Data Sources and Needs for Active Travel-Based Accessibility Analysis: A Canadian Perspective

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## Abstract

Active travel is a key element to achieve robust and healthy urban transportation policies. As the analysis of transportation needs in cities shifts from a focus on mobility to accessibility, the need to assess accessibility by cycling and walking has become increasingly pressing. The distinguishing features of these modes—lower speeds, shorter trips, and potentially different purposes compared to motorized trips—mean that the data inputs required for accessibility analysis are not necessarily the same as those used for the study of accessibility for motorized travel. The objective of this review is to assess the sources of data and data needs to implement active accessibility analysis. Walking-specific and cycling-specific geographic accessibility measures and data applied within recently published literature are reviewed. Walking and cycling accessibility measures are compared in terms of the types of metrics, the origins and destinations considered, geographic scales, and travel time or distance calculations. In comparing approaches for walking versus cycling, this report also highlights possible considerations, challenges, and questions that emerge when considering the future of active travel accessibility-based analysis. The discussion in this review is centered on the Canadian context, but the lessons may be more broadly applicable to other national contexts.

## Introduction

For decades, transportation planning has been focused on providing mobility for the private car, which was first introduced in North America as a solution to problems caused by rapid urbanization and later copied elsewhere (Angotti 1996; Brown, Morris, and Taylor 2009a). However, it is now clear that mobility centered on the private car is inefficient, inequitable, and unsustainable, requiring immediate attention. This includes environmental issues such as climate change (Chapman 2007), as well as numerous other social (Boschmann and Kwan 2008; Lucas 2012, 2019), health (Khreis et al. 2016; Milne 2012), and equity concerns (Bocarejo S and Oviedo H 2012; Martens, Golub, and Robinson 2012; Pereira, Schwanen, and Banister 2017).To reduce car use, the transportation agenda has aimed to focus on the creation of mobility polycultures that offer a broader menu of transportation alternatives (Lavery, Páez, and Kanaroglou 2013; Millera 2011). Polycultures are resilient and adaptable systems with numerous mobility options, including mobility substitutes such as information technologies. This is more complex than a monoculture, as it requires not only a broader range of mobility technologies but also a much higher level of coordination among modes and travelers. Therefore, active travel, such as walking and cycling, is a key component of efforts in urban areas as they try to achieve more robust and healthy urban transportation polycultures (Millera 2011; Lavery, Páez, and Kanaroglou 2013; Lira and Paez 2021).

Cycling and walking are effective modes for short- and mid-range travel in urban areas that have, over a period of decades, grown to accommodate travel by automobile (Brown, Morris, and Taylor 2009b; Wiersma et al. 2020) while treating other modes almost as afterthoughts (Brezina, Leth, and Lemmerer 2020; Koglin 2020; Ruffino and Jarre 2021).On the one hand, there are concerns about the externalities of the current (car-centeric) transportation system; on the other hand, there is a growing understanding and awareness of the numerous co-benefits of active mobility in terms of health, efficiency, and social inclusion (Banister 2005; Gärling, Ettema, and Friman 2014; Gössling et al. 2019; Mueller et al. 2015). Along with a focus on motorized travel, the focus of transportation planning has been to plan for mobility mainly by car. Transportation and land use systems have been designed to produce mobility, and this is reflected in the use of measures of efficiency that ignore the reason for most travel, which is to reach destinations (S. L. Handy and Niemeier 1997).

The idea of producing mobility seems intuitive when planning for inexpensive motorized travel, in an era when automobile users have been, as a matter of policy, shielded from paying –and even becoming aware– of the full cost of their travel (Taylor 2006). In recognition of the contradiction of trying to generate mobility while also hoping to reduce the ill effects of mobility, an argument in the transportation literature for decades has been to shift from mobility-based to accessibility-based planning (S. L. Handy and Niemeier 1997; Social Exclusion Unit 2003). Transportation accessibility is commonly defined as the potential of transportation-land use systems to generate access to opportunities (Páez, Scott, and Morency 2012) and conceptually strikes at the heart of wasteful mobility-based planning by focusing on the ability to reach destinations. Despite mixed evidence regarding the adoption of accessibility in planning practice (Boisjoly and El-Geneidy 2017; Proffitt et al. 2019) there are reasons to believe that the future belongs to accessibility-based planning (S. Handy 2020).

