility addresses the ease of reaching desired destinations, which is in fact the reason why people undertake trips (Preston & Rajé, 2007). Accessibility is one of the most comprehensive measures to assess the complex performance of land use and transport systems in a region. As it has been well documented in the literature, accessibility can help in reducing car use, increasing social equity, and support economic development. Accordingly, transport planning is increasingly framed in terms of access to opportunities (Geurs et al., 2012; Handy, 2008; Lucas, 2012; Manaugh et al., 2015; Preston & Rajé, 2007). Nevertheless, the concept of mobility is still prioritized over accessibility in practice (Halden, 2011; Levinson & Gillen, 2005; Proffitt et al., 2017).

The aim of this paper is to critically assess how accessibility is incorporated into metropolitan transport plans and translated into performance indicators around the world. This analysis seeks to identify best practices and provide guidelines on how to effectively use accessibility in planning. In order to do so, a qualitative content analysis of 32 recent plans from metropolitan areas in North America, Europe, Australia and Asia is conducted. The analysis focuses on the vision, goals, objectives and performance indicators stated in the plans. The general trends as well as the best practices are highlighted in this study. This study contributes to a greater understanding of practical challenges and successes associated with accessibility planning. This research is of relevance to decision-makers and transport planners wishing to better integrate accessibility in their plans and practice. It also provides researchers with a greater understanding of the current planning practices, and potentially contribute to bridging the gap between ongoing research and planning practice.

2.3 LITERATURE REVIEW

2.3.1 What is accessibility?

In simple words, accessibility can be understood as the ease of reaching services and activities (Litman, 2013). For the purpose of this study, we focus on geographical accessibility, that is the ease of reaching destinations (Preston & Rajé, 2007). Following this definition, accessibility is largely contingent on the spatial distribution of destinations, the land use component, and the ability to move from one place to another, the transport component (Geurs & van Wee, 2004). The land use component is related to the spatial distribution of opportunities. Urban opportunities can include, but are not limited to, jobs, health services and retail stores. The transport component refers to the transport infrastructure specific to each mode. In addition to transport and land use, there are temporal and individual components to accessibility (Geurs & van Wee, 2004). The availability of opportunities for example (opening hours of shops and services, job starting time) represents temporal elements, whereas personal characteristics such as income and car ownership reflect the individual component.

Given the multiple components of accessibility, accessibility can be measured in different ways (Geurs & van Wee, 2004; Handy & Niemeier, 1997; Paez, Scott, & Morency, 2012). Firstly, accessibility can be measured at the individual level (person-based), or at the location level (place-based) (Miller, 2005). Whereas person-based metrics focus on the individual component, place-based metrics mainly account for the land use and transport components. The individual component is sometimes included in location-based studies by stratifying population by age group or socio-economic characteristics, and by segmenting destinations (by job types for example) (Fan, Guthrie, & Levinson, 2012; Legrain, Buliung, & El-Geneidy, 2015; Legrain et al., 2016; Paez et al., 2010a). Location-based accessibility is most commonly used by policy-makers as it provides a comprehensive measure of the land use and transport system at the regional level (Dodson, Gleeson, Evans, & Sipe, 2007). Location-based metrics typically accounts for the number of opportunities that can be reached from a specific location, based on the travel costs to destinations using a specific mode (Handy & Niemeier, 1997).

Travel costs are generally measured based on travel time or distance (Geurs & van Wee, 2004; Handy, 1994; Hansen, 1959; Vickerman, 1974). Two location-based measures are commonly used in accessibility research. The first one is the gravity-based measure which discounts all opportunities based on their travel costs. The second one is the cumulative-opportunity measure, which only counts the opportunities that are within a specific travel costs threshold. Gravity-based measures better reflect travel behavior as it accounts for the travelers' perceptions of time (Ben-Akiva & Lerman, 1979). This measure is, however, more complex to generate, as a distance-decay function must be calculated, and more difficult to interpret and communicate, as it is not directly expressed in terms of the number of opportunities (Geurs & van Wee, 2004). On the other hand, cumulative-opportunity measures are easy to generate and interpret. Furthermore, these measures are highly correlated with gravity-based measures (El-Geneidy & Levinson, 2006), and hence represent an adequate measure of regional accessibility (Boisjoly & El-Geneidy, 2016).

2.3.2 From mobility to accessibility

Transport planning has emerged as an isolated field that focused mainly on mobility, defined as the ease of moving. In this context, mobility indicators such as travel speed and travel times were put forward, with a focus on motorized transport (Banister, 2008). Accessibility was first introduced by Hansen in 1959 to capture the interaction between the land use and the transport networks. Following Hansen's work, researchers started to emphasize the need to include accessibility as a performance indicator in land use and transport plans as an alternative approach to mobility-based transport planning (Koenig, 1980; Morris et al., 1979; Wachs & Kumagai, 1973). They argued that accessibility better reflected the economic and social benefits of the network, namely in terms of land values and quality of life (Koenig, 1980; Wachs & Kumagai, 1973). More recently, accessibility has been put forward as a key element of land use and transport planning (Banister, 2008; Handy, 2002; Straatemeier, 2008), namely with respect to social equity, economic development and environmental impacts (Handy, 2002; Lucas, 2012; Preston & Rajé, 2007). Whereas mobility-based approaches focus on travel time minimization, planning for accessibility aims at providing all individuals with a reasonable travel times to a variety of destinations (Banister, 2008). As a result, planning for accessibility gives greater consideration to active and public transport, and incorporate land use policies that reduce distances between activities (Banister, 2008).

Although accessibility has been a central theme of research in the last decades and has recently gained attention in the planning sector, transport planning is still dominated by a mobility-oriented paradigm. In a quantitative assessment of American transport plans, Proffitt et al. (2017) found that accessibility is increasingly incorporated in plans, especially in larger metropolitan areas, but is still marginally addressed compared to mobility. Furthermore, in those plans accessibility is often not clearly defined and thus often used as a buzzword. Similarly, in an assessment of four metropolitan plans in California, Handy (2005) found that plans were developed around mobility. Nevertheless, the plans addressed some concerns with accessibility, although they were not defined as such. In the United Kingdom (UK) context, the concept of accessibility has been widely used, mainly due to the establishment of accessibility planning requirements by the national government (Halden, 2011). However, given the broad and flexible guidelines, accessibility is often "misused" and "abused in practice" (Halden, 2011). Furthermore, there is no consensus about which accessibility indicators and metrics should be used (Halden, 2011). While a plethora of measures have been developed in academic settings, their practical implementation remains limited, which raises questions about their usability (Boisjoly & El-Geneidy, 2016; Curl, Nelson, & Anable, 2011; Geurs & van Wee, 2004). Overall, research has shown that the paradigm shift from mobility to accessibility is far from complete. Accessibility is not yet a mature concept in planning and is accordingly not being used effectively.

Given the increased interest in accessibility planning and the challenges related to its implementation, this study critically assesses transport plans from metropolitan areas in North America, Europe, Australia and Asia. This study expands upon existing research in the United States (US) and the UK to include a greater variety of planning contexts. Furthermore, no study has, to our knowledge, investigated a broad range of plans from a qualitative perspective to identify best practices and successful implementations of accessibility indicators.

2.4 RESEARCH FRAMEWORK AND METHODOLOGY

The ultimate goal of this study is to investigate which practices effectively incorporate accessibility into transport planning. To achieve this research goal, this study explores the integration of accessibility into metropolitan transport plans and seeks to answer the following research questions:

- To what extent and how is accessibility included in metropolitan transport plans around the world?
- To what extent are accessibility goals translated into performance indicators reflecting the ease of reaching destinations?

- What are the best practices and how could accessibility objectives be better integrated in metropolitan transport plans?

To address our research questions, we assessed long-range metropolitan transport plans and related documents from 32 metropolitan areas around the world. We defined three inclusion criteria for the metropolitan areas: population size, availability of documents and location. Firstly, we focused on metropolitan areas located in high-income countries, in order to get a relatively homogenous sample. Secondly, metropolitan areas with a population greater than 2.5 million inhabitants were included. A lower population threshold (2 million) was selected for Europe, in order to include a broader variety of metropolitan areas. Thirdly, the metropolitan area needed to have a transport plan available in English or French. In total, 18 metropolitan areas in the U.S. were selected, 3 in Canada, 8 in Europe, 2 in Australia, and one in Asia (Singapore). The respective plans are presented in Table 2.

Metropolitan transport plans, which include goals, objectives, and indicators, have been selected to assess how accessibility is considered in urban transport planning, as done in previous studies (Handy, 2005; Proffitt et al., 2017). Handy (2005) examined four metropolitan transport plans to assess the use of mobility and accessibility in practice. Building on this approach, Proffitt et al. (2017) quantitatively assessed the use of accessibility in 42 metropolitan plans in the US. Manaugh et al. (2015) adopted a similar approach to examine how equity objectives are included in transport planning. Our study builds on these previous studies, and expands the analysis conducted by Handy (2005) and Proffitt et al. (2017) by assessing a broader variety of plans. Furthermore, a qualitative approach is taken to allow an in-depth understanding of the plans. Finally, metropolitan transport plans were selected, rather than specific public transport plans, in order to focus on authorities that typically deal with both land use and transport strategies, and to include all modes of transport. Nevertheless, in most cases, metropolitan transport plans incorporate the main elements of local public transport plans, and set orientations for future public transport development.

For each metropolitan area, the most recent transport plan was selected. Except for four plans, all of them are from 2010 or later. Due to differences in political structures, there are some discrepancies in the type of authority that developed the plan in each metropolitan area. It was typically a metropolitan planning organization, a City administration, or a public transport agency.

To answer our research questions, a structuring content analysis was conducted with the aim of extracting the relevant material from the plans (Mayring, 2014). The analysis was conducted in four phases. The first step consisted of skimming the planning document to identify the vision, goals, and objectives structuring the plan, if any. The second step was to carefully examine the performance indicators in each plan, with the purpose of extracting indicators reflecting accessibility or defined as such. A keyword in context analysis was then conducted, allowing to explore how the concept of accessibility was used (Hsieh & Shannon, 2005). Keywords such as access, accessibility, link, connection, reach, and "get to" were used. This step was conducted to find goals, objectives or indicators that might not have been collected in the first step, and allowed to gain general understanding of the use of the concept of accessibility in the plan. Finally, a subset of plans was assessed more in details to evaluate accessibility analysis and accessibility indicators. These plans were selected based on the previous steps, and the aim was to find relevant and various examples of the use of accessibility indicators.

The research method used in this study allows assessing the current trends and best practices in the use of accessibility in metropolitan transport plans. However, there are some limitations to our studies. Firstly, the study focuses on metropolitan transport plans, typically under the responsibility of a regional or municipal planning organization. As such, distinct public transport plans from local public transport authorities fall outside the scope of this study. While further research could look more specifically into local public transport plans, the current study allows assessing how accessibility is considered in transport planning at the metropolitan scale, and for all modes. Secondly, this study focuses on the general trends, but does not allow an in-depth comparison between the plans and planning contexts. Thirdly, this study evaluates the planning documents and does not provide an in-depth understanding of the planning processes underlying the development and the implementation of the plan. It also does not address how the indicators reflect individuals' perceptions or needs, as done by Curl et al. (2011). Further research could address these limitations. Nevertheless, this study provides valuable insight on the integration of accessibility in metropolitan plans and contributes to a greater understanding of the current practices.

Table 2: Accessibility-related objectives and indicators from selected metropolitan transport plans

Metropolitan transport plan	Accessibility-related vision, goals and objectives	Indicators	Comments
Transport 2025 - London, UK (Transport for London, 2006)	**Social goal:** To improve London's accessibility (p.10) **Objectives:** Economic development: Improvement in employment accessibility, Social inclusion: Improved access to employment from deprived areas (p.25)	• The change in the number of jobs accessible by public transport within 45 minutes travel time – indicators + maps • Percentage of population in the 10 percent most deprived areas of London within 45 minutes travel time of international and metropolitan centers (p.25) • Bus accessibility index – maps (p.94-95)	Accessibility metrics are used as performance indicators to evaluate the effectiveness of various scenarios. No weight is given to the different criteria, and the accessibility metrics are not present in the final scenario assessment table (p.130-131). Some results are stated in the plan (e.g.: An increase of almost 25% in employment accessibility) Bus accessibility index is used to present a regional evaluation of the bus service.
Plan de déplacements urbains Île-de-France – Paris, France (Conseil régional d'Île-de-France, 2014)	**Objectives:** Ensure access to mobility for all, Ensure spatial equity in access to mobility, Improve access to jobs and economic centres. (p.53)*	• Number of jobs accessible within 60 minutes of public transport – map (p.36) *	Accessibility maps are presented but they are not discussed in the plan.
Urban Transportation Development Plan 2025 – Berlin, Germany **(Senate Department for Urban Development and the Environment of the State of Berlin, 2014)**	**Goals:** Improve accessibility in all outer city areas. (p.12) **Objectives:** Further improving links between Berlin and the housing areas along the axes radiating from the city. Strengthening the polycentric city structure through improved accessibility to urban neighborhoods and between districts and the main downtown centers. (p.5)	Accessibility to both the main centers and district centers	This indicator was included in a scenario assessment (not available in English)
Plan de mobilité régionale – Brussels, Belgium (Iris II) (Bruxelles Mobilité, 2011)	**Goal:** Improve regional accessibility with the most appropriate modes, to support economic and social dynamism (p.4)*	None	The plan states that an accessibility map should be generated in the near future, but no such map was found.

Local Transport Plan 3 – Manchester, UK **(Greater Manchester Combined Authority, 2011)**	**Objectives:** To support economic growth across the subregion and improve access to jobs for all. (Integrated Assessments Report p.19)	Will the LTP improve access to jobs, particularly for people who suffer income or employment deprivation? Will the LTP reduce journey times and improve accessibility for local businesses? Will the LTP improve or reduce accessibility to health care facilities, particularly for those who need the most health services e.g. the elderly, people with disabilities and those without a car? Will the LTP encourage healthier lifestyles by promoting the use of walking, cycling and public transport and increase accessibility to open greenspace and sports facilities particularly for the most deprived communities and sections of the community whose access needs are often not catered for? Will the LTP help improve accessibility through integrated spatial planning? (Integrated Assessments Report p.16-19)	Questions addressing accessibility were included in the integrated assessments report of the Local Transport Plan 3.
Plan de déplacements urbains 2010-2020 – Lille, France (Lille Métropole Communauté Urbaine, 2011)	None	None	
Local Transport Plan 3 – Birmingham, UK **(West Midlands CEPOG, 2010)**	**Goals:** To enhance equality of opportunity and social inclusion by improving <u>access</u> for all to services and other desired destinations within and adjacent to the West Midlands Metropolitan Area.	None	An accessibility analysis was conducted in 2006, prior to the elaboration of this plan. Accessibility is very present throughout the document, but not quantified in this plan.
Urban Mobility Strategy – Stockholm, Sweden **(City of Stockholm, 2010)**	**Objectives:** <u>Accessibility</u> in the road and street network is to be enhanced by increasing speeds for high-capacity transportation means and raising travel-time reliability for all road users	None	The plan focuses on accessibility and proximity but no quantified metrics are available.
Land Transport Master Plan – Singapore **(LTA, 2013)**	**Vision:** We see a future where we all can <u>get to more places</u> faster and in greater comfort as we enhance our rail, bus, cycling and sheltered walkway networks, take steps to improve the quality of our public transport services and support new options such as car sharing. (p.51)	Vision: 8/10 households living within a 10-minute walk from a train station	Access to public transport indicator is used to set the vision.

Transport Strategy 2012 - Planning for growth – Melbourne, Australia **(City of Melbourne, 2012)**	**Objectives:** Making our public transport system more effective: Accessibility (p.64)	Accessibility provided by the public transport network. (p.85)	The plan indicates that an extensive accessibility by public transport assessment was conducted. This is reflected in the justification of the measures (increased tram running speed and increased service frequency). The accessibility indicator is however not detailed in the plan itself.
Sydney Long Term Transport Master Plan – Sydney, Australia **(NSW Government, 2012)**	**Goals:** Support economic growth and productivity – by […] improving accessibility of people to other people, opportunities, goods and services. Support regional development – by improving accessibility to jobs, services and people, […]. Reduce social disadvantage – by improving access to goods, services and employment and education opportunities for people across all parts of the State. (p.22) **Objectives:** Jobs and services need to be more accessible (p.120)	Proportion of metropolitan jobs accessible within 30 minutes by public transport and private vehicle – map (p.120)	A regional evaluation is conducted to identify the gaps in accessibility to jobs.
Vancouver Transportation Investment – Vancouver, Canada (Mayor's Council on Regional Transportation, 2014)	None	Access to potential workers, jobs, and markets. (p.28)	The plan states that the projects were assessed based on these accessibility indicators.
Transportation Plan – Montreal, Canada **(Ville de Montréal, 2008)**	None	None	Improving accessibility to employment clusters is discussed in the text as a benefit of various transportation projects, but only in general terms. There is no objective or indicators related to accessibility.
The Big Move – Toronto, Canada **(Metrolinx, 2008)**	**Objectives:** Increased transportation options for accessing a range of destinations, Improved accessibility for seniors, children and individuals with special needs and at all income levels. (p.15)	• Percent of people who live within two km of rapid transit, from 42% to 81%. (p.58)	An access to public transport indicator shows the results of the modelling forecast, and is used to highlight the benefits provided by The Big Move.
The Atlanta Region's Plan – Atlanta, US **(Atlanta Regional Commission, 2016)**	None	• Number of low-wage jobs within 60 minutes by transit from equitable target areas. • Transit (60 minutes) and walking (0.5 miles) travel sheds from i) libraries, ii) school, ii) grocery stores, iii) major	Accessibility metrics are used to conduct an EJ** assessment. It provides diagnosis of accessibility to various destinations for deprived areas.

		hospitals, and iv) public parks, located in equitable target areas. • Areas within 0.5 miles of a transit station (Appendix J)	
Maximize 2040 – Baltimore, US **(Baltimore Regional Transportation Board, 2016)**	**Goals:** Improve Accessibility: Help people of all ages and abilities to access specific destinations. (p.S-2)	None • Access to Job/Activity Centers (Highway): Degree to which project improves infrastructure enabling access to and supporting major Job/Activity Centers (1/2 mile buffer analysis – per mile benefits) • Transit station/stops: Degree to which project supports access to specific destinations (EJ population – 1/4 mile buffer analysis • Access to Job/Activity Centers (Transit): Degree to which project improves infrastructure enabling access to and supporting major Job/Activity Centers (1/4 mile buffer analysis – per mile benefits) (p.F-2)	With respect to the accessibility goal, no accessibility indicators are used. Rather, it is mobility indicators. Accessibility indicators are used in a multi-criteria assessment of projects submitted to Maximize 2040 by local jurisdictions. A score is given based on specified criteria.
Long Range Transportation Plan 2040 – Boston, US **(Boston Region Metropolitan Planning Organization, 2015)**	**Vision:** A modern transportation system that is safe, uses new technologies, and provides equitable access, excellent mobility, and varied transportation options… (p.ES1) **Objectives:** Increase percentage of population and places of employment within one-quarter mile of transit stations and stops. Increase percentage of population and places of employment with access to bicycle facilities (p.ES3)	None • Number of industrial, retail, and service jobs within a 40-minute transit trip and a 20-minute auto trip • Number of hospitals, weighted by number of beds, within a 40-minute transit trip and a 20-minute auto trip • Number of two- and four-year institutions of higher education, weighted by enrollment, within a 40-minute transit trip and a 20-minute auto trip	Clear accessibility objectives are stated, but they are not discussed in the plan. An EJ assessment is conducted and analyzes the different in accessibility from equity and non-equity zones.

Connections 2040 – Philadelphia, US **(Delaware Valley Regional Planning Commission, 2013)**	**Goals:** Increase accessibility and mobility (p.4) **Objectives:** Provide access to key employment, commercial, institutional, and tourism centers in the region (p.78)	None	There are no accessibility indicators although there are clear accessibility objectives and goals.
Bridging Our Communities – Houston, US (Houston-Galveston Area Council, 2016)	**Vision:** In the year 2040, our region will have a multimodal transportation system through coordinated investments that supports a desirable quality of life, enhanced economic vitality and increased safety, access and mobility. (p.5)	None	There are no accessibility objectives among the set of objectives or goals.
Regional Transportation Plan – Phoenix, US **(Maricopa Association of Governments, 2006)**	**Vision:** To enable people in Maricopa County to travel with ease using safe, accessible, efficient, dependable and integrated public transportation services. (p.3)	None	There are no accessibility objectives among the set of objectives or goals.
2040 Transportation Policy Plan – St-Paul, US **(Metropolitan Council - St-Paul, 2015)**	**Goals:** Access to Destinations: People and businesses prosper by using a reliable, affordable, and efficient multimodal transportation system that connects them to destinations throughout the region and beyond. (p.62)	None Access to jobs and activities (p.6-55) • Increase in job accessibility on the transit system within 45 min. • Number of regional job concentrations served • Number of jobs reachable within 30 min. by car/public transport (p.10-13)	Performance measures related to Access to Destinations goal do not reflect accessibility. Possible accessibility-based measures are defined for setting regional transitway priorities. A comparative accessibility analysis is conducted for people of color, the general population and people with low incomes, as part of the EJ assessment
Bay Area Plan – San Francisco, US (Metropolitan Transportation Commission, 2013)	None	None	Two accessibility performance measures are defined. However, the related indicators do not reflect accessibility.
Financially Constrained Long-Range Transportation Plan for the National Capital Region – Washington, D.C., US **(National Capital Region Transportation Planning Board, 2015)**	Goals: Provide reasonable access at reasonable cost to everyone (p.12)	• The change in the number of jobs accessible by public transport and automobile within 45 minutes travel time between 2015 and 2040 – indicators + maps (p.30)	Accessibility metrics are used to evaluate the performance of the transportation plan. They are, however, not included in the summary performance analysis.

Plan 2040 – New York City, US **(New York Metropolitan Transportation Council, 2013)**	None	None	The plan states that the New York metropolitan transit authority is conducting an equity analysis based on public transport access. This analysis is however not readily available.
Mobility 2040 – Dallas, US **(North Central Texas Council of Governments, 2016)**	**Goals:** Ensure all communities are provided access to the regional transportation system and planning process. (p.14)	• Population within 15 minutes to hospitals • Number of jobs accessible within 30, 60 and 90 minutes by auto/transit and within biking/walking distance (2 miles) (p.B-28)	A detailed EJ assessment is presented. The accessibility indicators are generated for various socio-economic groups.
Plan 2040 – Newark, US (North Jersey Transportation Planning Authority, 2013)	None	None	There is no accessibility objectives among the set of objectives or goals
Transportation 2040 Plan Update 2014 – Seattle, US **(Puget Sound Regional Council, 2014)**	None	• How well does the project improve access to areas of opportunity? • How well does the project support job retention or expansion by improving access? • How well does the project provide access to job-related training or educational opportunities? (p.D-19 in Appendix P)	Accessibility indicators are used in a multi-criteria prioritization framework. Scores from 1 to 4 are given for each indicator based on specific conditions.
2050 Regional Transportation Plan – San Diego, US (San Diego Association of Governments, 2011)	**Goals:** Better link jobs, homes, and major activity centers by enabling more people to use transit and to walk and bike. (p.1-3) Social equity goal: Ensure access to jobs, services, and recreation for populations with fewer transportation choices. (p.4-4)	• Access to transit: percentage of homes within half a mile of a transit stop, including Trolley and light rail stations, bus stops, etc. • Access to Amenities (auto and transit): Percentage of Population within: 30 minutes of education institutions/of the airport and 15 minutes of healthcare/of parks or beaches (p.4-16)	A social equity analysis was conducted for all scenarios to make sure they were consistent with EJ assessment. A broad variety of destinations is included.
Regional Transportation Plan 2040 – Detroit, US (Southeast Michigan Council of Governments, 2013)	**Vision:** [The plan should contribute to] access to services, jobs, markets, and amenities (p.3) **Objective:** Increasing the percentage of households with access to jobs, services and recreational opportunities. (p.46)	•Percent of households with access to jobs/to amenities/to services (p.4)	Specific performance indicators are defined to measure progress towards achieving desired outcomes. A broad variety of destinations is included. Yet, the current plan does not include these performance indicators. Indicators of access to transport are included in the plan to describe the public transport service coverage.

		• Percent of the region’s population/elderly population/low-income households/jobs is within 1/4 mile/1/2 mile of an existing bus route. (p.65) • Average number of job/shopping opportunities from traffic analysis zone (25 minutes by transit, 50 minutes by car) • Percent of population close to a hospital/a college/a major retail center (25 minutes by transit, 50 minutes by car) (EJ: p.10-11)	A detailed accessibility analysis is conducted to assess the differentiated impacts on various demographic groups in the region (p.27).
Regional Transportation Plan 2040 – Los Angeles, US (Southern California Association of Governments, 2016)	**Goals:** Maximize mobility and <u>accessibility</u> for all people and goods in the region. (p.64)	None • Share of employment and shopping destinations within a one- and two-mile travel buffer from each neighborhood; within 30 minutes by auto or 45 minutes by bus or all transit modes during the evening peak period. • Share of population within a one- and two-mile travel buffer from a regional park or school; also, share of park acreage that can be reached within 30 minutes by auto or 45 minutes by bus or all transit modes during the evening peak period. (p.167)	There is no accessibility indicators related to the main accessibility goal. Accessibility indicators are used to conduct the EJ assessment.
The Southwestern PA plan – Pittsburgh, US (Southwestern Pennsylvania Commission, 2015)	None	• Proximity to transit: Housing units within 0.5 miles of a transit stop • Proximity to parks and trails: Proximity to parks and trails (0.5 miles) (p.5-7)	These indicators are identified as relevant performance measures for land use and transportation projects, but are not included in the current plan.

* These quotes were translated from French to English by the authors
** EJ stands for environmental justice assessment

2.5 RESULTS

The first section of the results presents a critical assessment of the integration of accessibility into plans, whereas the second section presents an in-depth assessment of plans using accessibility indicators and discusses the best practices.

2.5.1 Toward a greater integration of accessibility in transport planning

The results of the content analysis are presented in Table 2, and include the accessibility-related vision, goals, objectives and indicators. In this study, the term indicators refer to quantitative or qualitative performance measures, whereas metrics is strictly used for quantitative measures.

The keyword in context analysis revealed that almost all plans do mention the concept of accessibility in one way or another. Where earlier transport planning approaches focused merely on mobility (Banister, 2008), most plans include accessibility in their vision, goals or objectives (see Table 2). For example, plans state general goals such as: improving access for all; improving access to people, jobs and services; enhancing accessibility in the road and street network; developing more connections; and helping people get to more places.

In terms of objectives, many plans do include specific accessibility objectives (see Table 2). These are generally framed as a way to achieve broader economic and social goals such as economic development, social inclusion and equity. The most common accessibility-based objective is to increase access to jobs, both as a way to foster economic development and to reduce social inequities. For example, Transport for London identified two access to jobs indicators, one to support economic development (through improved employment accessibility) and one to improve social inclusion (through increased access to employment for deprived areas). With respect to social inclusion or social equity, a broader range of destinations is generally included (libraries, health care facilities, greeneries, supermarkets, etc.) such as done by the Greater Manchester area.

Overall most plans including accessibility objectives focus on economic development and social inclusion, mostly through access to jobs. Access to the transport system (see Houston-Galveston Area Table 2) or to mobility (see Ile-de-France Table 2) are also often stated as goals or objectives. However, these goals do not directly address access to destinations.

2.5.2 Accessibility as a buzzword

As we have seen in the previous section, almost all of the plans do mention accessibility in one way or another. In many plans, however, accessibility or access is used in a way that does not reflect the ease of reaching various destinations and does not translate into accessibility indicators.

Whereas many plans have “access for all” goals, such framing of the accessibility goals typically reflects the principles of universal accessibility. This is not to say that universal accessibility is not a meaningful goal, but rather to illustrate the importance of clearly defining what is meant by accessibility, to ensure that access to destinations is not limited the principles of universal accessibility, but also encompasses the design of the transport and land use system.

Furthermore, the term accessibility (or access) is often not defined and is used as a vague term that does not translate into clear accessibility objectives. *The 2040 vision of the Houston-Galveston Area Council* illustrates this vague use of the term access: “*In the year 2040, our region will have a multimodal transportation system through coordinated investments that supports a desirable quality of life, enhanced economic vitality and increased safety, access and mobility.”(p.5). Similarly, the Southern California Council of Governments (Los Angeles) uses accessibility as a vague goal: “Maximize mobility and accessibility for all people and goods in the region.”(p.64). This accessibility goal is also emphasized in the title of the plan: A Plan for Mobility, Accessibility, Sustainability and a High Quality of Life.* Yet, in both the Houston plan and the *Southern*

California Council of Governments (Los Angeles) plan, access to destinations is not addressed, although it is stated as a major goal. Accessibility is rather used as a buzzword, together with mobility, and does not refer to a distinct concept.

In fact, accessibility and mobility are often used interchangeably in plans, and most of the time when the two concepts are used interchangeably, the focus lies on mobility. Furthermore, access to mobility, rather than to destinations, is often emphasized in transport plans, as done in the *Plan de déplacements urbains Île-de-France* with the goal of ensuring access to mobility. This is often reflected in the choice of accessibility indicators related to access to public transport, rather than destinations. In sum, although accessibility is mentioned in many plans, it does not imply that the ease of accessing destinations is actually addressed.

Even when specific accessibility objectives are stated in the plans, they are often translated into indicators that do not reflect accessibility. As we can see in Table 3, travel time is used as an indicator of accessibility in the Metropolitan Transportation Commission (San Francisco and Bay Area) plan, the South California Association Council of Governments (Los Angeles) plan and the San Diego Association of Governments plan. Although travel time is a component of accessibility, it does not fully reflect access to destinations. It is an indicator of mobility and does not capture the potential of interaction for opportunities, as defined by Hansen (1959). Having shorter travel times does not necessarily equate to having access to a larger number of destinations. Furthermore, as discussed by Litman (2013), strategies aiming at increasing traffic speed may in some cases lead to an overall reduction in accessibility. In sum, increased mobility does not always result in increased accessibility (Halden, 2011; Levine, Grengs, Shen, & Shen, 2012). Interestingly, travel time is also defined as a main "accessibility" indicator at the national level in the UK (Halden, 2011).

In addition to travel times, the presence of transport infrastructures (length of bus lanes, roads or bicycle lanes, and proportion of roads with sidewalk) are sometimes used as indicators of accessibility, such as done by the Metropolitan Council - St-Paul and the Baltimore Regional Transportation Board. Mode share is also included as an indicator of accessibility in these plans. Overall, although these indicators are relevant in measuring the quality of a transport network, they do not necessarily indicate the achievement of an accessibility objective in the sense of the ease of reaching destinations. Whereas the presence of infrastructures and access to public transport typically lead to greater accessibility, the land-use dimension of accessibility is not accounted for. Hence, providing access to a public transport route that leads to the central business district does not result in the same improvement in accessibility than providing access to a public transport route leading to a low-density suburb. Furthermore, although lower travel time and mode choice are generally associated with greater accessibility, factors other than accessibility can influence these indicators, namely car access, income and fuel prices.

Table 3: Accessibility objectives translated into indicators that do not reflect accessibility

Metropolitan Area	Objective	Definition
Baltimore	Accessibility - Transit	Average Weekday Ridership
	Accessibility - Pedestrian / Bicycle	Percentage of urban area directional roadway miles that have sidewalks Bicycle/walk-to-work mode share
St-Paul	Access to Destinations	Average annual hours of delay per capita Transit ridership Number of miles of managed lanes Number of miles of bus-only shoulder lanes
Bay Area (San Francisco)	Equitable access	Decrease by 10 percentage points (to 56 percent from 66 percent) the share of low-income and lower-middle income residents' household income consumed by transportation and housing
	Access to Jobs	Average travel time in minutes for commute trips
San Diego	Job Access	The percentage of work trips lasting up to 30 minutes during peak periods by driving alone, riding in a carpool, and taking public transit
Los Angeles	Performance measures of accessibility and mobility outcome	Person delay per capita Person delay by facility type Truck delay by facility type Travel time distribution for transit, SOV and HOV modes for work and non-work trips Work trips completed within 45 minutes

In conclusion, taken together, the results reveal that there still is a strong focus on mobility, although accessibility is included in most plans. This is consistent with previous studies in the UK and the US (Handy, 2005; Proffitt et al., 2017). Furthermore, accessibility objectives are seldom translated into accessibility indicators. This suggest that planners and/or decision-makers do understand the relevance of the concept of accessibility for improving quality of life and meeting the needs of the population, but that mobility approaches are still strongly rooted in the decision-making and analysis processes. This can be attributed to various reasons, such as lack of tools, lack of knowledge or lack of resources. Investigating these factors further however falls outside the scope of this research.

2.6 IDENTIFYING BEST PRACTICES

We have seen in the previous section that while many plans mention accessibility, few of them comprehensively address the ease of reaching destinations. In this section, we focus on those plans that do use accessibility indicators reflecting access to destinations, in order to identify the best practices and provide policy recommendations. Figure 3 presents the different types of accessibility analyses conducted in the various plans, and the types of accessibility metrics used.

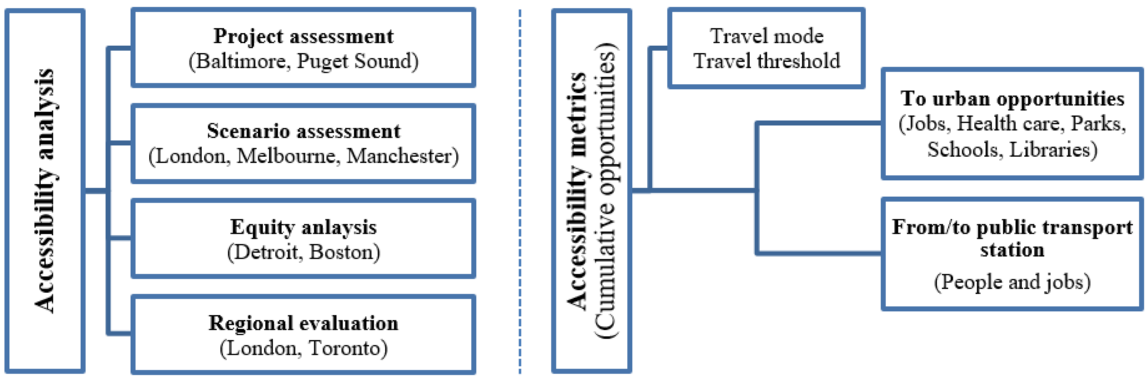

Figure 3: Use of accessibility indicators and type of accessibility metrics in regional land use and transport plans

2.6.1 Accessibility analysis

2.6.1.1 Project and scenario assessment

The most comprehensive accessibility analyses presented in the plans are generally related to project and scenario assessments (Figure 3). In such analysis, accessibility indicators are used to compare the benefits provided by different potential transport investments and to inform decision-making.

One of the most systematic and transparent ways to inform decision-making is by including accessibility indicators into multi-criteria analyses, as done by the Baltimore Regional Transportation Board, the Puget Sound Regional Council, Transport for London and the Greater

Manchester Combined Authority. For example, in Baltimore, a multi-criteria analysis was conducted to compare the projects submitted by local jurisdictions and to select the ones to be included in the Regional Transportation Plan (Maximize 2040). Similarly, the Puget Sound Regional Council included accessibility in their multi-criteria analysis used to conduct a prioritization of the projects. With respect to scenario assessments, Transport for London used a multi-criteria analysis including accessibility indicators to assess the effectiveness of various modelling scenarios.

The accessibility indicators included in the multi-criteria analyses range from broad questions to specific quantified metrics, which influence the flexibility of the analysis. For example, Transport for London defines clear specific accessibility metrics, for example the change in the number of jobs accessible by public transport within 45 minutes travel time (see Table 2). These access to jobs metrics are relatively easy to generate and to interpret. Accordingly, they foster the inclusion of accessibility indicators that adequately reflect the ease of reaching destinations. Furthermore, given their specific nature, they are easy to communicate as exemplified in the plan: "*Implementing the schemes will increase the employment catchment area of central London (the number of people within 45 minutes of central London employment) by almost 25 per cent.*" (p.74). In contrast, accessibility criteria in the Greater Manchester plan are defined with broad questions such as "*Will the LTP help improve accessibility through integrated spatial planning?*" and "*Will the LTP improve access to jobs, particularly for people who suffer income or employment deprivation*?" (see Table 2). These questions provide greater flexibility in the assessment of the plan, which can be beneficial as quantified metrics do not always reflect the benefits provided by improvements in accessibility (Curl et al., 2011). However, as emphasized by Halden (2011), it can also lead to the use and misuse of the concept of accessibility. An intermediate way of defining accessibility indicators is by attributing scores (from 1 to 3 for example) based on specific guidelines as done by the Baltimore Regional Transportation Board and the Puget Sound Regional Council. For example, in the Puget Sound multi-criteria analysis, a project receives 3 points if it supports access to institutions identified as economic foundations and another 2 points if it serves an area with an employment density above 15 jobs per acre. This approach has the advantage of defining clear weights associated with accessibility criteria, thus providing greater transparency. In the previous examples, the weights are not defined and accordingly do not indicate the relative influence of the accessibility aspects in the multi-criteria analysis. Overall, quantified metrics provide more specific guidelines that directly reflect the ease of reaching destinations. However, they provide lower flexibility and might not adequately reflect the outcomes of the different investments. Nevertheless, no matter the choice of indicators, including accessibility indicators in multi-criteria analysis provides a systematic alternative to mobility-focused decision-making. Furthermore, as highlighted by Halden (2011), the use of accessibility indicators "offers the potential for a new dimension in problem solving" (p.18).

Another important aspect of multi-criteria analysis is the clear distinction between mobility and accessibility indicators. In the Baltimore plan, the multi-criteria analysis includes the following goals: safety, accessibility, mobility, environmental conservation, security and economic prosperity. Interestingly, accessibility and mobility are included as two distinct goals with different criteria and methodologies, whereas in many plans accessibility and mobility are used interchangeably. This distinction ensures that distinct mobility and accessibility indicators are used for the respective objectives.

Other metropolitan areas have developed accessibility indicators to evaluate projects or progress toward accessibility objectives (Metropolitan Council - St-Paul, Southwestern Pennsylvania

Commission, Southeast Michigan Council of Governments). These metropolitan areas set accessibility-based performance measures as guidelines for future project assessments. However, unlike the multi-criteria analyses presented above, these metropolitan areas have not themselves conducted an accessibility-based assessment of the projects. While defining accessibility guidelines is a first step to foster the inclusion of accessibility-related performance indicators, directly including accessibility in the decision-making process of the plan sets a strong example and ensures that accessibility is directly taken into account. Overall, clear multi-criteria analysis, using clearly defined indicators, provide greater transparency and typically foster the inclusion of accessibility aspect in the decision-making process.

2.6.1.2 Equity analysis

Equity analysis based on accessibility indicators are conducted by many metropolitan areas, especially in the US due to federal requirements. They generally assess the level of accessibility of specific vulnerable groups relatively the general population, using detailed accessibility metrics. However, in most cases the use of the generated accessibility metrics is limited to the environmental justice assessment, although accessibility is also stated as a main planning factor by the federal government. Accessibility is mainly perceived as an equity indicator, while it has the potential to address multiple aspects of a land use and transport system. The marginal use of accessibility indicators for a general assessment of transport investments might be explained by the lack of clarity of the federal planning factor, which requires to "*increase the accessibility and mobility of people and for freight*".

2.6.1.3 Regional evaluation

Accessibility-based regional evaluation, which can be found in some of the plans, often provides greater transparency and efficient communication tools. Accessibility is discussed in terms of service coverage and/or service gaps, and in terms of regional benefits provided by the potential projects. For example, the NSW Government's Sydney Long Term Transport Master Plan identifies spatial transport gaps by mapping access to jobs by public transport and by car. The maps are used to discuss the regions in need of improvement in terms of accessibility and are the result of an extensive accessibility analysis. Similarly, the Paris transport plan provides maps of access to jobs by public transport and by car. Accessibility maps and metrics are useful tools to provide an overview of the land use and transport network and they illustrate an underlying accessibility analysis. However, in the cases presented above, it appears unclear how accessibility metrics were used in the decision-making processes.

2.6.2 Accessibility metrics

In terms of accessibility metrics, very similar metrics are used across the plans. Accessibility metrics are typically location-based and focus on the transport and land use components of accessibility. In all cases, measures are based on cumulative opportunities, using a travel time or distance threshold, mainly for public transport and driving (Figure 3, right). Cumulative-opportunity measures are easy to communicate and interpret, and thus better suited for planning documents (Geurs & van Wee, 2004). Although they are not as theoretically sound as gravity-based measures, they are highly correlated with such measures (El-Geneidy & Levinson, 2006) and are appropriate to measure accessibility at a regional level (Boisjoly & El-Geneidy, 2016).

As illustrated in Figure 3, the measures can be divided in two categories: access to destinations, and access to or from public transport stations. Access to public transport is the most common measure used in the plans. This measure is generally presented as the percentage of people or jobs that are within 0.5 mile of a public transport station. This is a measure of service coverage and is generally used by public transport authorities as a performance measure (see Southeast Michigan

Council of Governments – Detroit Table 2). While the access to public transport dominates the plans, it does not directly address the ease of reaching urban opportunities. The second type of metrics (access to urban opportunities) directly measures the ease of reaching various destinations, generally jobs, using a specific mode. This measure is however more complex to generate, as the locations of the destinations is needed. Nevertheless, access to destinations, namely jobs, is not uncommon in the plans that we have assessed, especially with respect to social equity. Access to jobs provides an adequate indicator of regional accessibility, as many people commute across the region for work. Access to jobs can also be a reflection of the level of services available around a certain location, as the delivery of services often equates a certain number of employees. Other types of destinations include libraries, schools, grocery stores, hospitals, public parks, educational services as exemplified by the Atlanta Regional Commission. Many of these destinations reflect local accessibility and are thus often associated with cycling and walking. With respect to the individual components, many areas segment the accessibility analysis by socio-economic groups. However, only few of them (Atlanta Regional Commission, Boston Region Metropolitan Planning Organization) do address destination segmentation. This is an important improvement as the accessibility to all jobs may not represent the opportunities that are available to different groups of populations.

In terms of modes and thresholds (Figure 3), accessibility to jobs is generally generated for public transport or automobile, using travel time thresholds varying from 30 minutes to 60 minutes. Based on the existing literature, accessibility measures based on travel time thresholds adequately reflect accessibility, as they are highly correlated with mode choice (Legrain et al., 2016; Owen & Levinson, 2015b). Measures of generalized costs (including the costs and time of travel) have been developed in the literature (Bocarejo & Oviedo, 2012; El-Geneidy et al., 2016). These measures better reflect the total costs of travel as they include both financial and time burdens. They are however very challenging to generate due to complex fare structures and availability of data. Yet, excluding the financial costs of travel results in an overestimation of accessibility (El-Geneidy et al., 2016), especially for low-income individuals. In this regard, accessibility based on financial and time costs is closer to reality and can also provide an insight on fare structures and trip affordability. From a planning perspective, travel time measures of accessibility adequately represent accessibility patterns with respect to the transport networks and locations of activities, but do not address the financial constraints that vulnerable individuals may face.

In terms of mode, most transport plans concentrate on including accessibility by public transport and car, while few plans address access to destinations by cycling and walking. The most common metrics for cycling and walking are measures of local accessibility (to grocery stores, schools, parks or public transport station for example), as done by the Atlanta Regional Commission. Access to jobs by cycling or walking is included in the North Central Texas Council of Governments plan. With respect to local accessibility walking and cycling distance thresholds are used instead of travel time thresholds (0.5 miles for walking). These appear to be appropriate measures of accessibility, as time is generally proportional to the distance travelled by bicycle or foot. With public transport and driving, the travel distance is not always representative of the travel time, due to different speed limits, levels of congestion, and public transport route time efficiency.

Overall, the cumulative-opportunities accessibility metrics are generated for access to transport, and to a lesser extent, for access to destinations, mainly jobs. Ideally, plans would integrate both types of metrics. Access to transport provides a good indication of transport coverage, whereas access to destinations captures the performance of the land use and transport systems, which better reflect the social and economic benefits (Banister, 2008; Koenig, 1980; Wachs & Kumagai, 1973).

Furthermore, although this study focused on the physical component of accessibility, the results suggest that other dimensions of accessibility might currently be neglected in metropolitan transport plans. For example, affordability, transfer and multimodal connectivity, as well as travel information did not come up as main aspects of accessibility objectives. These are however key component of accessibility and should thus be addressed in further research.

2.7 ACCESSIBILITY BEYOND METROPOLITAN TRANSPORT PLANS

Although this study was limited to metropolitan transport plans, it is important to note that several academic, governmental and private institutions have come further in the generation of accessibility-based metrics planning tools than what is displayed in the plans.

To start with, multiple private, governmental and non-governmental institutions, namely in the US, have generated access-to-destinations metrics by various modes and have made them openly available on the web, generally through accessibility maps (Accessibility Observatory, 2016; City of Portland, 2016; New York Regional Plan Association, 2016; Travel Behavior & Urban Systems Research Group at University of Illinois at Chicago, 2016; US Environmental Protection Agency, 2016; Walk Score, 2016). As observed in the plans, cumulative-opportunities access-to-jobs metrics, namely by public transport, car and walking, are commonly used, with a variety of time thresholds. Interestingly, a few institutions provide access-to-jobs metrics by sector (Walk Score, 2016), level of education (New York Regional Plan Association, 2016; Travel Behavior & Urban Systems Research Group at University of Illinois at Chicago, 2016) or other characteristics such as income level and ethnicity of workers (Travel Behavior & Urban Systems Research Group at University of Illinois at Chicago, 2016). In addition to jobs, destinations such as parks, municipal services, hospitals and grocery stores are sometimes included (City of Portland, 2016; Travel Behavior & Urban Systems Research Group at University of Illinois at Chicago, 2016). While the accessibility maps and metrics are openly available, the dataset, which can directly be used to conduct accessibility analysis, is typically not. The US Environmental Protection Agency (2016) however provides the Access to Jobs and Workers Via Transit Tool, from which data can be downloaded. In addition to the data readily available, multiple institutions provide accessibility instruments or software that can be used by planning agencies or municipalities to generate accessibility metrics and analysis. For example, the COST initiative Accessibility Instruments For Planning Practice In Europe provides an overview of several such instruments (COST, 2016; te Brömmellstroet, Silva, & Bertolini, 2014).

This section has highlighted the variety of tools potentially available to planners or municipalities to collect or generate accessibility data. The low penetration of accessibility metrics in metropolitan transport plans calls for further research examining the dissemination and use of existing accessibility tools. Such efforts have been initiated by researchers aiming to assess the usability of accessibility metrics and instruments in practice (Boisjoly & El-Geneidy, 2016; te Brömmellstroet et al., 2014). Remaining issues include the barriers and opportunities associated with the dissemination of tools and their uptake by planners. These issues are investigated in the next chapter of this dissertation.

In addition to the tools discussed above, detailed metropolitan accessibility analyses have been conducted by academic research groups. For example, the Center for Transportation Studies (CTS) published an extensive analysis of access to destinations in the Minneapolis-St. Paul metropolitan region (CTS, 2010). Yet, there is no indication that this specific analysis was included in the Metropolitan Council - St-Paul 2040 Transport Policy Plan. The Transportation Research at McGill group also conducted an accessibility analysis for the region of Toronto (El-Geneidy et al., 2015). The analysis was specifically prepared for Metrolinx, Toronto's metropolitan transport authority, which has included some of the metrics in its Discussion Paper for the next Regional Transportation (Metrolinx, 2016). In this regard, further research should examine the collaboration processes between academic institutions and research groups, as it provides a fertile area for supporting the implementation of accessibility-based approaches.

2.8 DISCUSSION AND CONCLUSION

The assessment of multiple plans reveals that there is a trend toward the integration of accessibility objectives, rather than merely mobility. Most plans emphasize the need to improve accessibility, or access to destinations, which indicates a shift from the traditional transport planning approaches (Banister, 2008). However, the transition towards accessibility-based planning is far from complete. Practically speaking, few plans have accessibility-based indicators that guide their decision-making processes. There is indeed often a discrepancy between the accessibility objectives that are stated in the plans, and the performance indicators that are actually used to make decisions.

Although the concept of accessibility dates back to the 1950s, it is a relatively recent planning tool. Mobility approaches, which have dominated transport planning since the widespread use of the car in the 1950s, are still strongly rooted in practice. More efforts are needed to effectively implement accessibility-based approaches. In this regard, this section discusses the best practices to help practitioners and cities wishing to integrate effective accessibility planning approaches. The best practices are identified in light of the assessment given and are presented in Table 4.

Table 4: Best practices for a greater inclusion of accessibility planning and metrics

Recommendation	Description	Key examples
Accessibility goals and objectives	Clearly defined goals and objectives are included in the plan. The plan is structured around the goals and objectives.	London
Distinction between accessibility and mobility	Distinct accessibility and mobility objectives and indicators are defined.	Baltimore
Multi-criteria analysis including accessibility indicators	Accessibility indicators are systematically included in the performance analyses. Accessibility metrics are used to assess the general performance of the land use and transport system, in addition to social equity.	London, Baltimore, Puget Sound (Seattle), Manchester, Melbourne
Access to destinations metrics	The accessibility indicators are based on access to destinations (e.g.: jobs), rather than to transport amenities (e.g.: public transport stop)	Boston
Multiple modes	Accessibility is measured for various modes of transport	North Central Texas, Atlanta
Visualization tools	Accessibility maps are included in the plan.	London, Sydney

The goals and objectives are key elements of a transport plan, as they guide the specific planning targets (Handy, 2008). Although not always translated into practice, planning goals can determine the main directions of a plan. This is especially the case when plans are clearly structured around the goals and objectives as demonstrated by Transport for London, rather than around projects or investments. Furthermore, to ensure that accessibility goals are translated into practice, it is key to have clearly defined goals reflecting the ease of reaching destinations. In contrast, broad accessibility goals can be interpreted in multiple ways that do not necessarily address access to destinations (Curl et al., 2011; Halden, 2011). For example, the US federal government defines eight planning factors that guide the development of the Transportation Plans by the MPOs, one of which is to "increase the accessibility and mobility of people and for freight" (U.S. Department of Transportation, 2014). As accessibility is not clearly defined, access to destinations is often not reflected in the plans. Accessibility goals should hence be clearly defined to encourage the establishment of accessibility-based performance indicators.

Another key element to ensure that accessibility goals are translated into accessibility indicators is to have distinct mobility and accessibility goals. As accessibility objectives are often translated into mobility indicators (see Table 3), the definition of two distinct objectives can prevent such practices as seen in the Baltimore plan. In its multi-criteria analysis, the Baltimore plan defines six distinct goals, one of which is accessibility and one of which is mobility. As a result, the indicators falling under the accessibility goal are specific to accessibility and reflect the ease of reaching destinations. Furthermore, a clear distinction should be made between access to mobility, access to destinations (Levine et al., 2012) and universal accessibility. This can be encouraged by the clear definition of objectives, as highlighted in the first recommendation.

In this regard, the use of access to destinations metrics such as cumulative-opportunity metrics provide indicators that typically reflect the ease of reaching destinations and is thus encouraged. More specifically, the use of cumulative-opportunities measure of accessibility to jobs by public transport and car is suggested. These measures provide adequate indicators of the regional patterns of accessibility, and are easy to generate, to interpret, and to communicate (Boisjoly & El-Geneidy, 2016; Geurs & van Wee, 2004). More detailed analysis can include other types of destinations, or segmentation by job types, to address specific social issues, all depending on the context of analysis. Temporal fluctuations in accessibility can also be addressed to improve the quality of the accessibility analysis. Furthermore, while most plans focus on car accessibility, and to a lesser extent on accessibility by public transport, all modes should be included in the accessibility objectives and indicators. Increasing accessibility by public transport, cycling and walking can contribute to achieving broader environmental, economic and social goals.

In order to further foster accessibility-based planning approaches, accessibility indicators should systematically be included in multi-criteria analyses as in the case of London, Baltimore and Puget

Sound. Although this does not ensure that decisions will be made based on the accessibility analysis, it offers an alternative to mobility-based decisions and potentially provide greater transparency in the decision-making process (Halden, 2011). Furthermore, national and regional authorities can require local authorities to address accessibility in their project analysis. One especially effective way of doing so is by including accessibility criteria in the selection process of projects, as done by Baltimore. Another approach is by defining guiding factors on which projects should be analyzed, as done by the St-Paul Regional Council. This encourages the integration of accessibility-based indicators but might not be as efficient as a systematic multi-criteria analyses conducted to select projects. It is also important to note that accessibility indicators should be used as general performance indicators and should not be limited to social equity analyses. Many plans from American metropolitan areas generate accessibility measures to address the environmental justice federal requirement. Yet, accessibility allows tackling multiple objectives, including environmental and economic benefits (Handy, 2002; Koenig, 1980), and should hence also be used to assess the overall benefits of potential investments.

Another good practice to address accessibility in transport plan is the use of visualization tools such as maps. Accessibility maps provide a clear way to communicate gaps and benefits of a transport and land use network, and thus helps decision-makers, planners and the general population to better grasp the impacts of transport investments. A key example is the London plan which provides before and after maps of accessibility to highlight the impacts of the transport plan.

This study has explored the current use of accessibility in metropolitan transport plans and provided several recommendations for promoting accessibility-based approaches. Yet, important aspects of accessibility fall outside the scope of this research and could be further explored in future studies. In order to understand to what extent decisions are made based on accessibility issues, it would be relevant to examine decision-making processes in their ensemble. Furthermore, an important aspect is to evaluate the actual social and economic impacts of accessibility improvements resulting from plans. Lastly, an evaluation of the implementation of the projects presented in the plans would be essential.

CHAPTER THREE: THE INSIDER: A PLANNERS' PERSPECTIVE ON ACCESSIBILITY[3]

3.1 OVERVIEW OF CHAPTER

As we have seen in the previous chapter, the use of accessibility indicators in practice is generally limited and more efforts are needed to understand which factors support or limit their use by practitioners. The goal of this chapter, therefore, is to explore the challenges and opportunities experienced by land use and transport practitioners to use accessibility metrics in their work. In order to achieve this objective, a survey on the use of accessibility metrics was conducted among 343 practitioners around the world. Findings from the survey show a gap between knowledge of the concept of accessibility and its use by land use and transport practitioners. While 90% of the respondents are familiar with the concept, only 55% stated that they use accessibility metrics in their work. Whereas lack of support and interest does not appear to be a major obstacle to using accessibility metrics, lack of knowledge and data are highlighted as the main barriers to the use of metrics in practice. These results suggest that further training and collaboration is required to support the use of metrics by practitioners. Furthermore, including clear accessibility indicators in planning documents is key to promoting the use of metrics in policy and practice, as it was stated as a main reason motivating the generation of accessibility metrics. This research highlights some of the main barriers to the integration of accessibility metrics in practice, which are then addressed in Chapter 4 and 5 of this dissertation.

3.2 INTRODUCTION

Accessibility, the ease of reaching destinations, is a key land use and transport performance measure (Wachs & Kumagai, 1973). It is increasingly used by researchers to spatially assess the

[3] Boisjoly, G., & El-Geneidy, A. (2017). The insider: A planners' perspective on accessibility. *Journal of Transport Geography, 64*, 33-43.

joint benefits provided by the transport network and the land use system in a region (Bocarejo & Oviedo, 2012; Huang & Wei, 2002; Kawabata & Shen, 2007; Manaugh & El-Geneidy, 2012) and to identify spatial gaps in access to opportunities (Paez et al., 2010a, 2010b). Understanding and visualizing accessibility patterns and changes across a region contributes to developing spatially targeted land use and transport interventions. While accessibility has been extensively researched with the ultimate purpose of informing decision-making and influencing land use and transport planning, little is known on the use of accessibility metrics in transport practice. In fact, although transport issues are increasingly framed in terms of access to opportunities (Geurs et al., 2012; Handy, 2008; Lucas, 2012; Manaugh et al., 2015; Preston & Rajé, 2007), accessibility is still largely marginalized in practice (Halden, 2011; Levinson & Gillen, 2005; Proffitt et al., 2017). More specifically, accessibility goals are increasingly incorporated in transport plans, but the use of performance indicators reflecting the ease of reaching destinations is limited (Boisjoly & El-Geneidy, 2017a; Handy, 2008; Proffitt et al., 2017).