The relevance of accessibility-based planning is even more evident when active modes are considered: who would rather make long trips if equivalent destinations could be reached with shorter trips? Not only can pedestrians and cyclists not be shielded from the cost of travel, the effort of reaching destinations is inherently visceral (Hsu and Tsai 2014; Iseki and Tingstrom 2014; Páez et al. 2020). As interest in active travel-based accessibility (ATB accessibility) grows globally (Arranz-López et al. 2019; Li, Huang, and Axhausen 2020; Ortega et al. 2021; Rosas-Satizábal, Guzman, and Oviedo 2020), transportation scholars have built on decades-worth of accessibility research that mainly focused on motorized travel. In principle, accessibility analysis is sufficiently general to be applicable for ATB accessibility analysis. In practice, it is important to recognize the differences between motorized and active travel, and how they can impact their implementation with a focus on active travel (Iacono, Krizek, and El-Geneidy 2010). Active modes of transportation absorbed the interest of researchers because they have significant implications and combines unrivalled advantages such as environment, health, and social inclusion (Pucher et al. 2010; Rojas-Rueda et al. 2011, 2012; Otero, Nieuwenhuijsen, and Rojas-Rueda 2018; Koszowski et al. 2019; Tinessa et al. 2021). They have been linked to a variety of health benefits. For example, they improve longevity (Hakim et al. 1998), cognitive function (Weuve et al. 2004), quality of life (Strawbridge et al. 1996; Leveille et al. 1999), and are perceived as cleaner and more efficient sustainable modes of transportation (Bhopal and Unwin 1995). They also become an excellent alternative for mobility, lowering transportation costs for families, promoting gender equality, building resilient structures, and contributing to the aesthetic value of the environment (Koszowski et al. 2019). They also improve accessibility for those who do not have other modes of transportation and aid in the development of local and regional economies. However, compared to motorized travel, active travel is slower, occurs on smaller scales, has less safety due to their higher risk of being severely injured in collisions than motorized vehicle drivers, is used to reach potentially different destinations, and involves costs, such as physical effort, that are typically ignored in motorized travel analysis (Ng, Debnath, and Heesch 2017; Akgün et al. 2018; Pokorny, Pritchard, and Pitera 2018; Oehl, Brandenburg, and Huemer 2019; Useche et al. 2019).

The objective of the present study is to investigate ATB accessibility with a focus on data sources and needs, using Canada as case study. The research is prompted by a recent Canadian project that has been tasked with developing data-driven standards for the analysis of transportation equity. The need to propose methods that can be used consistently across regions requires a sound understanding of how analysis and outputs can be conditioned by the data inputs. it is important to acknowledge that other reviews of ATB accessibility measures exist (Geurs and Van Wee 2004; Iacono, Krizek, and El-Geneidy 2010; Maghelal and Capp 2011; Talen and Koschinsky 2013; D. S. Vale, Saraiva, and Pereira 2016). The contribution of this paper is to fill a gap in the literature by focusing on the data required by various measures of ATB accessibility and comparing measures that can be implemented consistently in different contexts, as well as data needs for consistent implementation of the rest.

The reminder of this paper is organized as follows. Section 2 presents a background of methods. Section 3 presents methods for ATB accessibility analysis, section 4 provides a categorization of the required data according to each of the accessibility measurements. Section 5 provides Important considerations and possible challenges for calculating accessibility by active mode; discussions and conclusions are provided in Section 6.