The aim of this study is, therefore, to explore the challenges and opportunities experienced by a variety of land use and transport practitioners with respect to the use of accessibility metrics in their work. This study assesses the familiarity with and use of the concept and metrics as well as the motivations and barriers to using accessibility metrics among 343 practitioners from around the world, mainly North America and to a lesser extent Europe. In order to achieve the study aim, a survey on the use of accessibility metrics was conducted among land use and transport practitioners through an on-line platform. This study contributes to a greater understanding of the practical challenges related to the use of accessibility metrics by practitioners. Understanding such challenges is essential to bring accessibility indicators into practice, and accordingly provide planners and decision-makers with performance indicators to spatially assess the benefits provided by land use and transport improvements. This study is of relevance to researchers, planners and policy-makers wishing to foster accessibility-based planning approaches.

3.3 LITERATURE REVIEW

Accessibility, defined as the ease of reaching destinations (Preston & Rajé, 2007), is one of the most comprehensive performance measures of land use and transport systems (El-Geneidy & Levinson, 2006). As such, accessibility reflects the multiple benefits provided by land use and transport systems (Ben-Akiva & Lerman, 1979). For example, greater accessibility is associated with higher land values (Du & Mulley, 2012; El-Geneidy & Levinson, 2006; Koenig, 1980) and employment rates (Blumenberg & Ong, 2001; Ornati et al., 1969; Pignatar & Falcocch, 1969; Sanchez, 1999; Sari, 2015; Tyndall, 2015), as it provides residents with greater access to a variety of opportunities. In the same way, increased accessibility contributes to reducing the risks of social exclusion for vulnerable individuals (Lucas, 2012; Preston & Rajé, 2007). Furthermore, accessibility by public transport is associated with greater public transport use (Chen, Gong, & Paaswell, 2008; Owen & Levinson, 2015b), and can thus help in reducing car use and the resulting greenhouse gas emissions (Handy, 2002; Levinson, 1998). Accessibility improvements can also have negative impacts on individuals. For example, increased accessibility can lead to neighborhood gentrification, as it is often associated with increase in land values, and adversely affect low-income residents. Furthermore, congestion is often associated with areas with high levels of accessibility (Mondschein, Taylor, & Brumbaugh, 2011). Nonetheless, as accessibility comprehensively reflects the outcomes of land use and transport systems, it is increasingly put forward as a key element of a transport planning (Banister, 2008; Handy, 2002; Straatemeier, 2008).

Accessibility is contingent on a variety of interacting factors. Firstly, access to destinations is largely influenced by the distribution of residential, economic, cultural and social activities (the land use component). Accessibility further depends on the transport network which determines the travel time, costs and convenience from a place (for example, home) to another (for example, work) (the transport component). In addition to the exogenous factors, individual characteristics such as income, level of education, gender and vehicle ownership affect one's abilities and needs to access destinations (the individual component). Time restrictions also play an important role in determining accessibility. These include land use, transport and individual constraints such as the availability of opportunities (i.e., opening hours), personal schedules, and the schedule of public transport services.

Given the wide scope of factors affecting accessibility, multiple and diverse accessibility metrics have been developed (Geurs & van Wee, 2004; Handy & Niemeier, 1997; Miller, 2005; Paez et al., 2012), differing in their level of disaggregation and their ease of operationalization. Person-based measures of accessibility are generated at the individual level, and are concerned with the level of accessibility experienced by a specific person (Geurs & van Wee, 2004; Miller, 2005; Owen & Levinson, 2015b). These measures incorporate the characteristics of the land use and transport systems, as well as the spatial and temporal constraint of the individual into a single measure (Miller, 2005). Person-based measures are helpful in understanding individual experiences of accessibility but entail significant challenges to assess land use and transport systems at a regional scale. A second type of measures are the utility-based measures, which capture the benefits provided by changes in the network in terms of consumer surplus, as done by Geurs, Zondag, De Jong, and de Bok (2010). Utility-based measures account for most components of accessibility and can be included in traditional economic appraisal, such as cost-benefit analyses (van Wee, 2016; Zondag, de Bok, Geurs, & Molenwijk, 2015). Yet, these measures are rarely used in practice due to the challenges related to their interpretability and communicability (van Wee & Geurs, 2016).

In contrast, location-based metrics are most commonly used in planning as they provide a comprehensive measure of regional accessibility (Boisjoly & El-Geneidy, 2017a). These metrics indicate the ease of accessing destinations from a specific location and accounts for the spatial distribution of opportunities (for example, jobs or healthcare services) and the ability to move from one place to another. The transport component, the ability to move from one place to the other, is generally mode specific and based on travel time or distance (Geurs & van Wee, 2004; Handy, 1994; Hansen, 1959; Owen & Levinson, 2015a; Vickerman, 1974). A common location-based metric is a measure of cumulative-opportunities, which counts all opportunities that can be reached within a travel costs threshold. For example, the number of jobs that are within 45 minutes of travel times by public transport from a specific place is used to assess the access to jobs by public transport. Another common metric is the gravity-based measure, which discounts opportunities based on a distance-decay function. Accordingly, opportunities that are located farther (by distance or time) receive less weight than closer opportunities. While this measure is more reflective of travel behavior, cumulative-opportunities are simpler to generate, interpret and communicate.

Although accessibility has been extensively researched, its inclusion in transport planning is limited; the mobility-based approach still dominates transport planning (Halden, 2011; Levinson & Gillen, 2005; Proffitt et al., 2017). This approach, which traditionally focused on motorized traffic, aims at facilitating the smooth movement of vehicles. In this regard, the goal is to minimize travel times by increasing travel speeds and reducing travel delays. Within this approach, interventions are generally developed to meet the demand through improvements on the network, while neglecting the land use components that can contribute to improving access to destinations. This approach is widely used for car traffic, but also for public transport and cycling. Through a detailed assessment of four transport plans in California, Handy (2005) found that although accessibility emerged as a concern in most plans, these plans were still dominated by a mobility-oriented paradigm. Similarly, in an assessment of 42 American transport plans, Proffitt et al. (2017) found that less than a quarter of the plans measured success based on accessibility indicators. In the United Kingdom (UK), the national government has established a framework for accessibility planning. However, the broad and flexible guidelines resulted in a "misuse" and "abuse in practice" of accessibility (Halden, 2011). Research has also shown that there is a lack of consensus on the accessibility indicators to be used in transport evaluations (Halden, 2011; van Wee, 2016).

Increasing interest is given to accessibility metrics as a tool to better integrate land use and transport planning and to address issues of geographic access to opportunities. While many studies have focused on accessibility metrics and indicators, no study has, to our knowledge, looked into the use of accessibility metrics by practitioners. Yet, understanding how and to what extent accessibility indicators are used in practice is essential to bridge the gap between planning and research, and to foster the implementation of accessibility-oriented planning approaches.

3.4 DATA AND METHODOLOGY

To explore the factors influencing the use of accessibility metrics in practice, a survey was conducted among land use and transport practitioners. The survey was conducted on-line and disseminated through various mailing lists and social media groups of planners. The main goal was to identify practitioners that use accessibility in their work and determine the motivations and barriers behind generating accessibility metrics. Since this study is mainly concerned with the use of accessibility metrics in land use and transport planning, the survey focused on location-based metrics. As discussed above, these metrics address the characteristics of the land use and transport systems at a regional level and are most commonly used in the planning realm given their ease of interpretation and communication.

The selection and subdivision of respondents included in this study are presented in Figure 4. In total, 440 fully completed surveys were collected. As the objective was to focus on land use and transport planning practice, only land use and transport practitioners were included in the sample. The term land use and transport practitioners is broadly used to refer to any individual involved with land use and/or transport planning and does not include individuals mainly concerned with research activities. Respondents were, therefore, included or excluded based on their sector of employment, company/organization and job title. Firstly, any respondent who selected academia as their sector of employment (70 respondents) was excluded from the sample. Secondly, respondents who indicated educational or research institution as their organization were also excluded (9 respondents). Finally, architects working in an architecture firm were also excluded from the original sample (3). Overall, in this study, land use and transport practitioners are mainly planners, managers, analyst or engineers working in the public, private or non-governmental sector, and all of them are involved with transport and/or land use projects.

Furthermore, all respondents were asked about their familiarity and use of the concept and metrics (see detailed questions in Figure 4, right). Respondents that were neither familiar with the concept nor the metrics were removed (15 respondents). In total, 343 non-academic respondents were included in the final sample, of which 274 were from North America, 45 from Europe, and 24 from other regions. These respondents were then divided in three subsamples, based on whether they used the concept and metrics of accessibility in their work. Respondents that "neither agreed nor disagreed", "agreed" or "strongly agreed" with the statement "I use the CONCEPT of accessibility in my work" were considered as using the concept. Similarly, respondents that "neither agreed nor disagreed", "agreed" or "strongly agreed" with the statement "I use accessibility METRICS in my work" were considered as using the metrics. The three subsamples are as follows:

A. Respondents that used accessibility metrics in their work (Metrics; N=247).
B. Respondents that did not use accessibility metrics in their work, but that did use the concept of accessibility (Concept; N=68).
C. Respondents that did not use the concept of accessibility, nor the metrics, in their work (Others; N=28).

The survey was divided in 4 sections. The first section included general questions about the respondents' work context. The second section asked respondents about their familiarity with and use of the concept and metrics, to divide the respondents into subsamples. The third section asked respondents A and B about their use of the metrics and concept respectively. The first subsample (respondents that used metrics) was asked specific questions about the design and use of metrics, whereas the second subsample (respondents using the concept, but not the metrics) was asked specific questions about their use of the concept, and reasons for not using metrics. The fourth section questioned all respondents about their perception on the use of accessibility metrics in decision-making. Throughout the survey, agreement questions used a 5-point Likert scale (1-"strongly disagree", 2-"disagree", 3-"neither agree nor disagree", 4-"agree", 5-"strongly agree"). In the analysis of the results, respondents that selected "agree" and "strongly agree" were aggregated together as "agree", and respondents that selected "disagree" and "strongly disagree" were aggregated together as "disagree". Respondents who selected "neither agree nor disagree" were considered as "neutral".

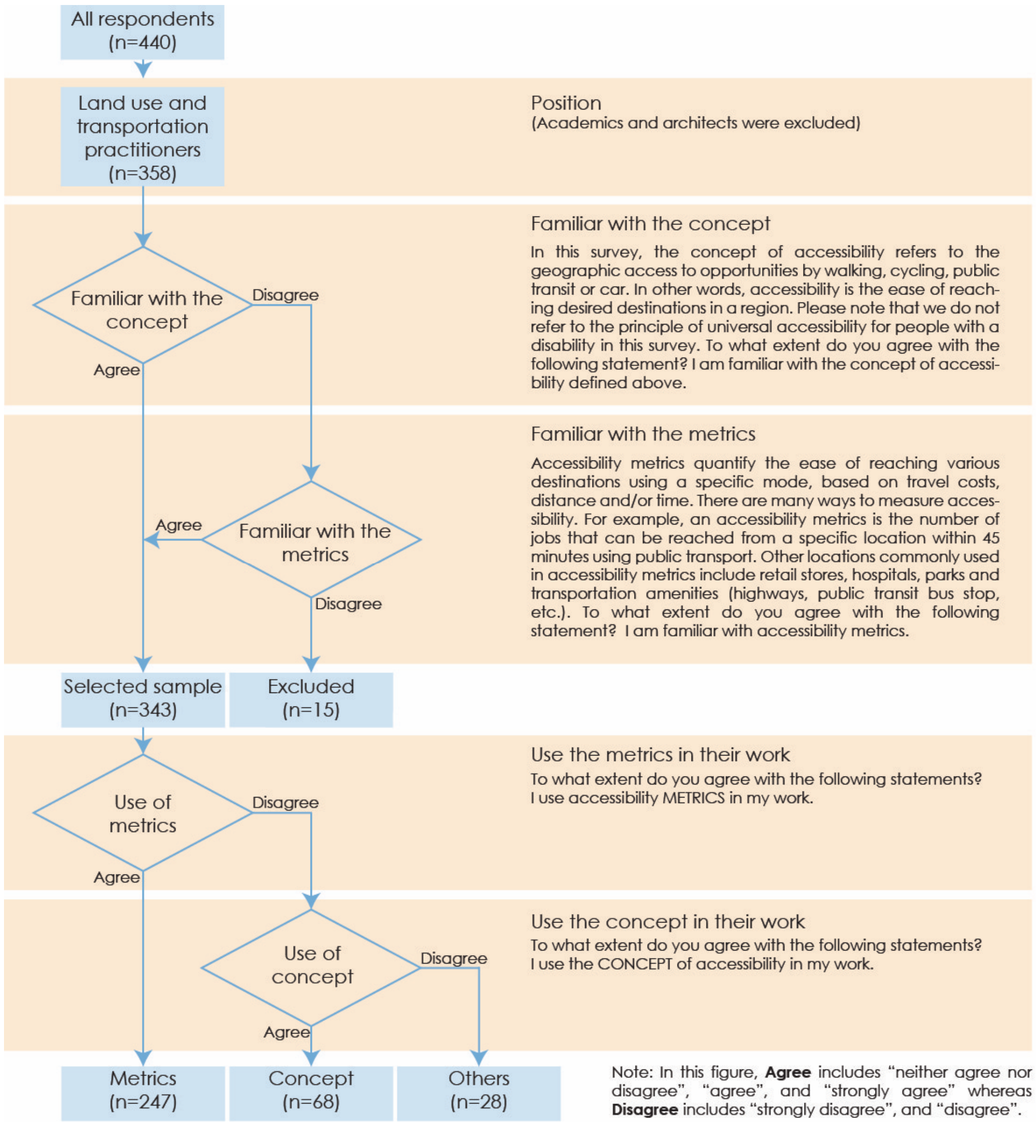

Figure 4: Description of the sample

The characteristics of the 343 respondents included in our sample are presented in Figure 5. Most respondents worked in the public sector (73%), and the majority were planners (62%). Respondents were mainly working within a governmental organization, a planning organization, or a consulting agency, while very few worked for a public transport providers. Furthermore, the majority of respondents were involved with transport projects (public transport, walking, cycling, driving, parking or land use) at the local or regional scale.

Since the sampling method used is this survey is non-probabilistic, the sample is not representative of all land use and transport practitioners. The results represents the views of the 343 respondents included in the survey, and are useful to explore the perceptions of a variety of practitioners. Although the results cannot be generalized to the whole community of practitioners, the findings uncover clear and homogenous trends that could be further investigated.

Figure 5: Profile of the respondents, by sector of employment, position, and organization

There are some limitations to this study. Firstly, the sample is largely composed of practitioners from North America, and to a lesser extent, Europe. Further research could include a greater number of respondents from a variety of countries. Doing so would allow comparative analyses between different countries and regions and could help investigate the influence of national and regional context on practitioners. Secondly, this research focuses on location-based accessibility metrics, as they are most commonly used in planning and well suited to provide a regional evaluation of land use and transport systems. Furthermore, compared to person-based and utility-based metrics, these measures are easy to operationalize and communicate (van Wee & Geurs, 2016), which supports their wide use in research and planning. Yet, further studies could look into the use of person-based and utility-based accessibility metrics. Thirdly, this study is mainly concerned with the geographic access to destinations and does not address the financial, cultural, and cognitive factors that can prevent someone from accessing opportunities. Furthermore, it does not account for communication technologies, or on-site services, that can provide access without the need to physically reach a destination. Nevertheless, geographic access is a key component of accessibility in the broad sense and has been shown to positively contribute to quality of life, employment and modal shift.

3.5 RESULTS

3.5.1 From knowledge to use of metrics

All respondents were asked about whether they were familiar with the accessibility concept and metrics, and whether they used them in their work, based on the definitions of the concept and metrics provided in the survey (see Figure 4). The patterns are similar across sectors of employment, positions, and organizations, and thus presented in an aggregated manner in Figure 6. Figure 6 illustrates the proportion of respondents that agreed with each of the statements. In all cases, more than 50% of the respondents agreed with the statement, suggesting that the majority of respondents are familiar with the concept and metrics, and use them in their work. This high penetration rate is partially explained by the non-random selection of participants. In fact, there was an effort to disseminate the survey to practitioners who do work with accessibility, as the aim was to understand how accessibility is designed and used in practice. Furthermore, practitioners with a prior knowledge of accessibility were more likely to fill out the survey.

Nevertheless, the comparative assessment of the familiarity and use of the concept and metrics sheds light on current practices. Interestingly, 90% of the respondents are familiar with the concept of accessibility and 86% of the respondents use the concept of accessibility in their work. This indicates that almost all the respondents that are familiar with the concept use it in their work. Not surprisingly, a slightly lower proportion of respondents (78%) are familiar with the metrics. Yet, only 55% of these respondents use them in their work. There is an important discrepancy between the number of respondents that are familiar with the metrics and the ones who use it. These findings suggest that although practitioners are familiar with the metrics, some factors prevent them from using them in their workplace. These factors are further explored in the next section.

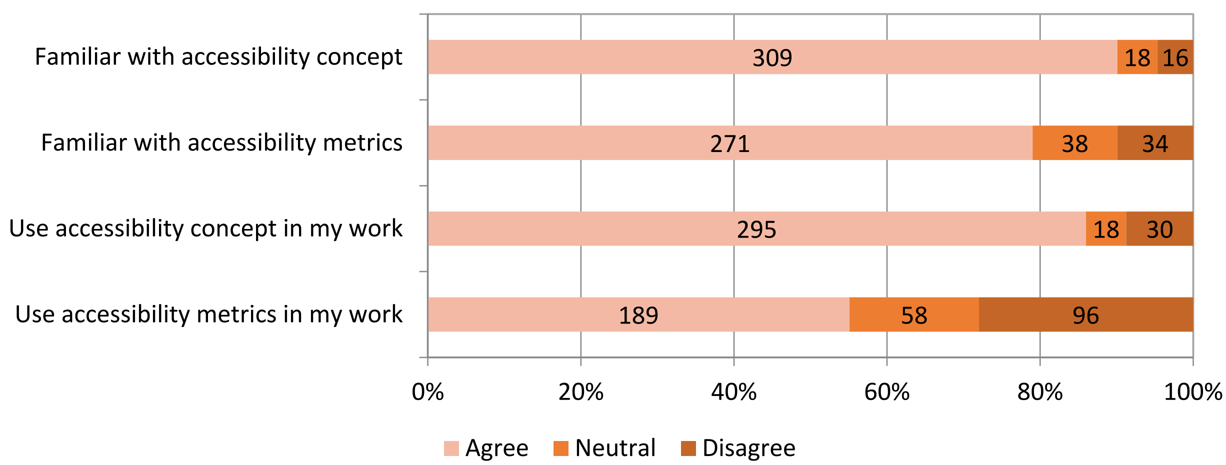

Figure 6: Familiarity with and use of accessibility (Concept and Metrics)

3.5.1.1 Motivations and Barriers

To better understand the factors underlying the use of the accessibility concept and metrics, respondents were asked about the reasons for which they generated accessibility metrics. For those who did not use accessibility metrics in their work, we asked them about the barriers preventing it. For both questions, respondents had to select all options that applied from a predefined list of factors (see Figure 7 for the exhaustive list of factors). Respondents also had the possibility to select "other" and to write a different reason. Figure 7 shows the motivation for using accessibility metrics (among respondents who use the metrics) and the barriers to using them (among respondents who used the concept, but not the metrics).

Only 22% of the respondents that used accessibility metrics in their work stated that the metrics were present as a tool prior to their arrival. Similarly, few respondents (16%) stated that it was a request from their superior. These results suggest that, although most practitioners are familiar with the concept and metrics, accessibility is not widely implemented as a planning tool in our sample. In contrast, the main motivation for using the metrics comes from the respondent's initiative: 36% of the respondents stated that the generation of accessibility metrics was their own initiative. This indicates that promoting accessibility among practitioners can be an efficient way to foster the use of accessibility metrics as a planning tool. Furthermore, 30% of the respondents indicated that the generation of metrics resulted from a requirement from a planning document. Accordingly, integrating accessibility indicators in planning documents can help practitioners in integrating accessibility metrics in their work. Finally, a request from a client is the least important motivation. This could be due to the low representativeness of respondents from the private sector in our sample.

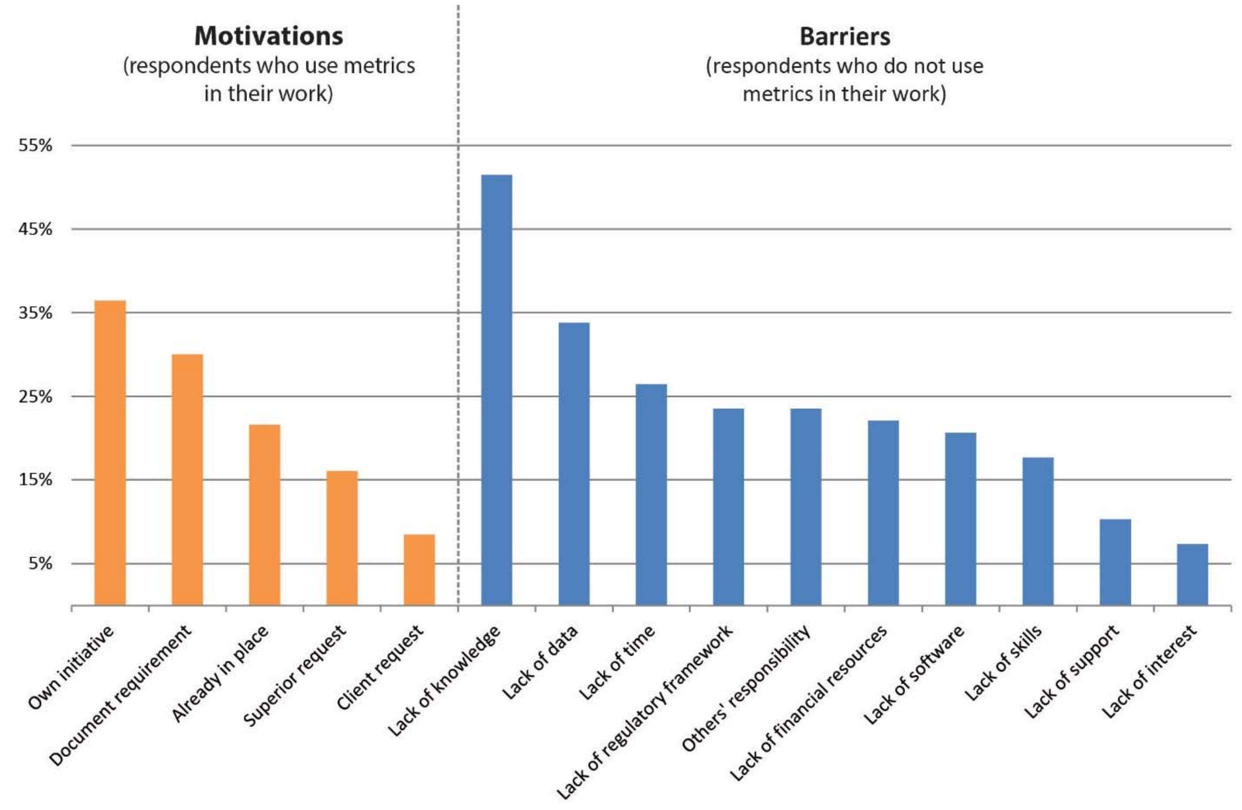

Figure 7: Motivations and barriers to the use of accessibility metrics

Figure 8 presents the motivations for using accessibility metrics, by sector of employment. Not surprisingly, the proportion of respondents who stated that the generation of accessibility metrics was their own initiative is greater for respondents from the private sector, whereas a requirement from a planning document is most frequently cited by respondents from the public sector. The generation of accessibility metrics due to a requirement from a planning document is in fact the most commonly cited reason in the public sector (47% of the respondents), highlighting the potential influence of planning documents on practitioners from the public sector. With respect to the private sector, a request from a client is the second most commonly cited motivation (33% of the respondents). As transport planning clients are often public entities such as municipalities or regional governments, planning documents can also play an important role here. Indeed, having clear accessibility requirements can support the integration of accessibility metrics in outsourcing contracts.

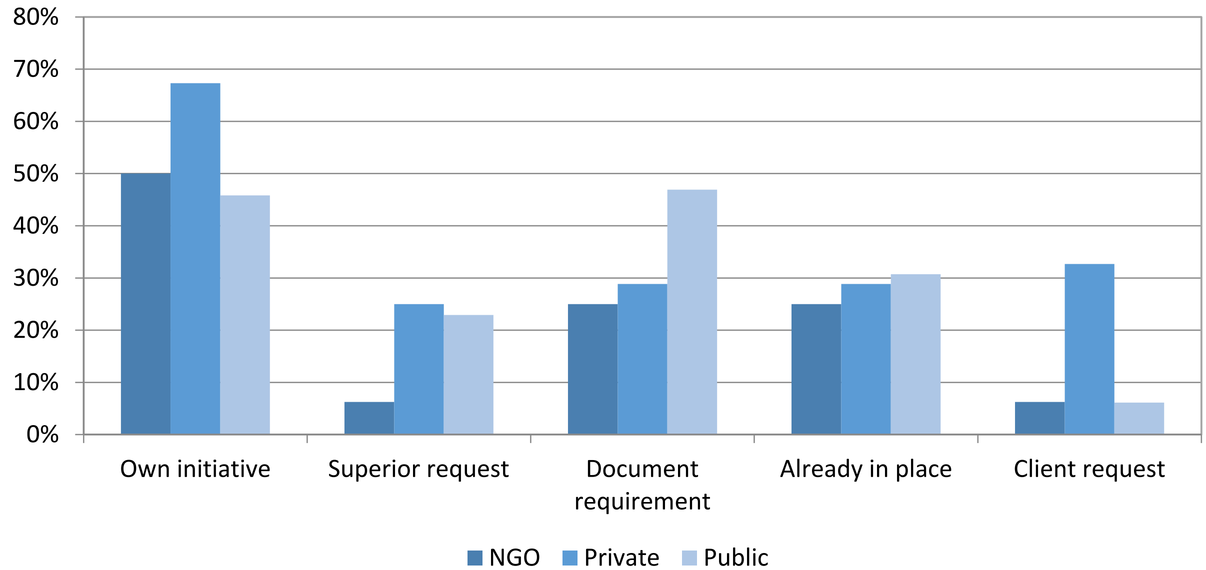

Figure 8: Motivations to the use of accessibility metrics, by sector of employment

With respect to the respondents who did not use accessibility metrics in their work (Figure 7, right), the barrier most frequently is the lack of knowledge (52%). These findings highlight the need to train future and current practitioners on accessibility metrics, especially since the survey revealed that most metrics were generated as a result of the respondents' own initiative. Furthermore, another important barrier is the lack of data to generate accessibility metrics (34%). Yet, many accessibility metrics can be generated through open-source data, for example using General Transit Feed Specification data, and open Geographic Information System (GIS) such as QGIS. With respect to the location of jobs or other opportunities, these can be obtained from various sources. Accordingly, the lack of data could also be addressed by training practitioners on how to collect adequate data to generate accessibility metrics, and on the different data sources and tools that are available in different regions. Finally, it is also interesting to note that the lack of interest (7%) and lack of support (10%) are the least commonly stated barriers to using accessibility metrics. Practitioners hence do not appear to be reluctant to implementing accessibility-based approaches. Rather, knowledge factors prevent them from generating accessibility metrics.

A previous study on the use of accessibility instruments by practitioners in Europe found that the lack of resources, including time, money, data and computational skills in the participants' organization were perceived as important barriers by the participants (te Brömmellstroet et al., 2014). Furthermore, the lack of funding and resources has been identified as a major barrier to the implementation of accessibility planning in the UK (Geurs & Halden, 2015; Lucas, 2006). In our study, many respondents (between 16% and 34%) also identified the lack of resources (either data, time, money, software or skills) as a barrier. Although the lack of knowledge is most commonly cited, our findings confirm the presence of institutional barriers to the adoption of accessibility metrics by practitioners. While the studies discussed above are based on European practices, our sample is largely represented by practitioners outside of Europe and thus suggests that these barriers are not unique to the European context.

Other cultural, political and institutional factors have also been found to limit the use of accessibility metrics in practice in Europe. Namely, researchers discussed the lack of integration and collaboration between urban and transport planning departments and practitioners as well the culture in the transport profession (Geurs & Halden, 2015; Papa, Silva, te Brömmelstroet, & Hull, 2014). In this regard, further context-specific research is needed to explore the institutional, cultural and political barriers to the adoption of accessibility metrics in practice, especially in North America. Nonetheless, our study suggests that targeting practitioners can contribute to fostering the use of accessibility metrics by removing a major knowledge barrier that has been identified in this study.

Taken together, the findings suggest that practitioners are open to using accessibility as a tool, but that the lack of knowledge prevents some of them from doing so. Accordingly, more effort is needed to train current and future practitioners about the generation of accessibility metrics. In fact, previous research has shown that an improved dialogue between researchers, practitioners, and software and tool developers can better support the use of planning tools, and more specifically accessibility planning tools, in practice (te Brömmellstroet et al., 2014; te Brömmelstroet, 2010; te Brömmelstroet, Curtis, Larsson, & Milakis, 2016). Namely, in a series of workshops on accessibility instruments in Europe, researchers reported a disconnect between practitioners' needs and the tools developed by researchers and developers (te Brömmelstroet, 2010; te Brömmelstroet et al., 2016). Accordingly, in addition to a traditional transfer of knowledge from researchers to practitioners, collaborative workshops can effectively contribute to a greater use of metrics in practice. This is, once again, especially relevant in the North American context, given that a large proportion of our respondents are from the United States and Canada.

3.5.1.2 Accessibility in planning documents

With respect to planning documents, respondents were asked about the presence of accessibility in the planning documents that they work with. The following questions were asked:

To what extent do you agree with the following statements?

- The concept of accessibility is included in the planning documents of the region I work in.
- Accessibility is stated as a main goal in the planning documents of the region I work in.
- Clearly defined accessibility indicators are included in the planning documents of the region I work in.

Around 74% of the respondents stated that the concept of accessibility is included in the planning documents of their region, whereas 59% indicated that accessibility was stated as a goal (Figure 9). Furthermore, only 38% of them agreed that clearly defined accessibility indicators were present in the planning documents. These findings are in line with previous studies that found that although accessibility is included in most planning documents, few of them have clear accessibility goals and indicators that guide the decision-making processes (Boisjoly & El-Geneidy, 2017a; Handy, 2005; Proffitt et al., 2017).

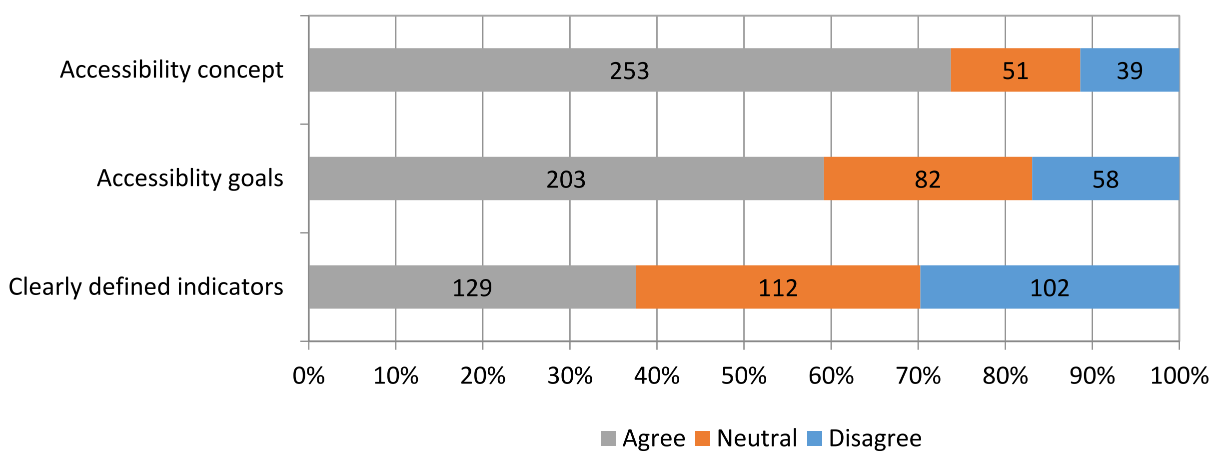

Figure 9: Presence of accessibility in planning documents

The presence of accessibility in planning documents is further explored by comparing the results between respondents that used accessibility metrics, respondents that used the concept but not metrics, and respondents that did not use accessibility in their work. Note that, for the purpose of this analysis, respondents who selected “neither agree nor disagree” with respect to the use of the concept or metrics were not considered as respondents that did use the concept or metrics, respectively. Figure 10 illustrates the proportion of respondents that agreed with each statement, for each group. Respondents that do not use accessibility in their work agreed in the lowest proportion that the concept of accessibility is included in the planning documents they work with, and that accessibility is stated as a goal. These results suggest that the presence of accessibility, and its statement as a goal, are associated with a greater use of accessibility (both in terms of the concept and metrics). Note that a statistical difference test (Tukey HSD) was performed to compare the average Likert scale values (from 1 to 5) between groups. Statistical differences (at the 90% confidence level) were observed between respondents that do not use accessibility, and the ones that do (metrics or concept), further supporting the results discussed above.

With respect to indicators, the proportion of respondents that agreed that clear accessibility indicators were included in the planning documents is much higher among respondents who used accessibility metrics in their work. In this case, statistical differences in the average Likert scale values were found between respondents that used metrics and the two other groups. These results suggest that the presence of clear accessibility indicators in planning documents foster the use of accessibility metrics by practitioners. Whereas goals are associated with respondents that use accessibility in general, clear indicators are more strongly linked to the use of metrics. This is once again not a surprising result but highlights the strong importance of having clearly defined indicators in planning documents.

These findings confirm that planning documents can play a key role in motivating practitioners to use accessibility metrics in their work. Furthermore, it emphasizes the need to include clearly defined indicators of accessibility in planning documents, in addition to the overarching goals. In this regard, Boisjoly and El-Geneidy (2017a) found that the use of broad accessibility goals in metropolitan plans is often not translated in performance indicators that reflect the ease of reaching destinations, especially when the accessibility goals are not clearly defined. In sum, this study reiterates the importance of defining clear goals and indicators in metropolitan land use and transport plans in order to support the use of accessibility metrics.

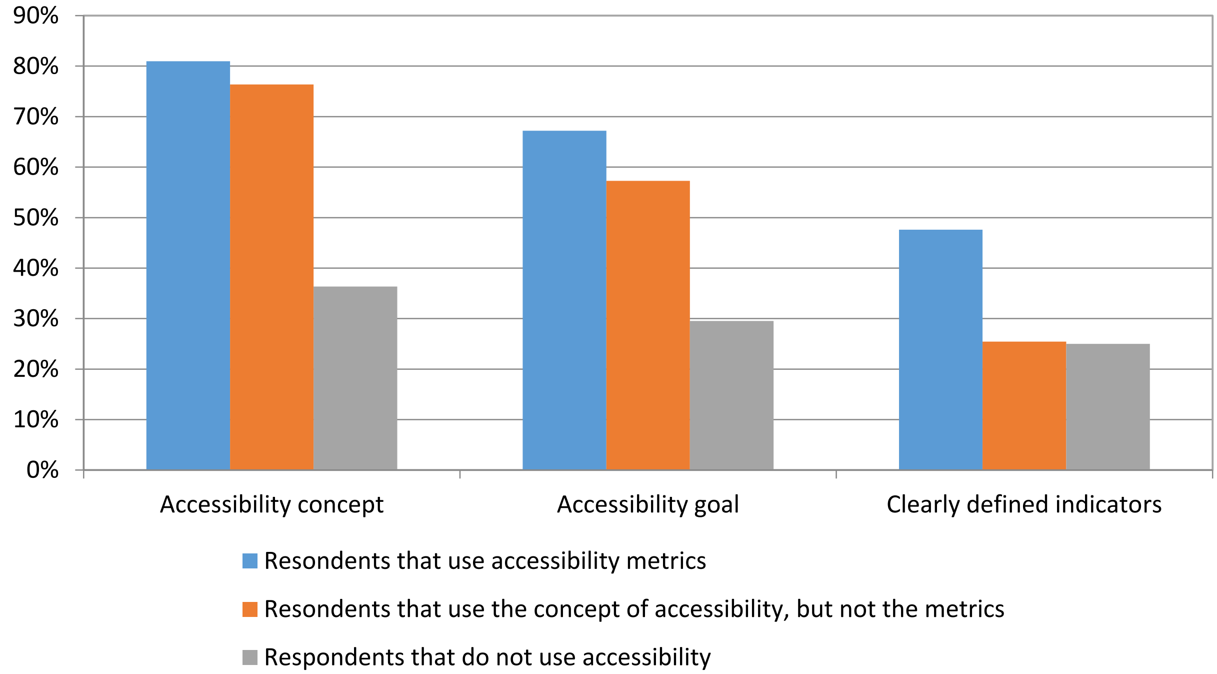

Figure 10: Presence of accessibility in planning documents, by use of accessibility

3.5.2 The use of accessibility metrics

3.5.2.1 Modes and destinations

In terms of accessibility indicators, the survey investigated which modes and destinations were considered by practitioners. As we can see in Figure 11 and Figure 12, public transport is dominant, both in terms of modes assessed and types of destinations (access to public transport stops). Access to public transport is a measure of service coverage that is widely used by public transport providers and in metropolitan transport plans (CMAP, 2014; LTA, 2013; Metrolinx, 2008). It is a simple and effective measure that reflects the spatial expansion of the network. Yet, such measure only captures one component of accessibility, as it does not include the location of opportunities. For example, an individual can have good access to a public transport stop, but the bus line serving this stop might not lead to a high number of opportunities. To effectively capture the ease of reaching opportunities, access to destinations must be considered. In this regard, access to jobs and employment clusters, although not as commonly used as access to public transport, is used by a vast majority of respondents (72% and 60% respectively), while access to other types of destinations (green amenities, retail stores, healthcare services, and cultural and leisure activities) is used in a lower proportion (between 40% and 50%). Access to jobs is also most commonly used in accessibility research, namely to explore unemployment rates and commuting mode choice (Korsu & Wenglenski, 2010; Owen & Levinson, 2015b). While access to other types of destinations also plays a key role in achieving social, economic and environmental goals, access-to-jobs metrics provides a regional assessment of the land use and transport systems, and is accordingly used in multiple studies and metropolitan transport plans (Bocarejo & Oviedo, 2012; Boisjoly & El-Geneidy, 2017a; Manaugh & El-Geneidy, 2012; Owen & Levinson, 2015a). Indeed, since most activities and amenities are associated with the presence of jobs, access to jobs reflects, to a large extent, the quality of the transport network in relation to the location of opportunities in a region. Since our sample is mainly composed of planners (62%), the relevance of job accessibility metrics for regional planning assessment likely explains the large proportion of respondents using jobs or employment clusters as destinations. The wide use of job accessibility metrics in research also contributes to its adoption by practitioners.

In terms of modes, access by public transport is used by the greatest number of respondents. A variety of factors might contribute to this result. Firstly, since the availability of GTFS data, accessibility by public transport has become a major trend of accessibility research (Lei & Church, 2010; Owen & Levinson, 2015b). It is also widely incorporated in accessibility instruments, more than car travel according to a recent study on accessibility instruments in Europe (Hull, Silva, & Bertolini, 2012). The wide dissemination of public transport accessibility metrics in research and by developers likely contributes to the use of such metrics by practitioners. Also, from a sustainability and equity perspective, improving accessibility by public transport is increasingly considered as desirable (Golub & Martens, 2014; Owen & Levinson, 2015b).

Whereas cycling and walking accessibility is not as commonly assessed by practitioners, researchers recently emphasized the need for accessibility research focusing on active transport modes (Hull et al., 2012; van Wee & Geurs, 2016). While there is a large body of literature on accessibility by car and public transport, few studies have assessed accessibility by walking or cycling. Although there seems to be emerging research on this topic (Iacono, Krizek, & El-Geneidy, 2010; Owen, Levinson, & Murphy, 2015), the gap in research likely explains the low penetration of active mode accessibility indicators.

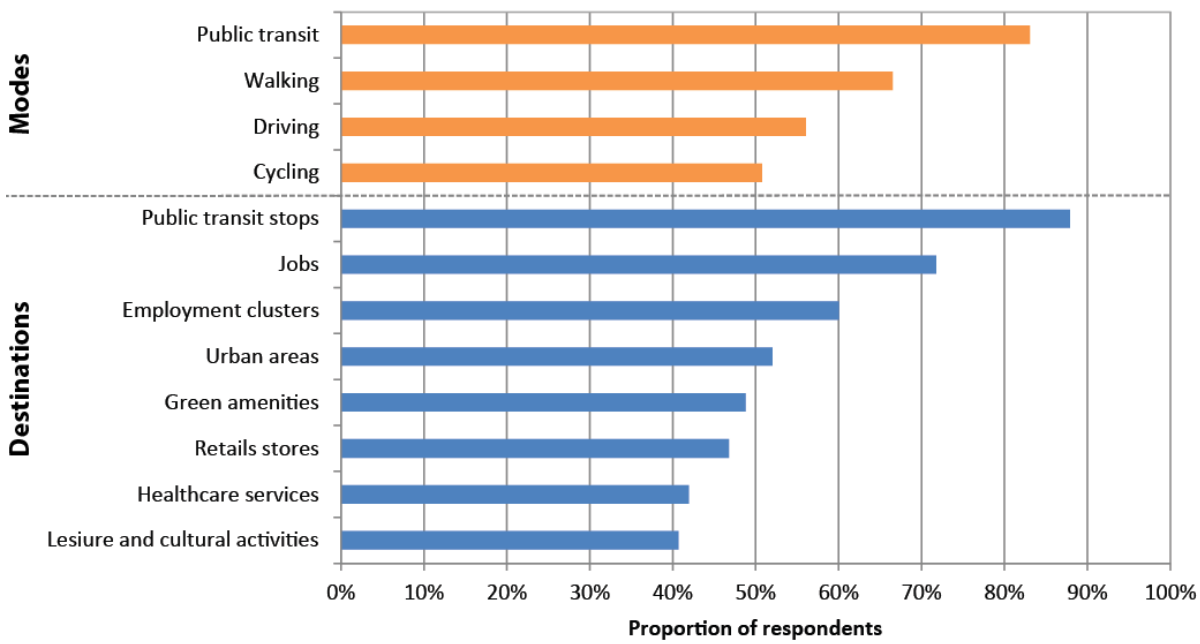

Figure 11: Accessibility metrics – Modes and destinations

3.5.2.2 Types of metrics

Respondents were also asked to select the types of metrics that they used in their work. As we can see in Figure 12, the most commonly used metrics are travel time proxies. In line with these findings, a recent study found that travel time proxies are also widely used in metropolitan transport plans across the United States (Proffitt et al., 2017). Density and land use mix proxies are also commonly used by the respondents, as shown in Figure 12. However, travel time, density and land use proxies do not fully reflect the ease of reaching destinations, as they do not address the interactions between the land use and transporation systems.

In this regard, a large proportion of respondents use location-based metrics (cumulative-opportunity and gravity-based metrics), which reflect the ease of reaching destinations and account for both the land use and transport components. Cumulative-opportunity metrics are used in greater proportion by the respondents, as can be seen in Figure 12. While gravity-based metrics more closely reflect travelers' perceptions of time (Ben-Akiva & Lerman, 1979), they are more difficult to generate and to communicate. In contrast, cumulative-opportunity measures are easier to generate and to interpret (Geurs & van Wee, 2004), and thus most commonly used in planning. Cumulative-opportunity metrics are highly correlated with gravity-based metrics, and thus represent appropriate measures of regional accessibility (Boisjoly & El-Geneidy, 2016; El-Geneidy & Levinson, 2006). The results indicate that accessibility metrics used by practitioners are generally based on travel time or distance. These thresholds are also largely used in accessibility research, while a few studies have incorporated generalized costs (Bocarejo & Oviedo, 2012; Currie, 2004; El-Geneidy et al., 2015). Although generalized costs better represent the time and monetary values associated with a trip, metrics based on time generally adequately reflect accessibility, as they are highly correlated with mode choice (Anderson et al., 2012; Legrain et al., 2015).

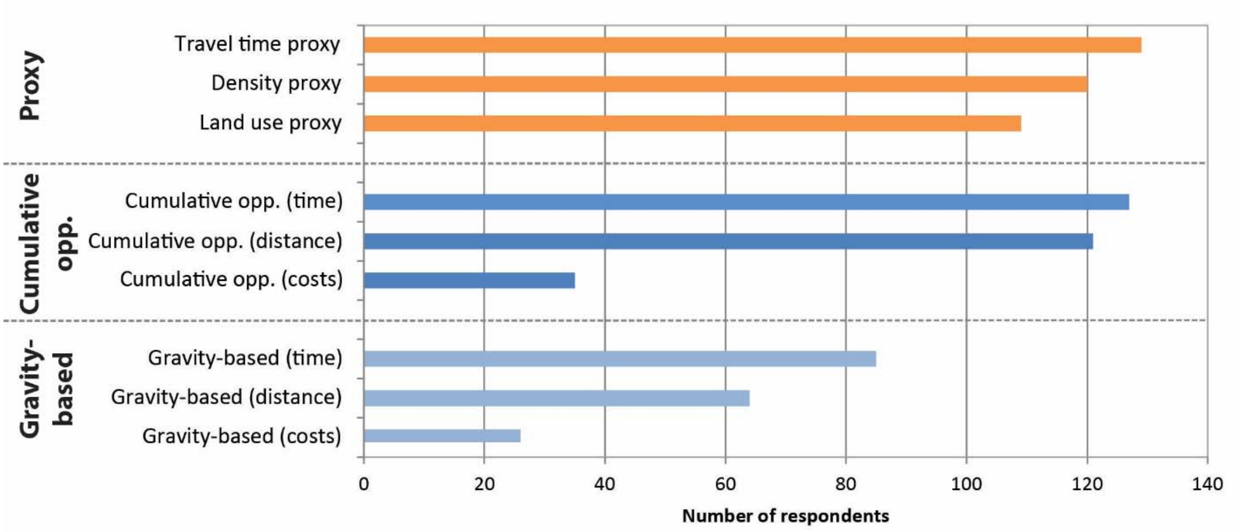

Figure 12: Types of accessibility metrics used by practitioners

In sum, among the 189 practitioners who agreed ("agree" or "strongly agree") that they use accessibility metrics in their work, 22% (42 respondents) of them did not use indicators that reflect access to destinations. 40 respondents merely used proxies (travel time, density, land use mix) and 2 respondents only used access to public transport metrics. Overall, 43% of all respondents (n=343) use metrics reflecting access to destinations, while 55% stated that they use accessibility metrics in their work (Figure 6).

The wide use of proxies is likely associated with their ease of generation, interpretation and communication. However, proxies do not fully capture the interactions between land use and transport systems as they do not jointly account for the characteristics of the land use and transport sytems. In fact, greater mobility, reflected in reduced travel times, does not necessarily equate with greater accessibility (Ferreira & Batey, 2007). While reduced travel times can reflect greater accessibility in the short run, they can also result in greater travel distances and costs in the long run (Levine et al., 2012). If reductions in travel times are due to road expansions and increased travel speeds, the interventions are likely to yield a greater dispersion of destinations, as a result of induced demand and land use development (Handy, 2002; Levinson & Krizek, 2007). Such mobility-oriented development typically leads to greater travel costs, increased driving, and greater discrepancies in accessibility. Accordingly, independent mobility goals might not fully address the broader societal goal of transport of providing access to destinations within reasonable time and costs (Banister, 2008; Handy, 2002; Levine et al., 2012). While the focus on mobility has favoured urban sprawl in the last decades, a focus on accessibility is more likely to provide all individuals with more options, and to reduce the need to drive (Banister, 2008; Handy, 2002). As highlighted by Geurs and Halden (2015), potential accessibility indicators, measuring the ease of access to a variety of destinations, need to be included in transport planning in addition to transport performance indicators such as travel times or costs. With respect to density and land use proxies, increasing density and mix of use has the potential to increase access to destinations, and is thus a relevant metric to address planning for accessibility (Levine et al., 2012). Yet, it does not account for the transport component.

Taken together, these findings reiterate the importance of training current and future practitioners about accessibility metrics and having clearly defined accessibility indicators in planning documents. More specifically, a clear distinction should be made between mobility and accessibility indicators, and access to destinations should be emphasized. Furthermore, a greater collaboration between practitioners, researchers and developers can contribute to bridging the gap between the effectiveness and the usability of metrics.

3.5.3 Accessibility and decision-making

Another important component of accessibility metrics is their potential to influence decision-making. In this regard, respondents were asked about the relevance of accessibility metrics to planning and decision-making. Results are presented in Figure 13. As in the previous analysis, respondents who selected "neither agree nor disagree" with respect to the use of the concept or metrics were not considered as respondents that did use the concept or metrics, respectively.

As we can see in Figure 13, more than 95% of the respondents who do use accessibility metrics agreed that accessibility metrics can and should influence decision-making, and that accessibility metrics are useful planning tools. The proportion of respondents that agreed that accessibility metrics can and should influence decision-making is lower, however, among respondents who do not use accessibility metrics, especially those who do not use the concept nor the metrics. Although not surprising, this finding could suggest that as more practitioners use accessibility metrics, a greater proportion will perceive those metrics as a potential planning tool to inform decision-making. It could also reflect that practitioners who perceive accessibility as useful for decision-making are more inclined to using accessibility metrics.

For all three statements, statistical differences were observed in the average Likert scale values between respondents that use accessibility metrics and the two other groups, whereas the difference between the respondents that use the concept (not the metrics), and respondents that do not use accessibility were not statistically different. As the latter group only comprised 28 respondents, future research could specifically survey practitioners who do not use accessibility in their work to obtain a larger sample and deepen our understanding of the factors that limit the implementation of accessibility indicators in practice.

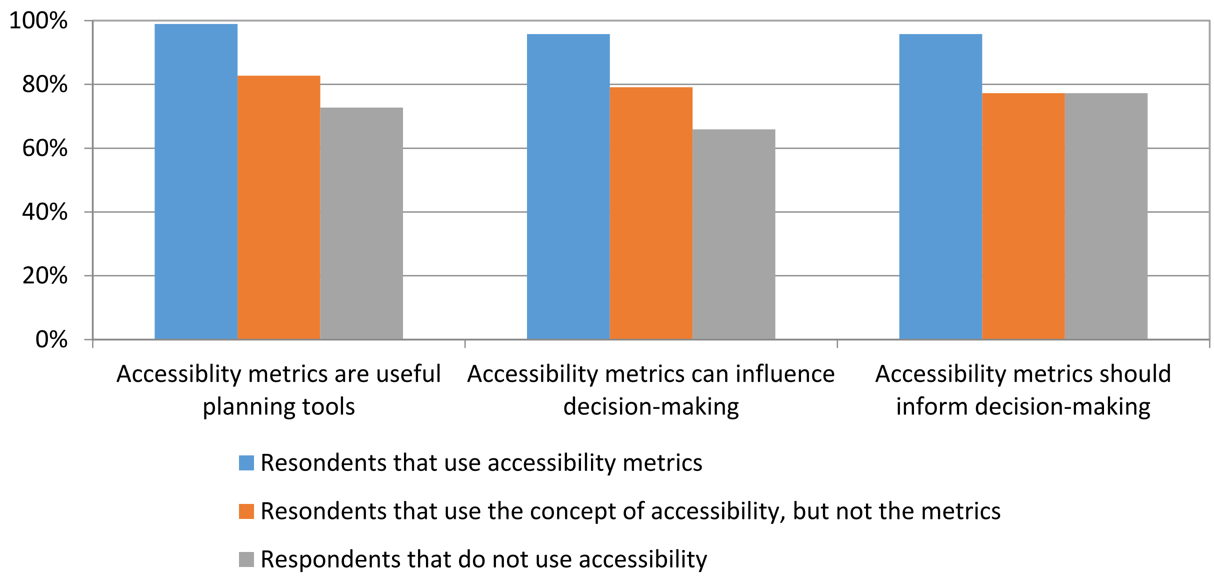

Figure 13: Relevance of accessibility metrics to planning and decision-making

Respondents who did use accessibility in their work were also asked for what purpose they used the concept or the metrics of accessibility. Interestingly, in both cases, the main purpose was for decision-making (59% for the concept and 47% for the metrics). These findings are coherent with the results discussed above. Clearly, there is an agreement among most practitioners that accessibility is an important component of decision-making.

3.6 CONCLUSION

This study investigated the design and use of location-based accessibility metrics by land use and transport practitioners. It has shown that there is an important gap between the knowledge of the concept of accessibility, and the use of accessibility metrics by practitioners. While most practitioners surveyed are familiar with the concept of accessibility, a much lower proportion of respondents (55%) stated that they use accessibility metrics in their work and only 43% of the respondents used accessibility metrics that actually reflect the ease of reaching destinations. In contrast, access to public transport and travel time proxies were most commonly used by practitioners.

Whereas lack of support and interest does not appear to be a major obstacle to generating accessibility metrics, lack of knowledge and data are highlighted as the main barriers. In contrast, the use of metrics is largely due to the planners' own initiative. These findings suggest that working directly with practitioners can effectively foster the use of accessibility metrics in practice. More specifically, such efforts can contribute to the use of metrics in practice by: i) providing practitioners with a greater understanding of the various types of metrics, ii) improving their knowledge on how to generate such metrics, and iii) highlighting the value of using these metrics for land use and transport planning. Furthermore, greater collaboration between researchers and practitioners as well as developers can help aligning research and development with the practical challenges and needs. Given that accessibility is now a mature field of research, there is a potential to strengthen the links between the different actors and to increase collaborations between academics and practitioners. In the European context, the Cost Action on accessibility instruments, bringing together developers, researchers and academics, found positive results suggesting that workshops can contribute to promoting the use of accessibility instruments in practice. Namely, they reported that participants were satisfied with the workshops and intended to use the insights gained from the workshop in their work, and share them within their organizations (te Brömmellstroet et al., 2014). Our study highlights the need for similar projects, especially in North America.

In addition to working closely with practitioners, the presence of clear accessibility indicators is key to promote the use of accessibility metrics by practitioners. Planning document requirements are key motivations stated by practitioners using accessibility metrics. Yet, most respondents, especially the ones that do not use accessibility metrics, indicated that the planning documents of the region they work in do not include clear accessibility indicators. National and regional governments and organizations can play a key role in setting clear accessibility requirements for transport planning processes and planning documents. For example, in the early 2000s, the UK established a framework for *accessibility planning* to ensure that local transport planning authorities addressed issues of access to opportunities. As a result, accessibility had to be included in transport plans at the local level. Yet, as discussed in the introduction, the flexibility of the guidelines resulted in a multitude of interpretations that did not necessarily translate into access-to-destinations indicators (Curl et al., 2011; Halden, 2011). Nevertheless, the focus on accessibility has contributed to positive achievements in terms of accessibility (Geurs & Halden, 2015). Similarly, the United States has federal transport planning requirements, one of which emphasizes the need to improve mobility and accessibility. As a result, most regional transport plans address accessibility in one way or another. However, accessibility goals are rarely translated into accessibility indicators, and accessibility and mobility are often used interchangeably (Handy, 2005; Proffitt et al., 2017). In sum, national policy documents can influence local transport planning processes, but in order to ensure that accessibility indicators reflecting the ease of reaching destinations are included, clear guidelines must be provided and a clear distinction between mobility and accessibility must be made.

Overall, this study provides a first insight into general and potential measures that can support practitioners in developing accessibility metrics. Training practitioners and setting clear accessibility performance measures in planning documents can contribute to the use of accessibility metrics in practice, which can foster a shift from a mobility-based approach to an accessibility-based approach. While the use of metrics does not encompass all challenges associated with a shift of paradigm in transport planning, the presence of performance indicators can significantly contribute to including issues of accessibility in decision-making. Indeed, accessibility goals are increasingly incorporated in transport plans, but the lack of performance indicators limits their influence on planning. Namely, Handy (2008) found that goals without performance indicators received the least weight in metropolitan transport plans in the US. Similarly, Manaugh et al. (2015) discuss the importance of measuring policy goals, in this case social equity goals, to ensure that they receive greater attention in decision-making. Lucas (2012) also emphasizes the need to establish metrics guiding the provision of public transport for social inclusion, in order to promote the social inclusion agenda. In all cases, research points towards the fact that performance indicators are essential to support the achievement of goals, be it accessibility, social equity or social inclusion.

This study specifically sheds light on challenges associated with the use of accessibility metrics into practice to contribute to a greater consideration of accessibility issues in decision-making. This research also illustrates the need to bridge the gap between accessibility research and practice. The findings are of relevance to planners and policy makers wishing to support accessibility-oriented planning practices and are helpful for researchers to better understand the challenges experienced by practitioners.

CHAPTER FOUR: DAILY FLUCTUATIONS IN PUBLIC TRANSPORT AND JOBS AVAILABILITY: A COMPARATIVE ASSESSMENT OF TIME-SENSITIVE ACCESSIBILITY MEASURES[4]

4.1 OVERVIEW OF CHAPTER

This chapter addresses one of the barriers to the implementation of accessibility indicators in practice identified in Chapters 2 and 3: the lack of guidance on which measures to use in metropolitan transport planning. More specifically, with a rise in time-sensitive measures of accessibility by public transport, choosing the appropriate measure is increasingly challenging for engineers, planners and policy-makers. Accordingly, this research presents a comparative analysis of three accessibility measures, two of which are time-sensitive. Relative accessibility measures are generated for five time periods based on a) constant public transport service and number of jobs (constant); b) variable public transport service and constant number of jobs (static) and c) variable public transport service and variable number of jobs available (dynamic). The measures are first assessed by incorporating them into a public transport mode share model. Interestingly, findings show that all three measures behaved similarly in the three regression models. Furthermore, all accessibility measures are found to be highly correlated. The study suggests that the most commonly used accessibility measure (constant measure at 8 am) is representative of the relative accessibility (static or dynamic) over the course of the day and is thus appropriate and meaningful to be used by policy-makers, engineers and planners.

[4] Boisjoly, G., & El-Geneidy, A. (2016). Daily fluctuations in transit and job availability: A comparative assessment of time-sensitive accessibility measures. *Journal of Transport Geography, 52*, 73-81.

4.2 INTRODUCTION

Accessibility is increasingly incorporated into transport and land-use planning objectives (Geurs et al., 2012; Handy, 2008; Lucas, 2012; Manaugh et al., 2015; Preston & Rajé, 2007), as it is proven to be a relevant indicator for promoting equitable transport systems (Martens et al., 2012), sustainable urban transport (Banister, 2008; Boschmann & Kwan, 2008; Handy, 2008) and social inclusion among disadvantaged groups (Lucas, 2012; Preston & Rajé, 2007). Increasing accessibility by public transport allows meeting the needs of individuals while reducing automobile dependence (Handy, 2002). For engineers and planners, choosing appropriate metrics is central in order to evaluate desired goals and develop effective policies (Geurs & van Wee, 2004; Handy & Niemeier, 1997). A plethora of accessibility measures have been developed (Geurs & van Wee, 2004; Handy & Niemeier, 1997; Paez et al., 2012), with a trend towards more detailed and complex approaches (Geurs, De Montis, & Reggiani, 2015; Geurs et al., 2012). Namely, recent research seeks to address the fluctuation in accessibility by public transport that may occur over the day due to variations in service (Anderson et al., 2012; El-Geneidy et al., 2015; Farber et al., 2014; Wangtu, Ding, Zhou, & Li, 2015). Various approaches are put forward, based on different methodological and conceptual basis, and addressing different levels of complexity.

Given recent theoretical developments and a growing interest for applicable accessibility metrics, this methodological study explores whether time-sensitive measures of location-based accessibility to jobs by public transport throughout the day provide a more appropriate measure of accessibility than the constant ones. By doing so, this research seeks to address the gap between accessibility research and its practical applications. The research setting is the Greater Toronto Hamilton Area (GTHA). Building on previous studies (El-Geneidy et al., 2015; Fan et al., 2012; Legrain et al., 2015), we generate three accessibility measures for five daily time periods. The first accessibility measure is constant over the day, while the two other measures take into account the fluctuations in public transport and job availability during the day. Using one data set, this study compares the three different measures and is of relevance to engineers and planners who want to balance between the accuracy and the simplicity of a measure. This research, although based on one region, provides methodological insight that can be relevant to other regions.

4.3 LITERATURE REVIEW

4.3.1 Accessibility

In transport planning, accessibility is largely defined as the potential of an individual to reach opportunities (Preston & Rajé, 2007). While mobility studies are mainly interested in travel speed, accessibility includes a broader range of factors that affect the capacity or the ease of reaching a location. Based on an extensive literature review of accessibility definitions, Geurs & van Wee (2004) identify four components of accessibility: the transport component, the land-use component, the individual component and the temporal component. The transport component, widely studied in mobility and accessibility studies, is related to the transport infrastructure and is usually mode specific. The land-use component refers to the location and the characteristic of opportunities or the location of people. Most studies focus on opportunities such as jobs, health services and shops. The individual component reflects the personal characteristics that might affect one's travel needs or capacity, including factors such as age, gender, car ownership, education, household composition and income. The last dimension is the temporal component, including the availability of opportunities across the day (example, opening hours of shops), the individual's schedule, as well as the public transport schedule.

4.3.2 Accessibility measures

Given the wide scope of factors affecting accessibility, measures of accessibility are also diverse. The measures of accessibility can be person-based, measuring the opportunities at the individual level, or location-based, measuring the number of opportunities accessible from one location (Geurs & van Wee, 2004; Miller, 2005; Owen & Levinson, 2015b). Person-based accessibility accounts for individual factors affecting one's ease of reaching its desired destination, whereas location-based accessibility presents aggregated measures. While location-based measures do not capture the individual component of accessibility, they allow assessing it at the regional scale and are thus most commonly used by policy-makers (Dodson et al., 2007). Because of its planning relevance, location-based accessibility is the focus of our study. The most common measure of location-based accessibility is the cumulative-opportunity measure (Geurs & van Wee, 2004). This method counts the number of opportunities that can be accessed from one location within a given travel time. A second common method is the gravity-based method, first introduced by Hansen (1959), which takes into account all opportunities available in the region and then discounts them based on the travel time from the origin. While the cumulative-opportunity measure is simpler, the gravity-based measure provides an estimation that better reflects reality.

Accessibility measures can be translated into relative accessibility indicators to compare the levels of accessibility across groups or modes (Niedzielski & Boschmann, 2014; Paez et al., 2010a) or across a region (Manaugh & El-Geneidy, 2012; Widener, Farber, Neutens, & Horner, 2015). Zonal relative accessibility allows policy-makers to assess the geographic distribution of opportunities and transport services (Handy & Niemeier, 1997).

4.3.3 *Accessibility by public transport*

As public transport gained importance in accessibility research, numerous studies assessed accessibility to public transport (Moniruzzaman & Páez, 2012; Olszewski & Wibowo, 2005; Zielstra & Hochmair, 2011), counting for example the number of public transport stops within a specified walking distance. While these measures provide an indication of the presence of public transport service in an area, they do not assess the quality of this service to reach desired destinations. Accessibility by public transport to opportunities is hence increasingly researched as it provides a more comprehensive measure regarding the quality of public transport service in a region.

Typical measures of accessibility by public transport primarily focus on the transport component (transport infrastructure and public transport service availability) and the land-use component (location of homes, workplaces, health services, shops, etc.). Accessibility by public transport is based on travel time, calculated using the transport network characteristics, and on the location of opportunities and home locations. Measures are typically based on a single departure time, using a fixed number of opportunities, without considering opening hours of services, or, in the case of jobs, starting time (Owen & Levinson, 2015b).

4.3.4 *Time-sensitive measures*

While temporal factors are predominant in studies of person-based accessibility (Miller, 2005), using for example the space-time prism, first developed by Hagerstrand (1970), they are marginal in location-based accessibility studies. Although technical progress has been made for calculating travel time by public transport, namely with the use of the General Transit Feed Specification (GTFS) (Lei & Church, 2010; Owen & Levinson, 2015b), daily fluctuations are seldom taken into account when measuring accessibility (Owen & Levinson, 2015b). Furthermore, very few studies have included the combined influence of spatial and temporal factors in accessibility by public transport (Dodson et al., 2007).

Nevertheless, growing research highlights the importance of developing measures that are sensitive to temporal constraints (Anderson et al., 2012; Dodson et al., 2007; El-Geneidy et al., 2015). In this regard, some studies have attempted to address accessibility daily fluctuations by taking into account variations in public transport service. A first stream of research assesses variation of public transport service based on fluctuation of the demand (Polzin, Pendyala, & Navari, 2002; Wangtu et al., 2015). Most commonly, studies investigate public transport service variation with regard to public transport schedules. Mavoa et al. (2012) and Dill et al. (2013) address fluctuations in public transport service by adding a public transport frequency variable together with the accessibility measure while Dodson et al. (2007) measure public transport frequency at different times of the day to assess public transport service. Other studies take into account the daily fluctuations of public transport service by basing the accessibility measures on various departure times. Fan et al. (2012) calculate travel time at every hour of the day and provide a daily accessibility based on average hourly travel times. Anderson et al. (2012) and Lei & Church (2010) calculate the minimum travel time within a time window. On the other hand, Anderson et al. (2012) and Owen & Levinson (2015b) generate a continuous accessibility measure, accessibility being calculated at every minute. Farber et al. (2014) adopt a similar approach, measuring accessibility by public transport to supermarkets at every minute of the day. Minute-by-minute accessibility measurements provide a higher resolution than previous approaches based on hourly or single departure time, hence accounting for flexible departure times.

While variation in public transport service is accounted for in these studies, it is assumed that the opportunities at destinations (jobs in most studies) are available throughout the day. It does not take into account starting and leaving time constraints that are imposed on workers. For example, nurses or construction workers are more likely to work during non-typical working hours. This is especially relevant when travelling by public transport, since public transport service is generally lower during non-typical working hours. Legrain et al. (2015) address this limitation by combining variation in both public transport and jobs availability. They measure accessibility at five different time periods during the day, matching public transport time and number of jobs starting within a given time period.

Given the recent rise in the development of time-sensitive accessibility measures, assessing the different approaches is essential to help engineers and planners choose the method that best suits their needs. The utility of a measure depends on multiple criteria that are often in conflict with each other. On the one hand, measures must be theoretically sound, sensitive to multiple accessibility components (Geurs & van Wee, 2004; Handy & Niemeier, 1997). On the other hand, measures should be easy to operationalize, and easily interpretable and communicable (Geurs & van Wee, 2004; Handy & Niemeier, 1997). The choice of measure also depends on the objectives pursued by the engineers and planners (Geurs & van Wee, 2004; Handy & Niemeier, 1997).

Despite the recent progress in addressing the temporal component of accessibility, to our knowledge no study has yet assessed time-sensitive measures utility on a comparative basis. This study thus questions whether using time-sensitive measures, accounting for fluctuations in jobs availability and/or public transport service throughout the day, improves their utility relatively to traditional constant measures.

4.4 STUDY CONTEXT

The research setting of this study is the GTHA, an urban area including the City of Toronto, the City of Hamilton and the Halton, Peel, Yorkland and Durham regions. The population of the GTHA (5,574,140 in 2011) is constantly growing, primarily in the outer suburbs. In 2007, the region had 2,678,170 workers and 2,759,180 jobs (Shearmur, Coffey, Dube, & Barbonne, 2007). The GTHA draws workers from beyond its boundaries since the number of workers in the region is less than the number of jobs. Suburbanization of employment is also observed in the region (Shearmur et al., 2007).

The GTHA public transport network is composed of a commuter rail system (the GO Train), a centrally located subway system and streetcar network, and bus services that are provided by eight different public transport agencies. As shown in Figure 14, accessibility to all jobs available during the day by public transport calculated using the 8 am travel time is not evenly distributed across the region. Accessibility is greatest in the center and along the subway and commuter rail networks.

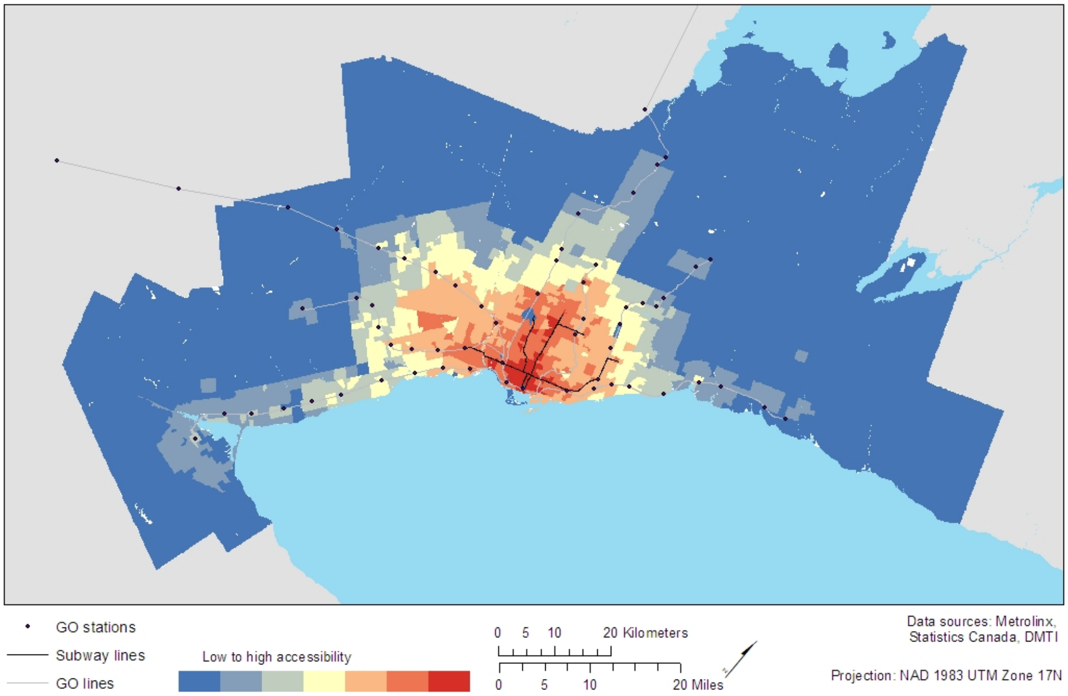

Figure 14: Accessibility at 8 am in the GTHA (number of jobs calculated with the gravity-based measure)

4.5 DATA AND METHODOLOGY

In order to compare the different methodological approaches of calculating accessibility, accessibility measures are generated based on different temporal measurements, using the same regional data. Three main data sources are used, all of which are at the census tract (CT) level. The first is the demographic census tract information from the Statistics Canada National Household Survey (NHS) collected in 2011 (Statistics Canada, 2011). This data includes household median income, unemployment rates, and percentage of immigrants and is used to determine social and economic deprivation.

The second dataset provides information regarding employed labour force commuting trips in the GTHA and is also obtained from the 2011 NHS (Statistics Canada, 2011). The number of trips from each CT to every other CT is provided for each travel mode. The data is organized in six time periods according to departure time (5 to 6 am, 6 to 7 am, 7 to 8 am, 9 am to noon, and noon to 5 am). Furthermore, the data is stratified by job category. Using this dataset, public transport mode share and number of jobs are estimated at the census tract level for each time period. The time periods used in this study are the ones provided by Statistics Canada. In order to avoid data suppression resulting from low amounts of data, data were aggregated from 9 am to noon, and from noon to 5 am by Statistics Canada. 341,875 workers departed to work between 9 am and noon, and 389,170, between noon and 5 am, comparatively to 747,765 departing between 7 and 8 am. The aggregation of data into extended time periods does not allow fully capturing the fluctuations throughout the day. Yet, to our knowledge, no data easily accessible to planners and researchers provides more detailed information on public transport mode share and especially jobs availability, for the whole region in a 24 hour detail. Nevertheless, variations between peak and off-peak hours are captured in our study, as well as variations throughout the morning hours (between 6 am and 12 pm), when most people travel (80%).

The final dataset is a public transport travel time matrix based on May-June 2014 General Transit Feed Specification (GTFS) data for all eight public transport agencies of the GTHA, calculated using the OpenTripPlanner Analyst provided by Conveyal (OpenTripPlanner, Accessed July 30, 2014).

4.5.1 Accessibility measures

Since the objective of this research is to compare measures of accessibility, the first step is to generate accessibility measures for all CTs in the study area. Based on previous research (El-Geneidy et al., 2015; Fan et al., 2012), three methods are chosen, which use different temporal fluctuations. Table 5 summarizes the three types of measure.

The constant measure reproduces the most common measure used in the literature (El-Geneidy & Levinson, 2006). It uses constant travel time and number of jobs across the day. The travel time is calculated based on an 8 am departure time, while the number of jobs corresponds to the total number of jobs available throughout the day. The static measure also uses a constant (total) number of jobs, but takes into account public transport service fluctuation across the day, as in most studies accounting for temporal variations. Accessibility is measured for each time period, using travel time for each time period. Finally, the dynamic measure accounts for public transport service fluctuation across the day and, additionally, the fluctuation in jobs availability throughout the day. Only jobs with a starting time associated with each time period are counted.

Table 5: Overview of the accessibility measures

Type of measure	Public transport service	Jobs availability
Constant	Constant (8 am travel time)	Constant (jobs available all day)
Static	*Variable*	Constant (jobs available all day)
Dynamic	*Variable*	*Variable*

4.5.2 Travel time, number of jobs and accessibility

Accessibility measures are all based on a travel time from each CT to every other CT and on the number of opportunities (jobs) available in each other CT. The public transport travel time for each hour is measured for departures at the top of the hour. It calculates the shortest trip (if walking, then walking) from each CT to every other CT with the time departure being the beginning of the hour. For the 9 am to noon time period, the average travel time of the departure at 9 am, 10 am and 11 am is calculated. For the noon to 5 am time period, travel time at noon is used in order to represent off-peak travelling time. Calculating the travel time based on an hourly resolution (at the top of the hour in our case) is imposed given the need to match the data available for public transport mode share and jobs availability.

The number of jobs available in one CT is calculated based on the number of workers arriving at the CT in question. The time period associated with the job is determined by the departure time of the worker, as provided in NHS commuting trips data (between 5 and 6 am, 6 and 7 am, 7 and 8 am, 9 am and noon, and noon and 5 am). Figure 15 shows the density of jobs in each CT across the day, which is generally higher between 7 to 8 am, and 8 to 9 am.

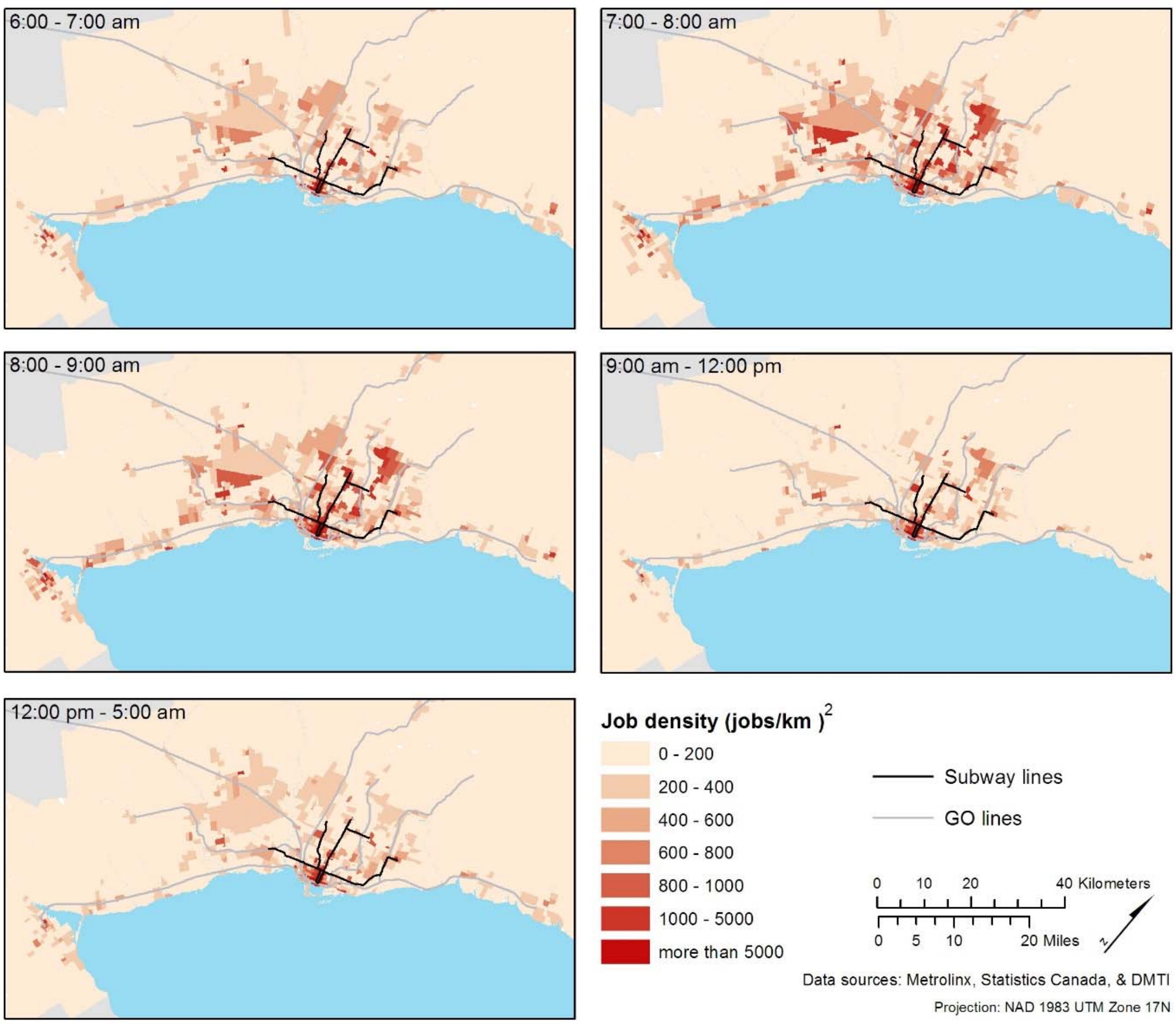

Figure 15: Density of jobs throughout the day in the GTHA

Both gravity-based and cumulative-opportunity measures were generated. However, since results were consistent and for simplicity reasons, this paper only presents the cumulative-opportunity approach. The cumulative-opportunity measure counts the number of jobs that are available from one CT within a certain travel time threshold, as indicated in equations 1 and 2.

$$A_i = \sum_{j=1}^{n} O_j f(C_{ij}) \qquad (1)$$

$$f(C_{ij}) = \begin{cases} 1 \text{ if } C_{ij} \leq t \\ 0 \text{ if } C_{ij} > t \end{cases} \qquad (2)$$

Where A_i is the accessibility at point i to all jobs at zone j, O_j the number of jobs in zone j and $f(C_{ij})$ the weighting function with C_{ij} being the time cost of travel from i to j and t, the travel time threshold. The weighting function used for cumulative-opportunity measure is a binary one, based on a travel time threshold. A 45-minute threshold is used in this study, as it showed a high correlation with the gravity-based measures. The estimation of the time cost of travel (travel times), C_{ij}, and the number of opportunities, O_j, depend on the method chosen (constant, static, dynamic) as indicated in Table 5.

Based on the cumulative opportunities, the relative accessibility is then calculated, since it allows for comparison and is easy to translate for policy-makers (Handy & Niemeier, 1997). Relative accessibility is used to compare accessibility across the region, and is defined as the level of accessibility of a CT compared to the level of accessibility of all other CTs. As done in previous research (Foth et al., 2013; Manaugh & El-Geneidy, 2012; Widener et al., 2015), standardized scores (z-scores) are used to express the relative accessibility.

4.5.3 Comparison of accessibility measures

Regression models predicting public transport mode share based on accessibility by public transport are developed in order to assess the accuracy of the three measures, as done in previous research (Owen & Levinson, 2015b). Since there is a well-established positive correlation between accessibility to jobs by public transport and public transport mode share (Dill et al., 2013; Legrain et al., 2015), the working assumption is that more accurate accessibility measures should result in better model fit to the data. Model fit is assessed based on adjusted R^2 value, where a higher value can be interpreted as a reduction in error (Menard, 2000). Note that the Aikaike information criterion is not adequate to compare the models in this case, since we have the same amount of independent variables in all regression models.

4.5.4 Description of the regression models

Regression models are generated using the same dependent and independent variables, except for the accessibility parameters. The dependent variable, public transport mode share for each time period, is calculated based on the NHS commuting trips data. Regarding the independent variables (other than accessibility), variables developed in previous studies (Foth et al., 2013; Legrain et al., 2015) are used. For example, we used a census demographic information variable, a composite indicator of social deprivation based on median income, unemployment rate, share of immigrant residents, and share of residents spending more than 30% of their income on housing was calculated for each CT. Then, CTs were placed into deciles from 1 to 10 (1 being the least socially deprived), and included in the models. Regarding the built environment and public transport proximity, dummy variables are provided for location (urban core, inner suburbs, and outer suburbs), public transport proximity (within 1 km of a subway and of a go station) and variables are calculated for the public transport frequency (trips per hour) and the distance to highway on-ramp (km). The mean distance (km) travelled by people leaving the CT is used to control for travel habits in the CT. Finally, the population density (persons/km^2) is added as an independent variable, since it showed high significance in our models and increased the model fitting. This is consistent with previous research (Cervero, 2006; Pucher, 1988; Taylor, Miller, Iseki, & Fink, 2009) suggesting that higher population density is related to higher public transport quality (Taylor et al., 2009) and lower car ownership (Messenger & Ewing, 1996) and thus results in higher public transport share. It is important to note that all these variables included are used as controls.

Three public transport share regression models are generated for each of the 5 time periods (6 am to 7 am, 7 am to 8 am, 8 am to 9 am, 9 am to noon, noon to 5 am), each one using a different type of accessibility measure (constant, static, dynamic), but keeping the other independent variables the same. Note that the 5 am to 6 am period is excluded from the analysis, given the high level of data suppression in the 2011 NHS and the low R^2 value of the regression models (lower than 0.3).

Since previous research showed different findings when measuring accessibility to low-wage jobs and accessibility to all jobs (El-Geneidy et al., 2015), this study also assessed the three accessibility measures (constant, static and dynamic) for accessibility to low-wage jobs, using the methodology described previously. Since the results between accessibility to all jobs and accessibility to low-wage jobs were consistent, only findings for accessibility to all jobs are presented in this paper.

4.6 RESULTS

Generally speaking, the model outputs are consistent with previous literature (Dill et al., 2013; Legrain et al., 2015; Owen & Levinson, 2015b). Table 6 provides examples of regression models which are representative of the other models developed in this study. All variables are positively related to public transport share, except for the distance to highway on-ramp, which is expected, and proximity to subway station for the 12 pm to 5 am time period. In this case, the relationship is not significant and the confidence intervals range from negative to positive values. The location (in urban core or in inner suburbs), the social indicator decile and the accessibility to jobs are all highly significant explanatory variables, similar to previous studies (Dill et al., 2013; Legrain et al., 2015). Proximity to a GO station as well as distance to highway on-ramp have the same sign as in literature (Foth, Manaugh, & El-Geneidy, 2014), but are not significant for all models (all time periods). Population density is significant for the 8 am to 9 am period, but not significant for the 12 pm to 5 am time period. The model fit (adjusted R^2) is lower for the 12 pm to 5 am period, which is likely due to the lower amount of data. Within each time period, the confidence intervals of each coefficient overlap with each other, suggesting that the models reflect the same measures.

Table 6: Regression result for public transport share at 8 and noon to 5 am am using constant, static and dynamic accessibility measures

Measure	Dynamic 8am	Static 8am (constant)	Dynamic 12 pm to 5 am	Static 12 pm to 5 am	Constant 12 pm to 5 am
Public transport frequency	0.000096	0.0000832	0.00026*	0.00026*	0.00027*
In urban core	0.16***	0.16***	0.18***	0.17***	0.17***
In inner suburbs	0.16***	0.16***	0.19***	0.19***	0.19***
1 km to subway station	0.028*	0.028*	-0.023	-0.028	-0.028
1 km to GO station	0.0058	0.0046	0.024	0.026	0.026
Distance to highway on-ramp	-0.00062	-0.0006032	-0.00025	-0.00026	-0.00016
Social indicator decile	0.011***	0.011***	0.015***	0.015***	0.014***
Mean distance travelled	0.0014*	0.0015*	0.00045	0.00036	0.00032
Population density	0.0018**	0.0019**	0.00039	0.00021	0.00010
Accessibility to jobs	[1]0.060***	[2]0.060***	[3]0.041***	[2]0.046***	[2]0.048***
Constant	0.030**	0.031**	0.061***	0.063***	0.066***
R^2 (adjusted)	0.7861	0.7854	0.6797	0.6821	0.6831

*p<0.05 **p<0.01 ***p<0.001
[1] Available jobs at 8am
[2] All jobs available during the day
[3] Available jobs between 12 pm and 5 am

4.6.1 Comparison of the models

Results of the regression models are presented in Table 7. First, all regression models that included an accessibility measure have more explanatory power (higher R^2) than models without the accessibility parameter (defined as *none* category in Table 7). Accessibility variables prove to be highly significant in all cases. No matter which accessibility measure is chosen, its effect on public transport share is observable.

Generally speaking, the sets of models using more detailed measures of accessibility (static and dynamic) do not provide better model fits than models using constant measures. Surprisingly, the values of the adjusted R^2 are similar, and different models score higher and lower depending on the time period (Table 7). This is contrary to our expectations, which predicted consistently higher R^2 for higher level of details in the measure. Different factors can explain these results. First, a smaller amount of data can lead to lower model fits. While the number of CTs is the same for all types of measures, the number of trips available for generating the measures is generally lower for the static measures, and even lower for the dynamic measures. The number of trips varies largely from one time period to another, with larger numbers found for the 7 to 8 am and 8 to 9 am periods. Regarding the dynamic measure, the number of jobs available is stratified by time periods, and thus necessarily lower than the number of jobs available throughout the day. This might explain the low fit of most of the dynamic measures.

Table 7: Performance of the models (R^2-adjusted reported)

Accessibility parameter	6am	7am	8am	9am to 12pm	12pm to 5am
None	0.5042	0.6817	0.7625	0.6338	0.6707
Constant	0.5259*	0.7070*	0.7854**	0.6432	0.6831*
Static	0.5258	0.7068	0.7854**	0.6441*	0.6821
Dynamic	0.5212**	0.7052**	0.7861*	0.6424**	0.6797**

*Highest R^2
**Lowest R^2 (excluding the models with no accessibility parameter)

4.6.2 Correlation between accessibility measures

Since no consistent difference is observed between the R^2 values of different models, and the interpretation might be misleading due to different amounts of data, additional tests are needed. In order to compare the accessibility measures relatively to one another, the correlation between the measures is tested in the following section.

First, accessibility at 8 am, which reflects the constant measure, is compared to accessibility at other time periods for static and dynamic measures (Table 8). All measures are highly correlated, with the lowest coefficient being 0.95. This shows that the relative accessibility of a CT at 8 am provides a valid approximation of its relative accessibility over the day both when using static and dynamic measures.

Table 8: Correlation coefficient between accessibility measured at each time period and accessibility at 8 am

Time period	Static	Dynamic
6 am	0.97	0.95
7 am	0.99	0.99
8 am	1	1
9 am to 12pm	0.98	0.98
12 pm to 5 am	0.98	0.95

*Note that all correlations are statistically significant ($p<0.05$)

A correlation matrix between all time periods was also generated and the coefficients are all higher than 0.95. These findings show that the relative accessibility of a CT is more or less constant over the day. Put simply, CTs enjoying a relatively high level of accessibility at a given time period also enjoy a relatively high level of accessibility during other time periods. Figure 16 illustrates the relative accessibility of CTs in the GTHA at four different periods. The patterns of the relative accessibility are very similar from one period to another.

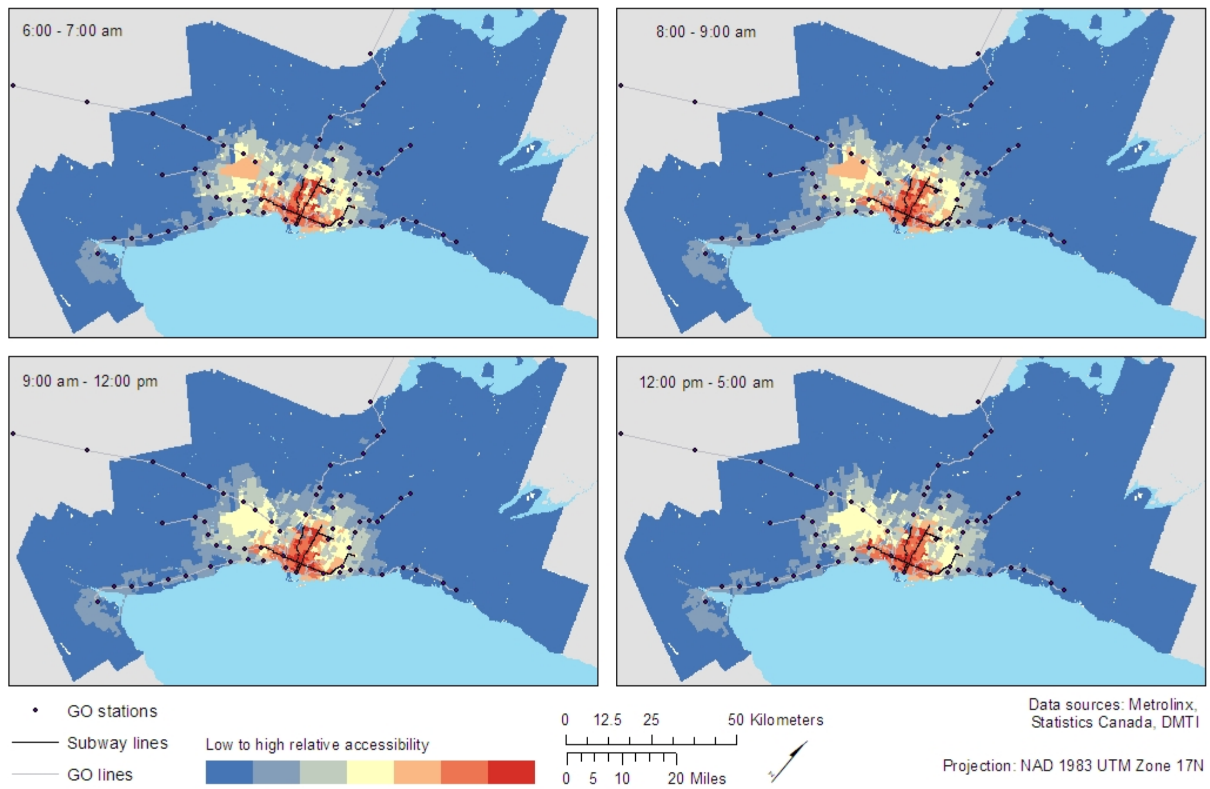

Figure 16: Relative accessibility to available jobs in the GTHA

Second, the dynamic and static measures are compared by generating correlation matrices between these measures for all time periods. The two measures are highly correlated (all above 0.985) (Table 9). The results show that, generally speaking, CTs with lower accessibility to jobs available at a specific time period also have a lower accessibility to all jobs available throughout the day. As shown in Figure 17, the relative accessibility patterns using static or dynamic measures are very similar.

Table 9: Correlation results between static and dynamic measures for all time periods

Time period	**Coefficient**
6 am	0.997
7 am	0.999
8 am	0.998
9 am to 12pm	0.995
12 pm to 5 am	0.986

*Note that all correlations are statistically significant ($p<0.05$)

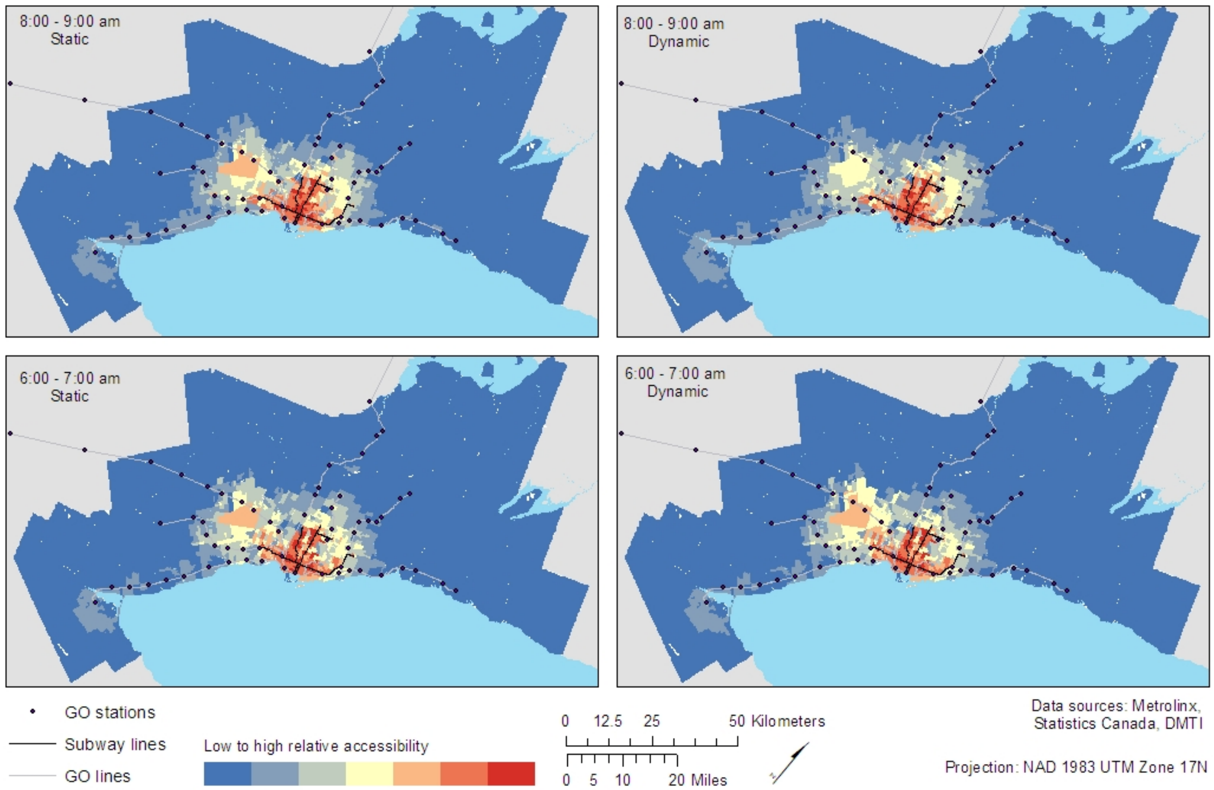

Figure 17: Relative accessibility to jobs in the GTHA

Based on the comparison between constant, static and dynamic measures, it is possible to conclude that the relative accessibility at 8 am to all jobs available is generally constant over the day. CTs enjoying a higher level of accessibility at 8 am to all jobs also enjoy higher levels of accessibility at other time periods to jobs available at that time period.

4.7 DISCUSSION AND CONCLUSION

From a general perspective, this research shows that the relative accessibility of a CT in the GTHA at 8 am to all jobs is representative of its relative accessibility throughout the day. No major or consistent differences are found in the quality of the regression models using constant, static or dynamic measures. Furthermore, constant, static and dynamic measures are highly correlated (above 0.95 in all cases). Relative accessibility is constant across time periods (using all-day jobs or only available jobs), showing that the CTs enjoying a higher level of public transport service at a certain time period also enjoy a higher level of service at other time periods. In the same way, CTs with access to a larger amount of jobs, all jobs taken into account, also have access to a larger amount of jobs when only available jobs are accounted for. This is in line with El-Geneidy et al. (2015) and Legrain et al. (2015), who find consistent travel times and accessibility results across all time periods.

From a planning and engineering perspective, several factors have to be taken into account when choosing an appropriate and meaningful accessibility measure. From a theoretical perspective, it should address transport and land-use systems, temporal fluctuations as well as individual needs (Dodson et al., 2007; Geurs & van Wee, 2004). All three methods address the transport and land-use components and can take into account individual needs by stratifying the data. The dynamic measure is the theoretically most sound, since it accounts for variations in public transport service and in opportunities. A second factor to be addressed is the data requirements (Geurs & van Wee, 2004; Handy & Niemeier, 1997). In this regard, the constant measure generally uses data that is widely available in most regions. The constant measure is based on travel time calculated at 8 am, which is generally the time period with the largest number of trips. Additionally, it does not require a stratification of data by time period, which otherwise reduces the amount of data available for calculating accessibility. Furthermore, an appropriate measure is one that is intuitive and easily interpretable and communicable (Geurs & van Wee, 2004; Paez et al., 2012). These criteria point towards simpler measures, which are easier to understand (Handy & Niemeier, 1997). The constant measure, simply understood as the number of jobs reachable in a region using public transport at 8 am, is the most easily communicable. In the same vein, the cumulative-opportunity measure directly represents the number of opportunities available within a certain travel time and might be more easily communicable. Also, the constant cumulative-opportunity measure is easier to generate and requires less time and data resources. Finally, measures have to be empirically sound to be meaningful to policy makers. As indicated in the results, all measures are highly correlated and thus provide a sound measure of the relative accessibility in the GTHA. Relative accessibility to all jobs at 8 am is representative of relative accessibility at other time periods. Although previous studies support time-sensitive accessibility metrics (El-Geneidy et al., 2015; Farber et al., 2014; Owen & Levinson, 2015b), the findings of this study suggest that a constant measure is appropriate for measuring the relative accessibility across CTs. In the same way, cumulative-opportunity accessibility, which is highly correlated to gravity-based accessibility, is representative of regional accessibility. This is in line with previous studies (El-Geneidy & Levinson, 2006).

All factors considered, the results suggest that the constant measure based on cumulative opportunities, most often used by planners and engineers, is appropriate and meaningful to assess relative accessibility to jobs in the GTHA, at the regional scale. While theoretically less sound, the constant measure is simpler and easily communicable. Although more detailed approaches are expected to provide more accurate measures, their accuracy is compromised by the reduction of usable data. These findings also support the use of aggregated data in extended time periods. As the amount of employees departing to work between noon and 5 am is very low (389,170 comparatively to 747,765 between 7 and 8 am), it is expected that using smaller time periods would result in very low amount of data and hence compromise improvements in measure accuracy. Coming back to our general findings, while other North American cities with similar characteristics are expected to yield the same results, further research is needed to test these results in different contexts.

The conclusion of this research might appear contradictory to Owen & Levinson's (2015b) study, which shows that using time-averaged accessibility and variation over the day increases the quality of mode share regression models in the Twin Cities metropolitan area. However, taking into account that planners want to balance between the accuracy and the simplicity of a measure (Geurs & van Wee, 2004), and given the very subtle increase in R^2 and the complexity of the measure developed by Owen & Levinson (2015b), our conclusion still holds; since the relative accessibility of a CT is constant over the day, the constant measure is appropriate for engineers and planners investigating geographic disparities in regional accessibility to jobs. It is however important to note that our measures, based on a hourly resolution, do not fully account for public transport frequency variations as they might be capturing repetitious cycles based on hourly departures (for example trains leaving at 7:05, 8:05, 8:35 and 9:05). Yet, as exemplified by Owen & Levinson's continuous approach (2015b), generating accessibility measures that fully account for public transport frequency requires substantial additional data and operationalisation resources that might not be easily available to planners. To overcome this limitation, simple public transport frequency indicators can be used together with accessibility measures, as done in previous research (Mavoa et al., 2012). To conclude, the constant approach provides an appropriate measure for policy-makers interested in relative accessibility, which can be used to better understand social equity or a public transport share in a region. However, it is not excluded that different goals might require more detailed temporal measurements. For example, public transport agencies specifically interested in public transport service fluctuation or in absolute levels of accessibility throughout that day (for example, setting minimal threshold for different time periods) might be interested in static and dynamic accessibility measures. Additionally, accessibility to other types of opportunities, such as health care services, leisure areas and retail stores might be more sensitive to temporal fluctuations. Further investigations are thus suggested regarding the utility of static and dynamic measures for other transport planning goals.

This work highlights the need to address the gap between accessibility research and its application in planning, by taking into account the usability of the measure. Theoretical developments of accessibility measures need to come with a reflection regarding their application in the field of planning.

CHAPTER FIVE: INEQUITY IN TRANSIT: EVALUATING PUBLIC TRANSPORT DISTRIBUTION THROUGH ACCESSIBILITY MEASUREMENTS IN SÃO PAULO, RIO DE JANEIRO, CURITIBA AND RECIFE, BRAZIL[5]

5.1 OVERVIEW OF CHAPTER

This last study was conducted in collaboration with local transport practitioners from the Institute for Transportation Development and Policy (ITDP) in Brazil in an effort to increase research applicability and knowledge transfer, thereby contributing to bridging the gap between research and practice. The specific research objective and the research design were developed together with the local transport practitioners from the ITDP, which works in the Global South with municipalities and non-governmental organizations to promote sustainable and equitable transport systems. As public transport services in cities of the Global South are increasingly seen as a tool to enhance social inclusion and support economic development, developing and evaluating indicators that quantify the distribution of public transport services from a social equity perspective is essential. The aim of the study is, therefore, to apply the measure of accessibility by public transport identified in the previous chapter to assess the equity of public transport services in four metropolitan regions in Brazil (São Paulo, Rio de Janeiro, Curitiba and Recife). A first indicator of proximity to rapid transit infrastructure (bus rapid transit, light rail and heavy rail stops with high frequency throughout the day) is considered, while the second indicator measures accessibility to jobs by public transport at peak hour based on cumulative opportunities. While simple indicators of proximity to public transport stops are most commonly used given their ease of operationalization and communication, accessibility to job indicators are more representative of the benefits provided to individuals by the public transport network. Combining these two

[5] Boisjoly, G., & El-Geneidy, A. (submitted). Inequity in transit: Evaluating public transport distribution through accessibility measurements in São Paulo, Rio de Janeiro, Curitiba and Recife, Brazil. *Journal of Transport Geography*.

indicators in one study provides a comprehensive view of the socio-spatial distribution of public transport services in four large metropolitan areas in Brazil and the results demonstrate that lower-income households are disadvantaged in terms of public transport services in all four metropolitan areas. Furthermore, the results highlight the importance of quantifying accessibility by public transport, in addition to proximity to rapid transit, and thereby sheds light on the importance of developing openly available public transport schedules and geographic data. This study is of relevance to planners and researchers wishing to measure and evaluate public transport equity in the Global South.

5.2 INTRODUCTION

Increasing attention is given to transport services and infrastructure in cities of the Global South as a tool to enhance social inclusion and support economic development and many international institutions are now stressing the importance of investing in transport. As such, the World Bank recently launched an initiative to increase accessibility to economic and social opportunities in an effort to reduce poverty (The World Bank, 2016). Public transport plays a key role to increase accessibility to opportunities, especially for low-income individuals (Hernandez, 2018). However, in rapidly urbanizing contexts, providing equitable public transport services that serve all population groups is a significant challenge. Furthermore, the lack of data in the Global South poses an additional barrier to evaluate the provision of service from a spatial and social perspective. While a few studies have been conducted in Latin America in relation to transport equity, no study has, to our knowledge, provided a comprehensive picture of the socio-spatial distribution of public transport services in metropolitan regions in Brazil.

The aim of the study is, therefore, to assess equity in the distribution of public transport services in four large metropolitan regions in Brazil (São Paulo, Rio de Janeiro, Curitiba and Recife), with two commonly used indicators of public transport provision. The first indicator measures proximity to rapid transit (bus rapid transit (BRT), light rail and heavy rail stops with high frequency throughout the day), while the second measures accessibility to jobs by public transport. The study is conducted at the metropolitan level to reflect the employment opportunities available in the whole region and census tracts are used as the unit of analysis to obtain a fine-grained resolution. The indicators are further combined with income data to assess how transport services are distributed across different income groups. This study is of relevance to planners and researchers wishing to measure, evaluate and understand the socio-spatial distribution of public transport in the Global South.

5.3 LITERATURE REVIEW

5.3.1 Public transport and (in)equity in Latin America

Large cities in Latin America have undergone rapid urbanization processes as well as sustained economic growth in the last two decades (Hidalgo & Huizenga, 2013). This rapid development has put significant pressures on urban transport infrastructure and land use, and most cities have not been able to respond to this rapidly growing demand in a coordinated manner. As a result, many Latin American metropolitan regions are now characterized by significant spatial and social segregation and an unequal distribution of infrastructure (Blanco, Lucas, Schafran, Verlinghieri, & Apaolaza, 2018; Keeling, 2008).

This poses significant challenges in terms of urban accessibility, especially for vulnerable populations. Several studies conducted in different metropolitan regions in Latin America found that low-income individuals typically experience lower accessibility to services and opportunities (Blanco & Apaolaza, 2018; Bocarejo & Oviedo, 2012; Delmelle & Casas, 2012; Hernandez, 2018; Hernandez & Rossel, 2015). For example, in a recent study conducted in Montevideo, Uruguay, Hernandez (2018) showed that individuals residing in low-income areas experience a significantly lower level of accessibility to jobs and education opportunities than other individuals. Furthermore, they found that low-income individuals often travel longer times for the same distance, as they depend on active and public transport modes, which are slower and often less direct than private car travel. Similarly, in Santiago de Chile, Martínez, Hodgson, Mullen, and Timms (2018) found that greater travel times are needed to access opportunities from peripheral areas, where most of the social housing clusters are concentrated. Along the same line, Vasconcellos (2018) demonstrated that low-income individuals residing in São Paulo and Rio de Janeiro, Brazil generally travel longer times for essential trips given their home location and their dependence on public transport. Also, in terms of public transport coverage, Jaramillo et al. (2012) found that, in Santiago de Cali, Columbia, areas in the lower socio-economic strata are typically underserved in terms of public transport relative to their needs.

The lack of adequate public transport services and accessibility has tangible consequences on low-income households. Such situation often results in suppressed trips and activities as found in previous studies in Uruguay, Argentina, Chile and Brazil (Falavigna & Hernandez, 2016; Ureta, 2008; Vasconcellos, 2018). Namely, in São Paulo and Rio, low-income households were found to have higher immobility rates given the lack of adequate mobility options (Vasconcellos, 2018). Furthermore, to cope with the lack of mobility options, many low-income households opt for proximity as a strategy, which limits the number of opportunities (jobs, health, education, etc.) they can reach and afford (Blanco & Apaolaza, 2018). The lack of access to opportunities has broad consequences as demonstrated by Boisjoly, Moreno-Monroy, and El-Geneidy (2017): they found that in the São Paulo Metropolitan Region, the lack of accessibility to jobs by public transport is associated with higher probabilities of being informally employed for low-income individuals. Along these lines, a recent study in Buenos Aires, Argentina demonstrated how spatial structure and differential mobility can exacerbate existing socio-economic inequalities (Blanco & Apaolaza, 2018).

5.3.2 Measurement of the distribution of public transport services

5.3.2.1 Proximity to rapid transit

The simplest geographic measure of public transport supply is a measure of proximity to public transport, which considers walking distance to public transport stops. Studies identify a walking distance buffer around public transport stops to identify areas that are served by public transport, considering a variety of thresholds typically ranging from 400 m to 1500 m (Blair, Hine, & Bukhari, 2013; Delmelle & Casas, 2012; Grengs, 2001). Using these buffers, researchers then calculate the proportion of the population or area that is covered by public transport. These measures directly represent service coverage, and are accordingly often used by researchers, public transport authorities and international institutions (Atlanta Regional Commission, 2016; Leadership Council of the Sustainable Development Solutions Network, 2015; Metrolinx, 2008; Singapore Land Transport Authority, 2013).

In the Latin American context, proximity to rapid transit (BRT, light rail and heavy rail stations) is generally measured to reflect access to an efficient, fast and reliable public transport service, given that regular bus service is often deficient in terms of travel speeds, reliability and frequency (Hidalgo & Carrigan, 2010; Vasconcellos, 2018). For example, Delmelle and Casas (2012) calculated the proportion of the population, grouped in six socio-economic strata, that is within walking distance (5, 10, 15, 20 minutes) of the new BRT network in Cali, Columbia. This allows assessing the coverage of the system in relation to the residential location of low-income individuals. Using a similar method, the Institute for Transport and Development Policy (ITDP) recently launched a large-scale analysis of the proportion of individuals near rapid transit for 25 urban areas around the globe to inform the debate on the quality and equity of public transport infrastructure in both OECD and non-OECD countries (Marks et al., 2016).

5.3.2.2 Accessibility by public transport

Another increasingly used indicator of public transport service measures accessibility to destinations by public transport. Accessibility captures "the potential of opportunities for interaction" (Hansen, 1959, p. 73) and can be understood as the "ease of reaching land use given the transport system" (Levinson & Krizek, 2007, p. 44). In line with this definition, accessibility is contingent on both the spatial distribution of activities and the characteristics of the transport network that determines the travel time, distance and cost needed to reach these activities.

To capture the ease of reaching destinations, many researchers use location-based accessibility metrics in public transport equity studies (Foth et al., 2013; Golub & Martens, 2014; Grengs, 2010). This measure counts the number of opportunities that can be reached from a specific location by public transport using a gravity-based or cumulative-opportunity cost function, generally based on travel time. The gravity-based approach discounts opportunities as a function of their travel cost, while the cumulative-opportunity approach equally values all opportunities located under a specific cost threshold, while all other opportunities are ignored. Most researchers focus on employment opportunities as a proxy for the density of activities, although broader concerns have recently been introduced in equity studies, namely accessibility to food supply (Ferguson, Duthie, Unnikrishnan, & Waller, 2012), recreation sites (Delmelle & Casas, 2012) and health care services (Delmelle & Casas, 2012; Paez et al., 2010a). Accessibility indicators are typically measured using travel times obtained from openly available Google Transit Feed Specification (GTFS) data. They are increasingly used in transport practice in the Global North, namely due to the availability of GTFS data and computing resources (Boisjoly & El-Geneidy, 2017a; Proffitt et al., 2017; Transport for London, 2006). Their use is although very limited in the Global South. One reason for this is likely the lack of available GTFS data, which has been found to be a significant barrier to the generation and implementation of accessibility measures (Boisjoly & El-Geneidy, 2017b; te Brömmellstroet et al., 2014).

Nonetheless, a few studies have considered accessibility to destinations by public transport in equity studies in Latin America. Delmelle and Casas (2012) measured accessibility to hospitals, recreation sites and libraries based on the formal public transport network. Travel times were generated through a multimodal network developed in a geographic information system, assigning specific speeds to the trunk, feed and express routes of the system. This method requires extensive data manipulation and speed assumptions, but allows for a detailed assessment of accessibility. Bocarejo and Oviedo (2012) measured accessibility to jobs by public transport in Bogota, Columbia using generalized costs (travel time and affordability), and where the costs were calculated based on travel behaviour. While this approach provides a measure that better reflects actual travel times, it is conducted for a few selected zones only, and accordingly does not measure accessibility across the whole city. Pereira, Banister, Schwanen, and Wessel (2018) measured changes in accessibility following the public transport developments spurred by mega-events such as the Football World Cup and the Olympic games. Travel times were measured using the GTFS data provided by the federation of transport companies of the municipality of Rio de Janeiro. Such data is, however, rarely available, and in this case, was limited to the municipality of Rio de Janeiro, thereby ignoring all jobs and individuals located outside the municipality boundaries. Overall, these studies contribute to a better understanding of how public transport allows individuals from different income groups to reach a variety of destinations. They also highlight the challenges associated with the development of comprehensive and detailed accessibility assessments in the Latin American context. The lack of widely available GTFS data in most metropolitan regions brings important limitations, either in terms of data generation and manipulation, or boundaries and scale.

As highlighted in previous work (Keeling, 2008; Oviedo & Titheridge, 2016), issues of transport, accessibility, poverty and social exclusion are still largely misunderstood in the Global South. This research complements the previous studies conducted in Latin America to address this gap by providing a quantitative assessment of public transport and equity in four large metropolitan regions. The approach provides an important contribution to the accessibility literature as it uses GTFS data covering the entire metropolitan regions, and thereby assesses accessibility at the metropolitan level.

5.4 AREA OF STUDY

Four metropolitan regions in Brazil are considered in this study: São Paulo, Rio de Janeiro, Curitiba and Recife. The characteristics of these regions are presented in Table 10. These cities were selected based on the availability of data and represent metropolitan regions of different scales in terms of population and rapid transit network. São Paulo and Rio de Janeiro are large metropolitan regions with more than 10 million inhabitants, and are characterized by extensive BRT and metro systems, with more than 300 kilometres and 260 stations. Conversely, Curitiba and Recife are smaller metropolitan regions (around 3 million inhabitants), with a rapid transit system composed mainly of a BRT network. In terms of spatial structure, Recife and Rio de Janeiro are coastal cities, with a large concentration of activities located by the seaside. In contrast, São Paulo and Curitiba are continental cities which follow a concentric distribution of activities. It is important to note that, while Curitiba has a large spatial extent (16,580 km^2), a large proportion of the metropolitan region is rural, with most urban areas concentrated in the centre of the region.

Table 10: Characteristics of the metropolitan regions included in the study

	São Paulo	Rio de Janeiro	Curitiba	Recife
Population (million inhab.)*	19,136,063	11,784,888	2,866,058	3,555,431
Number of jobs*†	5,221,492	2,287,911	730,077	620,922
Metropolitan region area (km^2)	7,946	6,738	16,580	2,772
Urban area (km^2)	2,844	2,869	1,033	723
Urban census tracts (#)	28,837	19,346	3,752	4,348
RT Modes	BRT, HR	BRT, HR	BRT	BRT, HR
RT network length (km)	333	334	75	70
RT network stations (#)	260	261	119	61

*number of jobs and population in urban areas only (which represents above 99% of the population)
†formal jobs in the private sector

5.5 DATA AND METHODS

5.5.1 Area and unit of analysis

The analysis encompasses all municipalities within the metropolitan regions, using census tracts as the unit of analysis. Since the study focuses on urban public transport, we only included census tracts characterized as urban, as defined by the *Institutio Brasileiro de Geografía e Estatistíca* based on municipal law and observation of land use. However, due to financial limitations, we had to limit the number of points for which we generated the measures of accessibility to jobs by public transport. To do so, the following approach was undertaken: for each metropolitan region, a 1.5 X 1.5 km^2 grid was laid over the metropolitan region and intersected with the urban census tracts. The resulting grid cells were then used as the unit of analysis for the measures of accessibility to jobs by public transport, calculating travel times between the centroids of the grid cells. The results were then interpolated using the four nearest neighbours approach to assign an accessibility value to each census tract based on their centroid.

5.5.2 Data

To generate the proximity to rapid transit indicators, three types of data were collected from various sources. The location of rapid transit stops was obtained from ITDP, that keeps an up-to-date map of Brazilian operational and under construction rapid transit corridors based on information from municipal, state and federal-level public institutions. All stations from rapid transit corridors that were operational at the time of the study (March 2018) were included in the dataset. Rapid transit corridors include BRT, LRT and heavy rail service that meet the ITDP criteria: for both BRT and LRT, only corridors that attain the BRT Basics as per ITDP's BRT Standard (*38*) are included, and with respect to heavy rail corridors, they must provide a high-frequency (20 minutes in both directions) throughout the day (6 am to 10pm) and operate entirely within a single built-up urban area[6].

With respect to the measures of accessibility to jobs by public transport, travel times were collected through the Google Maps Distance Matrix API (Google Maps, Accessed February, 2018), while the employment data was obtained from the *Relação Anual de Informações Sociais* from the *Ministério do Trabalho e Previdência Social (Ministério do Trabalho e Previdência Social, 2010).* The Google API returns the travel time by public transport, in minutes, of the fastest route requiring fewer transfers for each origin-destination pair. The travel time includes the access time, the in-vehicle time, the transfer time and the egress time. It is important to note, however, that the waiting time before departure is not counted in the Google API, which assumes that individuals are flexible with their departure time. Generating the travel times directly with the GTFS data would have allowed more customization of the travel time calculations, but such data was not available. To

[6] More details about the ITDP definition of rapid transit corridors and stations can be found in the following report: https://www.itdp.org/wp-content/uploads/2016/10/People-Near-Transit.pdf

our knowledge, only one study used detailed GTFS data in Latin America and such study was conducted at the municipal level (Pereira et al., 2018). For the purpose of this study, travel times were measured at peak hour (7 am departure time), as done in previous studies (Boisjoly et al., 2017; Pereira et al., 2018) . A 7 am departure time was set to reflect commuting behaviour in Brazil, based on the peak hour in the São Paulo Metropolitan Region (METRO-SP, 2008).

Data on population and household income, aggregated at the census tract level, was obtained from the 2010 census (Instituto Brasileiro de Geografia e Estatistica, 2010). The number of households within each income category is provided for each census tract. In this study, four household categories were used based on the minimum wage (MW) in Brazil:

- (i) income below half of the minimum wage (low-income households)
- (ii) income between half the minimum wage and minimum wage (low-income households)
- (iii) income between 1 and 3 times the minimum wage (medium-income households)
- (iv) income three times above the minimum wage (high-income households)

These income categories are used in Brazil in the implementation of social policies. Note that the first two groups are both referred to as low-income households in this study.

5.5.3 Methods

5.5.3.1 Proximity to rapid transit

Proximity to rapid transit was measured using a buffer approach. Two types of buffers were generated around the rapid transit stations. The first one is measured based on the airline distance (circular buffer). The second one uses the street network distance (street buffer) to reflect walking access to the rapid transit stations. The street networks were obtained from OpenStreetmap and connectivity was corrected for. While the airline buffer is more commonly used due to simplicity reasons and lack of data (Marks et al., 2016), especially in the Global South, the second one more realistically represents the access that individuals have to those stations by walking. In both cases, a 1 km buffer was used to reflect the distance individuals are willing to walk to access rapid stations, representing a 10-15 min walking distance. While shorter distances (400m) are typically used for regular transport stops (Blair et al., 2013; Grengs, 2001), research shows that individuals are willing to walk longer distances to access rapid transit service (El-Geneidy, Grimsrud, Wasfi, Tétreault, & Surprenant-Legault, 2014; Lachapelle & Noland, 2012). This is also consistent with Delmelle and Casas (2012) who considered a variety of thresholds ranging from 0.375 m (5 min) to 1.5 km (20 min) to assess proximity to BRT in Cali, Columbia.

To calculate the number of households living in proximity to transit, all households in a census tract for which the centroid falls in the buffer area are counted, as data on the exact location of households within the census tract was not available. In doing so, the number of households living in proximity to transit is likely overestimated. One measure is generated for the circular buffer and another one for the street buffer. The analysis is conducted across all four income groups.

5.5.3.2 Accessibility to jobs by public transport

A cumulative-opportunity measure was used to measure accessibility to jobs by public transport, considering all types of public transport services (all heavy rail, LRT, BRT services as well as conventional busses). This measure counts the number of jobs that can be reached from each census tract using public transport, under a specified travel time threshold. This measure, which is most commonly used in practice, has been found to accurately represent the relative accessibility experienced across a metropolitan region and to be more adequate for planning purposes (Boisjoly & El-Geneidy, 2016). It is calculated as follows:

$$A_i = \sum_{j=1}^{n} O_j f(C_{ij}) \qquad (1)$$

$$f(C_{ij}) = \begin{cases} 1 \text{ if } C_{ij} \leq t \\ 0 \text{ if } C_{ij} > t \end{cases} \quad (2)$$

where A_i is the accessibility at point i to all jobs in grid cell j, O_j the number of jobs in grid cell j and $f(C_{ij})$ the weighting function with C_{ij} being the time cost of travel from the centroid of i to centroid of j and t, the travel time threshold. As mentioned above accessibility to jobs was measured using a 1.5X1.5 km^2 gridcell unit[7]. The jobs are counted if they are located within the travel time threshold. In this study, a travel time threshold of 60 minutes is used as done by Pereira et al. (2018) in Rio de Janeiro, Brazil. While many studies in the Global North use 45 minute thresholds, large Brazilian metropolitan areas typically have longer commute times than other metropolitan areas (Pereira & Schwanen, 2013). As such, the average travel time by public transport in the São Paulo Metropolitan Region is 67 minutes (METRO-SP, 2008).

5.6 RESULTS

5.6.1 Households near rapid transit

The proportion of households, in each income category, that is near rapid transit is presented in Figure 18. The darker bars represent the proportion of households residing within 1 km of a rapid transit station using street distance, while the lighter bars represent the results for the 1 km circular buffer. Interestingly, we see that both buffers yield consistent trends in all four metropolitan areas, although the circular buffer tends to overestimate the proportion of households residing near rapid transit. It is accordingly important to consider this discrepancy when selecting an indicator.

Nonetheless, for both indicators, we observe a common trend in São Paulo, Rio de Janeiro and Curitiba: a lower proportion of low-income households (below ½ MW and between ½ MW and 1

[7] In the case of São Paulo, accessibility by public transport was measured using the Transport Analysis Zones (633 in the whole metropolitan region) as this data was available from a previous study.

MW) live within 1 km of a rapid transit station, while higher-income households (above 3 MW) are located in much greater proportion near rapid transit. This shows an inequitable distribution of rapid transit stations across income groups, especially since low-income populations are more likely to depend on public transport for long commute trips. With respect to Recife, we observe a lower variation between income groups. While low-income households exhibit similar proportions as in the other metropolitan regions, medium-income households (between 1 and 3 MW) and higher-income households (above 3 MW) yield much lower proportions. Interestingly, higher-income households (above 3 MW) have a lower proportion of households located close to rapid transit.

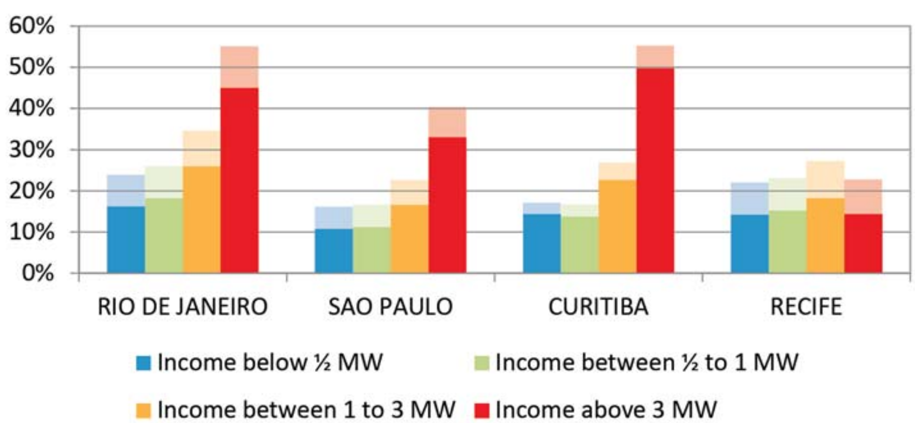

Figure 18: Proportion of households near transit by income category. Street buffers (dark). Circular buffers (light)

Figure 19 presents the buffer areas and predominant household income of each census tract to better understand the spatial patterns associated with these results. For each census tract, the predominant income corresponds to the income category with the greatest number of households. It is clear from Figure 19 that buffer areas are mainly comprised of higher-income census tracts in

São Paulo, Rio de Janeiro and Curitiba, while in Recife, a large proportion of high-income households live away from rapid transit, mainly by the sea. It is also interesting to note that Rio de Janeiro has an overall greater proportion of households near rapid transit across all income groups, likely due to the presence of rapid transit stations across most of the densely populated areas.

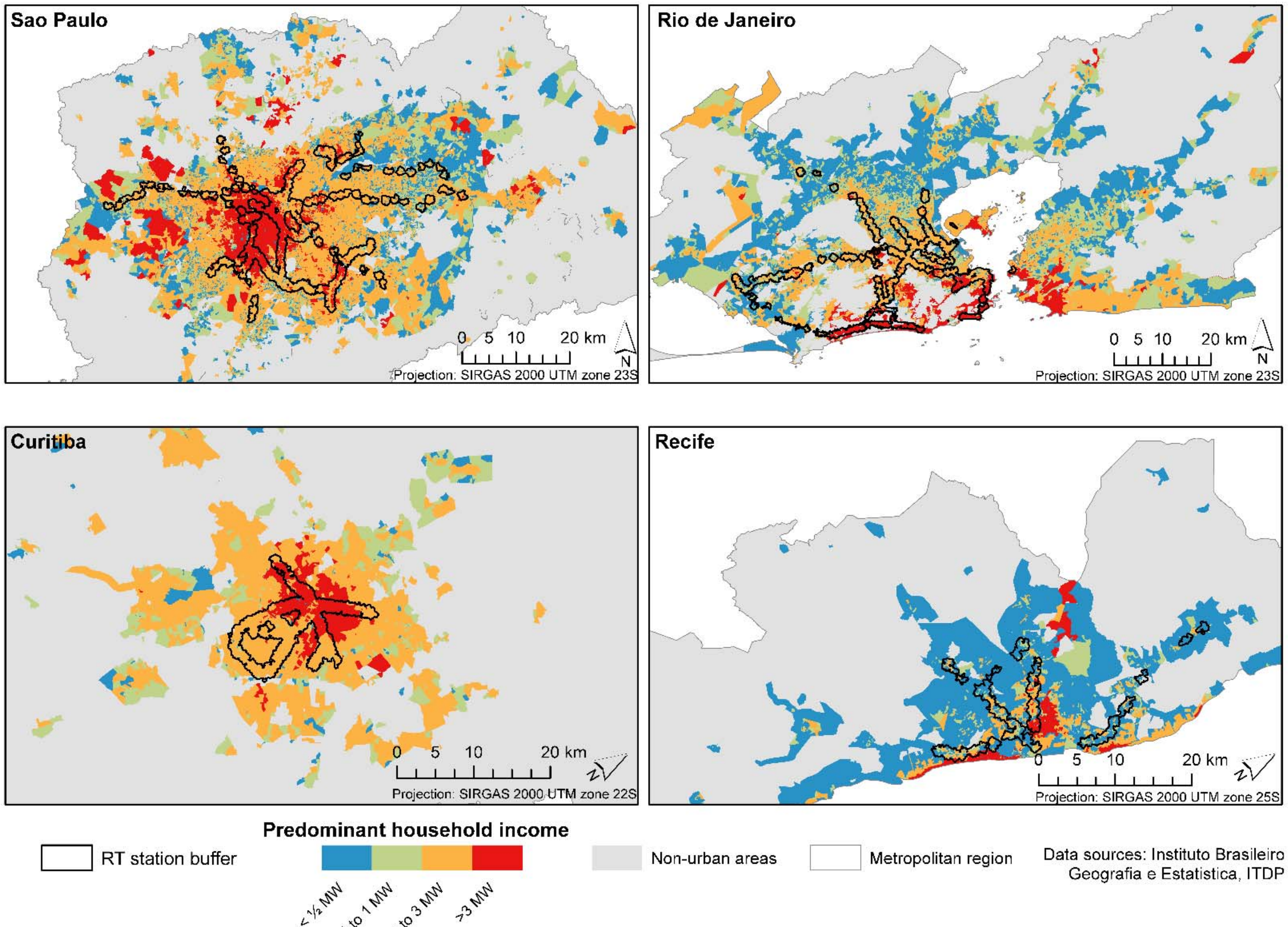

Figure 19: Predominant household income and rapid transit station street buffers

5.6.2 Accessibility to jobs by public transport

Figure 20 and Figure 21 present the accessibility to jobs and predominant household income in all four metropolitan regions. The accessibility is expressed as the proportion of all jobs located in the metropolitan region. For example, an individual that can reach 1,000,000 of the 5,221,492 jobs in São Paulo would have an accessibility of 19%. In all four metropolitan regions, census tracts located near the centre of the metropolitan region typically exhibit higher levels of accessibility. Similarly, many census tracts with predominantly high-income households are located in the centre. Conversely, lower-income households tend to be located away from the centre, where accessibility is lower. Furthermore, especially in São Paulo and Rio de Janeiro, for the same distance to the centre, higher accessibility is observed near the rapid transit lines. These areas are also characterized by a high density of predominantly high- and middle-income household census tracts. In Curitiba and Recife, the effect of rapid transit lines on accessibility patterns is less visible, likely due to the smaller size of the metropolitan region resulting in shorter commute times on average (Pereira & Schwanen, 2013). Regular busses are likely to yield similar travel times given the shorter commute and reduced congestion. Nonetheless, the results overall depict a clear trend in all four metropolitan regions: census tracts with predominantly low-income households typically exhibit lower levels of accessibility compared to other census tracts.

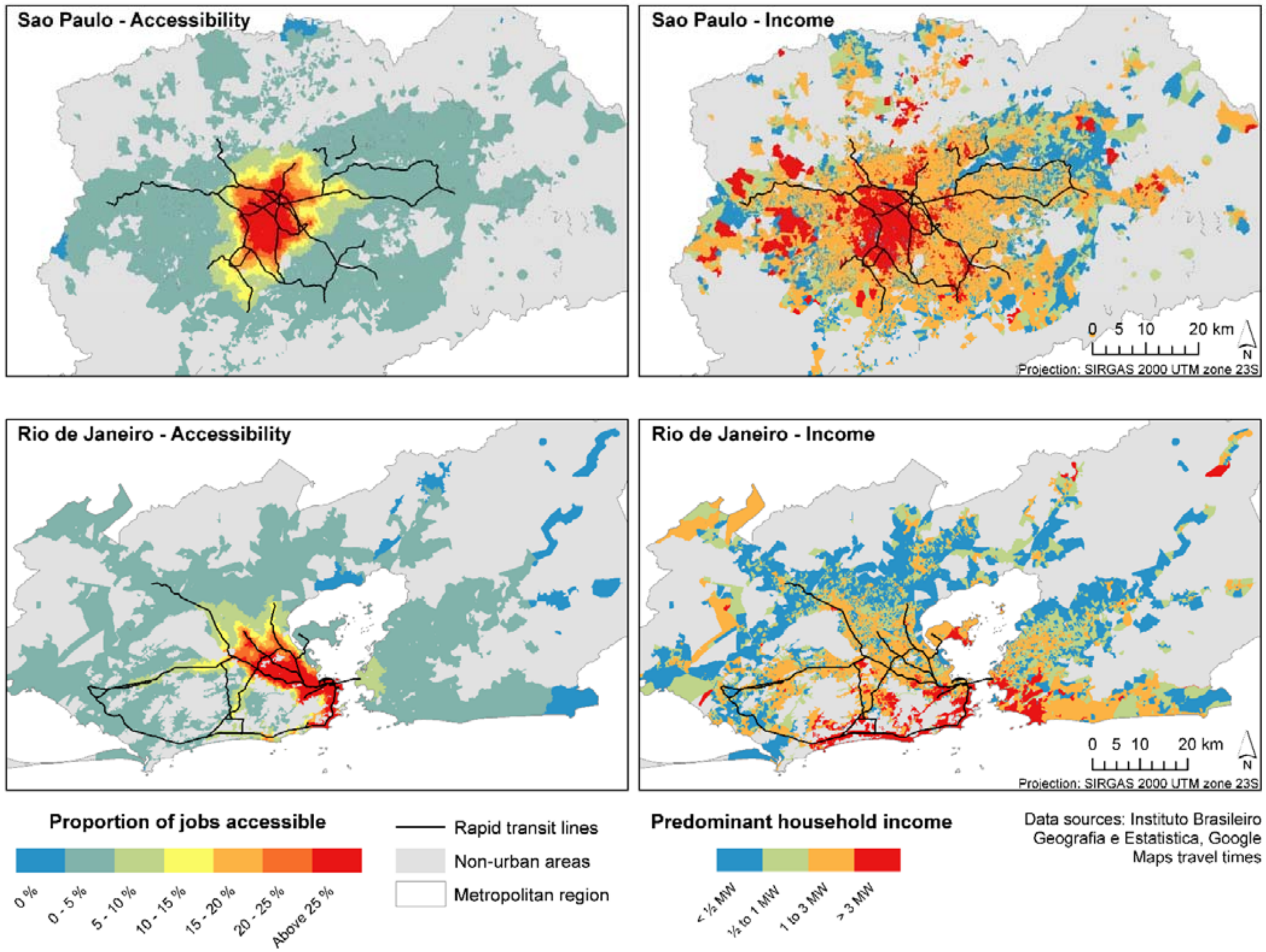

Figure 20: Accessibility to jobs by public transport and predominant household income in the São Paulo and Rio de Janeiro Metropolitan Regions

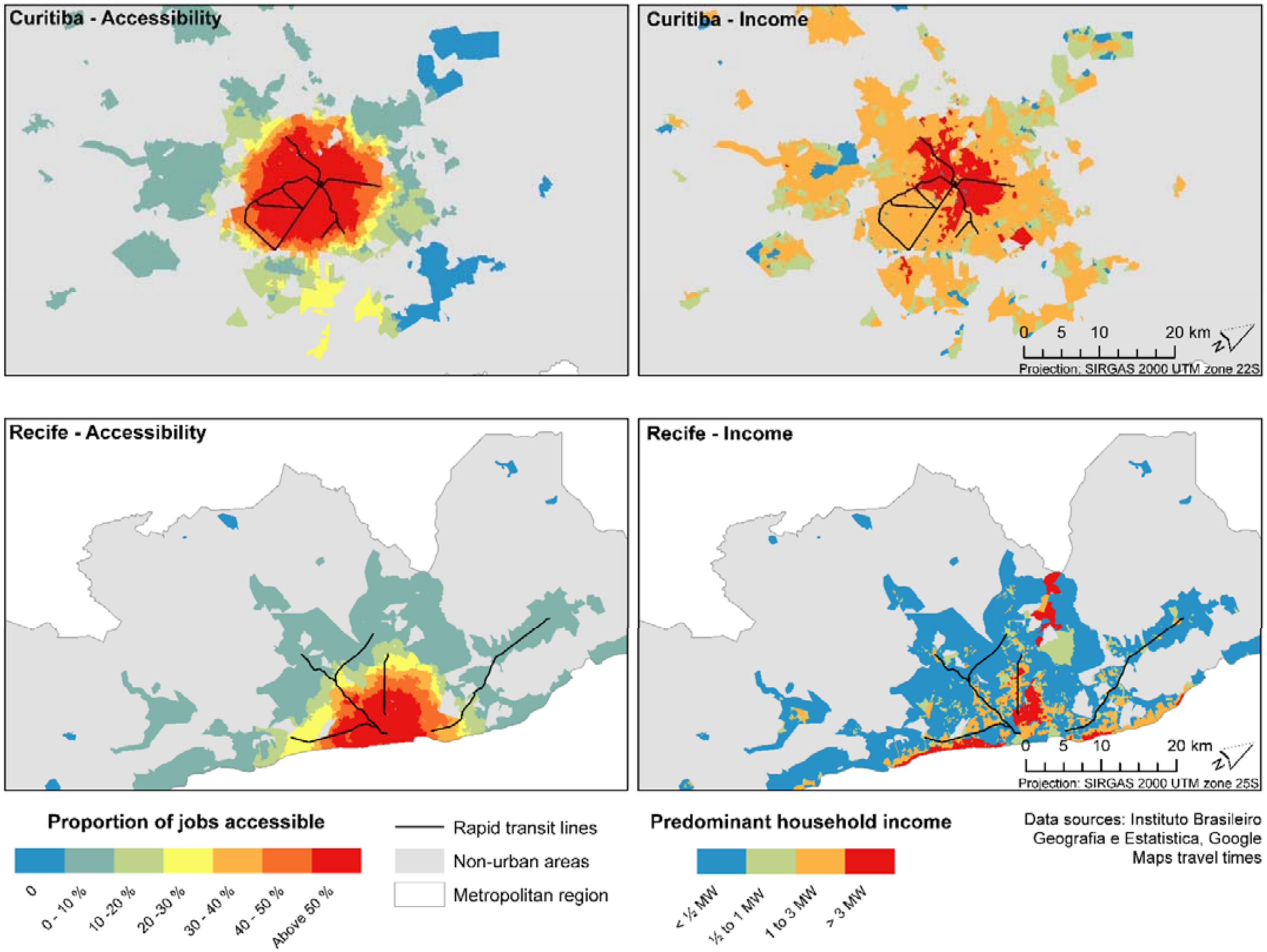

Figure 21: Accessibility to jobs by public transport and predominant household income in the Curitiba and Recife Metropolitan Regions

The distribution of accessibility across income groups is further explored by assessing the proportion of households that experience low and high accessibility for each income group. The level of accessibility is divided into four quartiles, to reflect the relative accessibility of each census tract relative to the metropolitan region. For each metropolitan region, the 25% census tracts with the lowest accessibility levels are grouped in the fourth quartile, while the 25% census tracts with the highest accessibility level are grouped in the first accessibility quartile. The proportion of households in each accessibility quartile is then calculated for each income group. The results are displayed in Figure 22. For example, in São Paulo, we observe that around 35% of the lowest-income households (<1/2 MW) experience the lowest level of accessibility (quartile 4), whereas only 11% of them experience the highest level of accessibility (quartile 1). Conversely, only 9 % of the high-income households (>3MW) experience low accessibility (quartile 4), whereas 56% of them are in the highest accessibility quartile (1). The results are consistent across all income categories: in a nutshell, in São Paulo, a lower household income is associated with a larger proportion of households in the lowest accessibility quartile and a lower proportion of households in the highest income category. Looking at the four metropolitan regions, the results are striking: the same trend is present across all four metropolitan regions, with a higher proportion of low-income households being in the lowest accessibility quartile and conversely for high-income households. These results suggest that all four metropolitan regions are characterized by an inequitable distribution of public transport services.

Another way to evaluate the equity in the distribution of accessibility is by looking at the household-weighted average accessibility, presented in red in Figure 22. The average accessibility of all households, of households near rapid transit stations and of households not near rapid transit are presented. For example, in São Paulo, the lowest-income households near rapid transit can access in average 10% of all jobs in the metropolitan region, while the lowest-income households not near rapid transit can only access 2% of the jobs in average. The results of the circular buffer are used here to reflect the most commonly used indicator of proximity to rapid transit in the Global South. Commencing with the average accessibility of all households, we observe that lower-income households experience, on average, lower accessibility to jobs by public transport in all four regions. The results thereby confirm that lower-income households are typically disadvantaged in terms of public transport services.

The results also hold when looking only at households near rapid transit (or only at households not near rapid transit). In other words, low-income households living near rapid transit nonetheless experience lower accessibility than high-income households living near rapid transit. Most notably, in the case of Recife, high-income households located away from rapid transit experience, on average, higher accessibility than low-income households near rapid transit. This highlights that not all rapid transit stations offer the same level of accessibility, and that the use of proximity to rapid transit indicators are limited in capturing the benefits provided by the public transport systems.

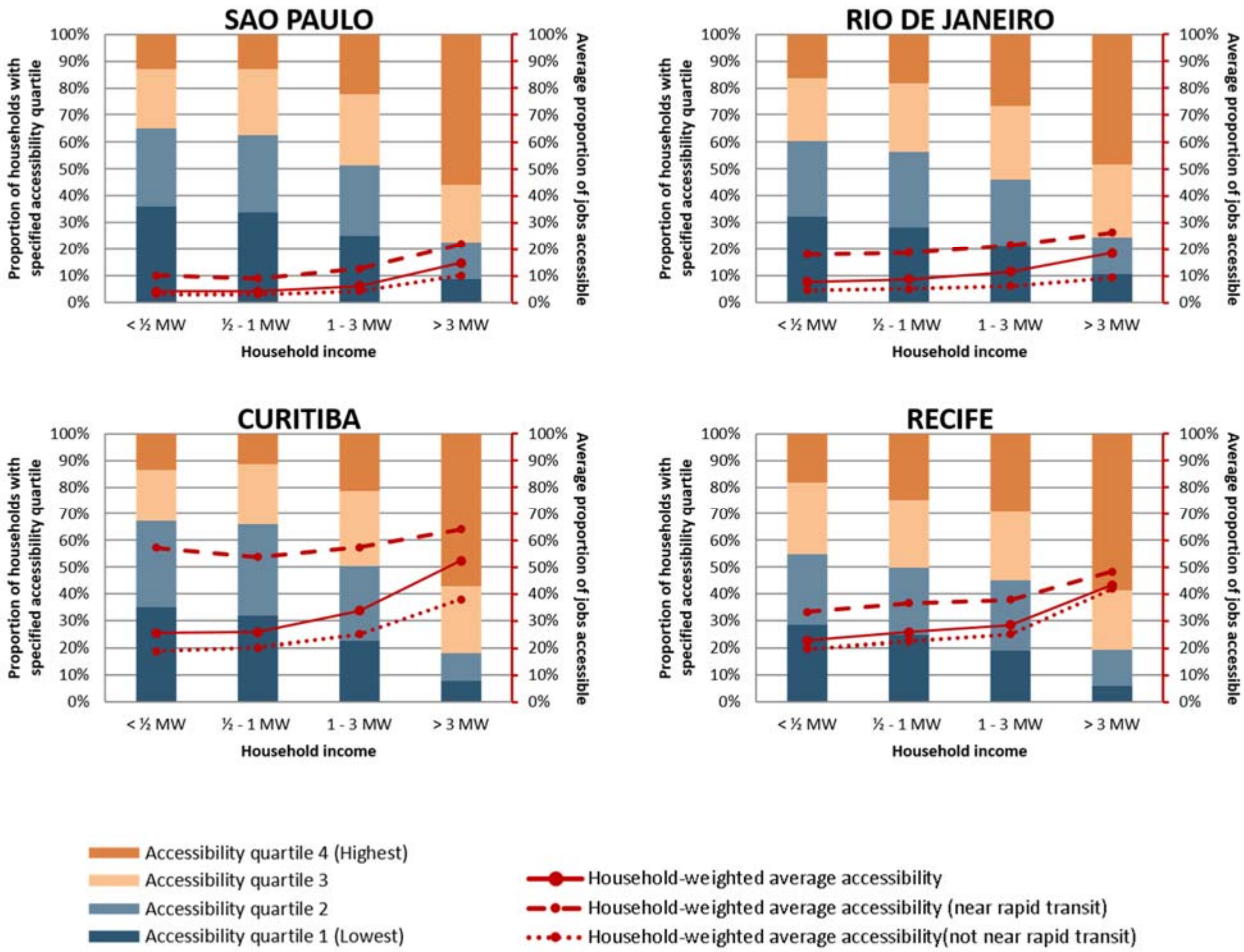

Figure 22: Proportion of households in specified accessibility quartile and household-weighted average accessibility, by income category

5.7 DISCUSSION AND CONCLUSION

This study examined the socio-spatial distribution of public transport services in São Paulo, Rio de Janeiro, Curitiba and Recife, Brazil. The results show a clear trend of inequitable public transport provision in all four metropolitan regions: (i) a lower proportion of low-income households (below ½ MW and between ½ and 1 MW) live near rapid transit compared to higher-income households and (ii) a greater proportion of low-income households experience lower accessibility to jobs by public transport. While the analysis only includes four metropolitan areas, it is likely that the results apply to other regions in Brazil, and more broadly in Latin America, as similar socio-spatial segregation and transport policies are present (Blanco et al., 2018). Also, by investigating four metropolitan regions of different scales, the study demonstrated that the results are not only limited to major metropolitan regions, but also to smaller regions. Finally, the results are consistent with previous research which found low-income households to be largely disadvantaged in terms of public transport service and accessibility in Latin American metropolitan regions (Blanco & Apaolaza, 2018; Martínez et al., 2018; Vasconcellos, 2018). Future research could build on this study to assess public transport equity in other regions of the Global South.

Accessibility to opportunities by public transport can be improved in two ways: (i) improving public transport services, and (ii) bringing origins and destinations closer. Regarding public transport services, the development of rapid transit that serve peripheral area is likely to have a significant impact on the accessibility of low-income populations, as highlighted in our study. However, as also shown in our study, proximity to rapid transit is not sufficient to ensure high levels of accessibility among low-income households given the significant spatial segregation. It is accordingly also essential to bring destinations closer to origins to support a more equitable distribution of accessibility. In this regard, Martínez et al. (2018) demonstrate how the social housing policies in Santiago de Chile, together with deficient transport investments, led to transport disadvantage among vulnerable individuals. In light of these findings, considering accessibility to jobs and services in social housing policies and transport investments would help bridge the gap in accessibility. Another key strategy is to support the decentralization of formal employment opportunities, given that formal job opportunities are mainly located in central areas in most large metropolitan regions in Latin America (Blanco et al., 2018; Boisjoly et al., 2017). A previous study found that the distribution of formal jobs is highly correlated with the distribution of informal jobs in Rio de Janeiro (Pereira et al., 2018). Accordingly, decentralization of formal jobs can also support the decentralization of jobs in the informal sector.

As there are multiple governance and political challenges in implementing such land use and transport changes (Vasconcellos, 2018), the development of indicators is an important tool to inform the debate. Indeed, previous research has demonstrated the importance of accessibility indicators to support decision-making and improve the quality of public transport systems in helping individuals to reach their destinations (Boisjoly & El-Geneidy, 2017a; Handy, 2008). In line with this, our study demonstrates the contribution of accessibility indicators in evaluating equity in public transport services and contributes to the literature on equity and accessibility in Latin America by providing some improvements to previous methodologies. Namely, a fine-grained analysis was conducted at the metropolitan level using tools and data that can be found in the Global South. The study also stresses the importance of developing GTFS data and making them fully accessible. While a Google API was used in this study, openly available GTFS data would allow a broader implementation of accessibility indicators (Boisjoly & El-Geneidy, 2017a; te Brömmellstroet et al., 2014).

There are some limitations to this study. The first one is that only jobs in the formal sector are included in the analysis, as informal jobs were not available for all four metropolitan regions. However, as highlighted by Pereira et al. (2018), the spatial distribution of formal and informal jobs is highly correlated at the traffic zone level in Rio de Janeiro. This is likely similar in other metropolitan regions in the country. Furthermore, formal jobs typically require a longer commute (Motte, Aguilera, Bonin, & Nassi, 2016), and are thus more likely to be accessed by public transport. Jobs in the public sector are also excluded from the analysis, as the location data was not reliable. This study therefore assumes that jobs in the public sector have a similar distribution to jobs in the private sectors. Further studies should be conducted to provide a better understanding of how jobs in the public sector are distributed across the region, and thereby identifying how it affects accessibility patterns. Furthermore, while this study aggregates all jobs in the private sector, segmented analyses could be conducted to account for the potential mismatch between job type and skills. A second limitation of this study is that accessibility is measured for 1.5X1.5 km^2 gridcell units. While smaller spatial units would yield more precise measurements of accessibility, the gridcell units used in this study allow obtaining a general pattern of accessibility at the metropolitan scale as can be observed in Figures 3 and 4. A third limitation is the reliance on Google Maps travel time. Since it is proprietary data, we do not know the exact algorithm behind the calculation of travel times. Nonetheless, the Google Maps Distance Matrix API was used in previous studies and shown to be consistent with mode choice data for example (Boisjoly & El-Geneidy, 2016). Another important limitation, as in most accessibility studies, is that the quality of service, including reliability and cleanliness of vehicle for example, is not accounted for in this research. Furthermore, affordability and walking access and egress conditions are not taken into account. Since lower-income areas are more likely to have a lower quality of service, higher budget constraints, and more difficult access conditions (safety issues, presence of important slopes, etc.) (Vasconcellos, 2018), our study likely underestimates their accessibility relative to the rest of the population, and thus underestimates the inequity of public transport provision. It is also important to note that this study did not investigate the causes of such inequities, nor the land use and transport planning processes. Nonetheless, the study provides a reliable comparative assessment of public transport provision based on travel time schedules across four metropolitan regions in Brazil. The study thereby presents a methodology to generate accessibility measures in a data-challenging environment and illustrates how such measures can be used to better understand the performance of land use and transport systems from an equity standpoint. In doing so, the study is of relevance to researchers and planners wishing to contribute to the development of more equitable public transport systems in Latin America and in the Global South more generally.

CHAPTER SIX: CONCLUSION

6.1 SUMMARY OF CHAPTERS

This dissertation explored how accessibility measures can be incorporated into current land use and transport planning practice to improve our understanding of the performance of land use and transport systems. Following the introductory chapter, the two first studies assess current planning practices, opportunities and barriers to implementing accessibility in practice. To address the main barriers identified in these studies, the third study compares the usability of different measures of accessibility, while the fourth study applies accessibility measures to an equity assessment in a data-challenging context, in collaboration with local practitioners. Altogether, these studies contribute to bridge the gap between accessibility research and transport planning practice.

The overarching finding of this research is that, while accessibility is increasingly considered in the realm of transport planning, further efforts are needed to support the implementation of accessibility metrics into practice. More specifically, Chapters 2 and 3 provide insight on how planners consider accessibility, and they identify the main challenges, opportunities and best practices for incorporating accessibility metrics in planning. Chapter 2 demonstrates that accessibility is not adequately considered in transport plans. The analysis of the plans reveals that although most plans include accessibility in their vision, goals or objectives, many of these plans are not specific in their use of the term. As a result, accessibility is often used as a buzzword and rarely translated into accessibility indicators. The study also identified several key elements that contribute to the integration of accessibility indicators in metropolitan transport plans, primarily the inclusion of distinct mobility and accessibility objectives and a clear definition of accessibility that reflects the ease of reaching destinations.

Chapter 3 complements the analysis of the metropolitan transport plans by directly surveying practitioners. It confirms, on one hand, the interest of practitioners for accessibility and, on the other hand, the confusion around accessibility indicators. Most practitioners agree that accessibility metrics can and should influence decision-making processes in their organizations or agencies. Yet, while nearly all practitioners surveyed for this study are familiar with the concept of accessibility, fewer than half (43%) consider the ease of reaching destinations in their work. The survey results led to the identification of key factors that contribute to, or limit, the use of accessibility metrics. The main contributors to their use are the presence of accessibility in planning documents and the practitioners' own initiatives, while the lack of knowledge and data represents the main barriers. Chapters 2 and 3 demonstrates that the concept of accessibility is of interest for many planners and planning agencies, and they identify key elements to foster accessibility-based planning approaches.

In response to the lack of consensus and guidance on how to measure accessibility and to the variety of approaches presented in the literature, Chapter 4 identifies an adequate measure of accessibility to assess land use and transport systems at the metropolitan level. The study demonstrates that the cumulative-opportunity measure of accessibility at morning peak hour, which is easier to generate and communicate, is closely associated with mode share. Accordingly, the study demonstrates that this simple measure is most appropriate for planning purposes and thereby fills a gap identified in Chapters 2 and 3.

Building on these results, Chapter 5 uses a measure of cumulative opportunities at peak hour to provide a clear example of how to use accessibility indicators to address equity planning objectives in a data-challenging environment. Accessibility to jobs, by public transport, is measured in four large metropolitan areas in Brazil, using data that is available to most planning and transport agencies and in collaboration with local planners. By doing so, the study addresses the knowledge and data barriers faced by many planners and contributes to an enhanced collaboration between researchers and planners. An equity analysis is also conducted, thereby illustrating how accessibility indicators can be used in practice to evaluate planning objectives. While the study is conducted in the context of the Global South, the data used and method proposed in the study can easily be applied in the Global North.

6.2 THEORETICAL AND METHODOLOGICAL CONTRIBUTIONS

A major contribution of this dissertation is to emphasize the discrepancy that exists between the willingness to adopt accessibility-based approaches, and their implementation in practice. As highlighted in Chapters 2 and 3, many practitioners are enthusiastic about accessibility and see the value of increasing the ease of reaching destinations; however, more attention to the concept and measures of accessibility is necessary to effectively plan for increased accessibility. This dissertation demonstrates the importance of carefully and critically thinking about how to include accessibility in planning practices, be it with respect to how it is defined or how it is measured.

Another important contribution of this thesis is to directly address the barriers to implementing accessibility indicators. By testing the usability of accessibility measures for planning purposes, Chapter 4 provides clear guidance on which criteria to consider and on which accessibility measures to use in metropolitan land use and transport assessments and plans. Chapter 5 then demonstrates the relevance of such measures in terms of equity planning by offering a methodology that can be replicated in most metropolitan contexts in the Global North, and increasingly, in the Global South.

Collectively, the four studies included in this dissertation demonstrate the importance of bringing research and practice closer together. The first two studies offer a critical assessment of planning practices identifying major barriers and challenges currently faced by planners and planning agencies, while the third and fourth studies directly respond to these challenges. This dissertation, thereby, argues for a greater consideration of the planning needs in accessibility research.

6.3 POLICY IMPLICATIONS

Of main concern in this dissertation is the gap that exists between accessibility research and the use of accessibility indicators in practice. This research has explored both the practice and research realms of transport to identify effective ways of moving forward to support the implementation of accessibility-based approaches. The studies included in this dissertation identified several aspects that require careful considerations as well as best practices that can guide planners in their use of accessibility indicators. These considerations and best practices are summarized below:

1. The inclusion of **clearly defined and distinct accessibility and mobility** goals and objectives in metropolitan transport plans is key for a wide implementation of accessibility indicators in practice;
2. While indicators of access to transport amenities are generally considered in metropolitan transport planning, **access-to-destinations** indicators are essential to capture the ease of reaching destinations, which better reflect the benefits provided by land use and transport systems;
3. Measures of **accessibility to jobs** adequately represent the overall land use and transport systems' performance in a region, as they act as a proxy for the presence of activities and opportunities, and should therefore be considered in metropolitan transport planning. Measures of accessibility to specific destinations such as healthcare

services or leisure centers are useful to inform specific policies and can be included in addition to the measures of accessibility to jobs;

4. The generation of constant measures of accessibility to jobs by public transport, based on **cumulative opportunities at morning peak hour**, are the most appropriate to assess accessibility patterns at the metropolitan level. These measures are empirically sound, easy to communicate and can be generated using **openly available GTFS data and job location data** accessible to most transport and/or land use planning authority.

These recommendations attempt to provide clear guidance to planners wishing to include accessibility in their work. While further, more detailed assessments are of value, these recommendations focus on the first steps to be taken to incorporate accessibility in practice.

Another important finding from this dissertation is the lack of GTFS data in the Global South. While most large transport agencies in the Global North make their GTFS data openly available, it is not a common practice in the Global South. This reality limits planners and researchers in their ability to generate accessibility measures. Knowing that transport plays a key role to support the socio-economic development of metropolitan regions and that accessibility indicators allow planning for more effective land use and transport systems, the availability of GTFS data is a crucial element to improve land use and transport planning. Accordingly, public transport authorities are strongly encouraged to generate and share GTFS data (public transport schedule and geographic information) in order to support accessibility analyses.

6.4 FUTURE RESEARCH

While this dissertation has filled some important gaps, several challenges still remain to further support the implementation of accessibility-based approaches in practice. First, while this research focused specifically on accessibility-based measures, a similar approach could be adopted in the future to investigate the trade-offs between accessibility and mobility measures from a planning perspective. For example, Chapter 5 could be expanded upon to assess the extent to which the use of mobility indicators would yield different results. This would further contribute to shed light on the potential contribution of accessibility indicators in improving our understanding of the performance of land use and transport systems.

Second, as the ultimate purpose of this research is to contribute to the implementation of accessibility-based indicators in land use and transport planning, the studies included in this dissertation focus on the different metrics and their use and usability in planning. The usability of metrics is a key component of accessibility-based approaches, and providing a deeper understanding of how metrics are and can be used in practice certainly contributes to the implementation of such approaches. Yet, other factors play an important role in whether accessibility-based approaches are adopted in planning practices. Namely, planning and political processes can impact the evolution of planning practices. It is, therefore, important to acknowledge that such issues should be addressed in further research. In this regard, Chapters 2 and 3 could be complemented by in-depth case studies and interviews to identify further barriers that limit the implementation of accessibility-based approaches in different contexts. Furthermore, given that the integration of land use and transport planning is a major challenge in most metropolitan regions, further studies could explore how accessibility metrics can contribute to a greater collaboration between urban planners and transport planners. Similarly, in-depth case studies could shed light on whether and how the use of accessibility indicators influences decision-making processes. Namely, it would be relevant to assess the impact of the emergence of accessibility research in Brazil on the planning approaches and decision-making processes.

Another important avenue identified in this dissertation is the need for a greater collaboration between researchers and planners. In line with this, future research should be conducted on the usability of various accessibility metrics for different planning purposes. While this research focused on metropolitan region and equity assessments, accessibility metrics are also of use to better understand travel behavior and socio-economic outcomes. Therefore, further studies could build on Chapters 4 and 5 to assess the relevance of various accessibility metrics for different planning purposes such as economic development, reduction in greenhouse gas emissions or population health, and in different contexts. Furthermore, while Chapter 4 assumed that the accessibility coefficients were constant across the region (in order to compare the measures at the metropolitan level), future research on travel behavior and accessibility could assess the spatial variation of the accessibility coefficients with the use of geographically weighted regressions. This would contribute to informing the development of context-specific land use and transport policies. Similarly, the assessment of various accessibility measures could be conducted in different metropolitan regions with distinct land use and transport characteristics. While the Greater Toronto and Hamilton region is characterized by a strong all-day transit service, smaller cities with limited transit services might yield different results. Lastly, to further contribute to the literature on accessibility and travel behavior, more efforts are needed to investigate the biases associated with spatial autocorrelation. With respect to the evaluation of public transport equity, the methodology presented in Chapter 5 could be replicated in other cities of the Global South, to expand our understanding of land use and transport systems in different contexts.

Finally, while this thesis primarily considers mode-specific accessibility measures, further research could build on this dissertation to evaluate how general accessibility indicators (accounting for all modes) could be incorporated in land use and transport planning. Similarly, this dissertation focuses on location-based accessibility, more efforts are required to generate and incorporate person-based accessibility indicators. Whereas location-based indicators are of relevance to assess metropolitan land use and transport patterns, person-based indicators can provide more guidance to target specific social issues (e.g.: vulnerable individuals' lack of access to food amenities) and allow addressing the relationship between provided accessibility and personal needs.

6.5 CONCLUDING REMARKS

With increasing concerns about population health, greenhouse gas emissions, land conservation and socio-economic exclusion, the idea of a paradigm shift in transport planning, from mobility to accessibility, is gaining traction among policy-makers, planners and engineers. This paradigm implies that transport planning is considered together with land use planning, as improving the ease of reaching destinations for the population as a whole cannot be accomplished solely by expanding and improving transport infrastructures. Conceptualizing and measuring land use and transport systems through the lens of accessibility is certainly a central tool for this shift to happen, as it allows measuring what matters for people. Indeed, most of the time individuals travel to reach a destination rather than for the sake of travelling. The use of accessibility indicators thereby contributes to developing strategic plans that directly address the needs of people. It also allows communicating to elected officials, professionals and the general population how transport planning can play a key role in improving individuals' quality of life and achieving a variety of societal objectives.

As is true of most paradigm shifts, changing mentalities is difficult. Changing the way people think about transport requires time and effort. This dissertation argues that accessibility is instrumental in changing how people perceive transport planning, but that the consideration of accessibility in practice – as well as in research and teaching – needs to be accompanied by a fundamental questioning of the approaches and goals to be achieved. By critically analyzing the use of accessibility indicators in planning practice, this dissertation generates a deeper reflection on accessibility in an effort to support and accelerate the paradigm shift towards accessibility planning.

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APPENDIX I: ACCESSIBILITY SURVEY QUESTIONS

Personal information

1. In which sector do you work?
   Please choose only one of the following:
   - Public
   - Private
   - Non-governmental/non-profit organization
   - Academia
   - Other:
2. What best describes your organization/company?
   Please choose only one of the following:
   - Government
   - Planning
   - Consulting
   - Public transport provider
   - Advocacy
   - Engineering
   - Other:
3. Which best describes your job title?
   Please choose only one of the following:
   - Analyst
   - Engineer
   - Manager (organization)
   - Manager (project)
   - Planner
   - Outreach worker
   - Elected official
   - Political staff
   - Technician
   - Other:
4. Which of the following project categories do you address in your job?
   Please choose all that apply:
   - Public transport
   - Cycling
   - Walking
   - Parking
   - Universal accessibility
   - Automobile / Traffic
   - Land use planning
   - Other:
5. What is the geographic scale that your employer serves?
   Please choose all that apply:
   - International
   - National
   - State / Provincial
   - Regional
   - County
   - Municipal
   - Sub-municipal
   - Other:
6. In which region(s) are most of your projects located?
   Please choose all that apply:
   - North America
   - Central and South America

- The Caribbean
- European Union
- Europe (non-EU)
- North Africa
- Sub-Saharan Africa
- Middle-East
- Central Asia
- South-East Asia
- East Asia
- Australia and New Zealand
- Pacific Islands
- Other:

7. In which specific country are most of your projects located?
   Please choose all that apply:
   - Does not apply
   - List of countries
8. What is the name of the specific municipality or local region (e.g.: County, State, Province) in which most of your projects are located?
   Please write your answer here:

Accessibility concept

9. In this survey, the concept of accessibility refers to the geographic access to opportunities by walking, cycling, public transit or car. In other words, accessibility is the ease of reaching desired destinations in a region. Please note that we do not refer to the principle of universal accessibility for people with a disability in this survey.
   To what extent do you agree with the following statement? I am familiar with the concept of accessibility defined above.

Accessibility metrics

10. Accessibility metrics quantify the ease of reaching various destinations using a specific mode, based on travel costs, distance and/or time. There are many ways to measure accessibility. For example, an accessibility metrics is the number of jobs that can be reached from a specific location within 45 minutes using public transport. Other locations commonly used in accessibility metrics include retail stores, hospitals, parks and transportation amenities (highways, public transit bus stop, etc.).
    To what extent do you agree with the following statement? I am familiar with accessibility metrics.
    Please choose only one of the following:
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree

Use of concepts and metrics

11. To what extent do you agree with the following statements?
    I use the CONCEPT of accessibility in my work.
    Please choose only one of the following:
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree

    I use accessibility METRICS in my work.
    Please choose only one of the following:
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree

Use of accessibility metrics

12. What types of accessibility metrics have you used?
    Please choose all that apply:
    - Access to public transportation
    - Access to jobs
    - Access to employment centers
    - Access to urban areas
    - Access to green amenities (parks, water, etc.)
    - Access to retail stores
    - Access to healthcare services
    - Access to leisure and cultural activities
    - Other:
13. Which of the following metrics have you used?
    Please choose all that apply:
    - Cumulative-opportunities measures based on travel time
    - Cumulative-opportunities measures based on travel costs
    - Cumulative-opportunities measures based on travel distance
    - Gravity-based measures based on travel time
    - Gravity-based measures based on travel costs
    - Gravity-based measures based on travel distance
    - Measures of average or median travel time as a proxy for accessibility
    - Measures of density as a proxy for accessibility
    - Measures of land-use mix as a proxy for accessibility
    - Other:
14. For which modes have you used accessibility metrics?
    Please choose all that apply:
    - Walking accessibility
    - Cycling accessibility
    - Accessibility by public transport
    - Accessibility by car
    - Other:
15. What do you use accessibility metrics for?
    Please choose all that apply:
    - Performance indicators
    - Equity analyses
    - Cost-benefit analyses
    - Environmental assessments
    - Decision-making processes
    - Communication purposes
    - Scenario assessments
    - Project selection criteria
    - Regional evaluation
    - Other:
16. The generation of accessibility metrics was:
    Please choose all that apply:
    - My own initiative
    - A request from a superior
    - A requirement from a planning document
    - Was present as a tool prior to my arrival in my current job
    - A request from a client
    - Other:
17. To what extent do you agree with the following statement: Some decisions in my organisation are made based on accessibility.
    Please choose only one of the following:

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

18. Which factors prevent decisions to be made based on accessibility metrics?
    Please choose all that apply:
    - Lack of communication
    - Lack of interest from decision-makers
    - Decisions are made based on political choices
    - Other:
19. How frequently does the organization you work for generate accessibility metrics in house?
    Please choose only one of the following:
    - Always
    - Often
    - Sometimes
    - Rarely
    - Never
    - I do not know
20. Which type of software do you use for generating accessibility metrics?
    Please choose all that apply:
    - Land Use Transportation Model (LUTM)
    - Transportation model
    - Desktop GIS
    - Web-based GIS (i.e. All Transit)
    - I do not know
    - Other:
21. Please rate the following aspects of a software for generating accessibility metrics.
    Please choose the appropriate response for each item:
    (Very unimportant Somewhat unimportant Neutral Somewhat important Very important)
    - Open-source
    - Quality of input dataset
    - Affordability
    - Fast calculation
    - Usability for economic evaluation
    - Real time interaction
    - Transparency of main assumptions
    - Ease of interpretation and communication
    - Flexibility
    - Ease of operationalization
    - Ease of collecting data
    - Accuracy of calculation
22. Which type of datasets do you use in your accessibility analysis?
    Please choose all that apply:
    - Financial data (i.e costs of household)
    - Socioeconomic data (i.e. number of jobs)
    - Travel times or distances
    - Trip purposes
    - I do not know
    - Other:
23. Since you previously answered that you never or rarely generated accessibility metrics in house, what kind of organization generates your accessibility metrics?
    Please choose only one of the following:
    - University
    - Private consultant
    - Other public department

- Non-governmental organization
- Other

Use of the concept of accessibility

24. Which concepts of accessibility do you or have you used?
    Please choose all that apply:
    - Access to jobs
    - Access to urban areas
    - Access to employment poles
    - Access to green amenities (parks, water, etc.)
    - Access to public transport
    - Access to retail stores
    - Access to healthcare services
    - Access to leisure and cultural activities
    - Other:
25. What do you use the concept of accessibility for?
    Please choose all that apply:
    - To set a vision
    - To set goal or objectives
    - Equity analyses
    - Scenario assessments
    - Cost-benefit analyses
    - Environmental assessments
    - Decision-making processes
    - Communication purposes
    - Other:
26. For which reasons do you not use accessibility metrics?
    Please choose all that apply:
    - Lack of financial resources
    - Lack of time
    - Lack of knowledge
    - Lack of skills
    - Lack of software
    - Lack of data
    - Lack of formal regulatory framework
    - Lack of interest
    - Lack of support from colleagues or management
    - It is the responsibility of others working in my organization.
    - Other:

Accessibility in plans

27. To what extent do you agree with the following statements:
    Please choose the appropriate response for each item:
    (Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree)
    - The concept of accessibility is included in the planning documents of the region I work in.
    - Accessibility is stated as a main goal in the planning documents of the region I work in.
    - Clearly defined accessibility indicators are included in the planning documents of the region I work in.

Relevance of accessibility metrics

28. To what extent do you agree with the following statements:
    Please choose the appropriate response for each item:
    (Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree)
    - Accessibility metrics are useful tools for land-use and transportation planners.
    - Accessibility metrics have the potential to influence decision-making processes.
    - Accessibility metrics should be used to inform decision-making processes.

Skills for graduate students

29. In order to help in educating future planners, we would like to know which skills recent graduates should have to be successful planners in the field of land-use and transportation

Using a scale of 1=not at all important to 7=very important, please rate the importance of the following skills:

- Project management skills
- Written skills
- Communication skills
- Knowledge of legal processes
- Knowledge of planning history
- Knowledge of planning theory
- Understanding of micro-economic theory and its application
- Graphic skills
- Geographic information systems skills
- Basic quantitative analysis skills (t-test, summary statistics)
- Advanced quantitative skills (regression analysis, factor analysis)
- Programming Survey design skills
- Focus groups facilitation
- Public consultation methods