## Background

Transportation planning has emerged as a distinct field centered primarily on mobility, defined as the ease of movement. Mobility indicators such as travel speed and travel time were proposed in this context, with a focus on motorized transportation (Banister 2008). The concept of accessibility has long been adopted in both spatial and transportation research to assess the quality and extent of the relationships between spatial development of a certain area and the transportation system serving it. The seminal work of Hansen (1959) defined accessibility as “the potential of opportunities for interaction”, measuring the number and variety of opportunities which can be obtained from a specific location by means of the transportation system.As a result of Hansen’s work, researchers began to emphasize the importance of including accessibility as a performance indicator in land use and transportation plans as an alternative to mobility-based transportation planning (Koenig 1980; Morris, Dumble, and Wigan 1979; Wachs and Kumagai 1973). Furthermore, the researchers argued that improved access reflects the network’s economic and social benefits, specifically in terms of land value and quality of life (Koenig 1980; Wachs and Kumagai 1973). Recently, accessibility has been promoted as a critical component of land use and transportation planning, specifically in terms of social equity, economic development, and environmental impacts (Banister 2008; S. L. Handy 2002; Lucas 2012; Preston and Rajé 2007). For example, in 2004, Geurs and van Wee deconstructed the concept of accessibility into four elements: (i) **Land use** describes the quality, quantity, and spatial distribution of opportunities as destination places, such as schools, jobs, hospitals, and recreational facilities, as well as demand for opportunities at origin places; (ii) **Transportation** refers to the transportation system represented by the disutility for a person to travel from an origin to a destination using a specific mode of transportation; (iii) **Time**, which accounts for the time constraints in terms of the availability of opportunities throughout the day and the time available for people to take advantage of such opportunities; and iv) **Individual**, which indicates specific (groups of) people’s capabilities (determined by income, education level, travel mode availability, etc.) and needs (determined by age, household situation, etc.).

Mobility-based approaches emphasize travel time reduction, whereas accessibility planning aims to provide all individuals with a reasonable travel time to a variety of destinations. As a result, accessibility planning prioritizes active and public transportation and incorporates land use policies that shorten distances between activities(Banister 2008).Accessibility refers to the ease of access to different destinations which are valuable and can be reached. In order to calculate accessibility, the implementation of access measures varies depending on the research need, mode of transport, data need, activities, and land use pattern, as well as the costs of travel over the transport infrastructure that connects it. So, the emphasis on different elements of accessibility has resulted in multiple measurement methods and indicators (for example, Geurs and Van Wee 2004; Kelobonye et al. 2019; B. H. Lee et al. 2010; Neutens 2015; Paez et al. 2010; Vandenbulcke, Steenberghen, and Thomas 2009), including proximity, cumulative, gravity, utility-based, and space-time prism models as the dominant approaches. However, there are disagreements about how to evaluate this concept (Castiglione et al. 2006; Fan, Guthrie, and Levinson 2012; Wang and Chen 2015).

In general, accessibility can be measured at the individual-based or locational level (place-based) (Miller 2005). Indeed, place-based metrics are concerned with the land use and transportation components, and focus on the physical separation of key locations, say an origin and potential destinations.Cumulative-opportunity accessibility and gravity accessibility are examples of this category. This kind of accessibility refers to the degree to which people can reach and use services, amenities, and opportunities located in a specific geographic location, such as a neighborhood, city, or region.On the other hand, individual-based metrics take into account some representation of the space-time behavior of individuals and refers to the degree to which an individual person can reach and use services, amenities, and opportunities based on their personal characteristics, such as age, gender, income, mobility, and health status.Space-time accessibility and utility accessibility belong to this category. Individual-based accessibility considers the unique needs and preferences of individuals, including their ability to access different types of transportation, travel routes, and modes of transportation. Individuals-based accessibility is sometimes included in location-based studies by stratifying the population by age group or socioeconomic characteristics, as well as by segmenting destinations (Harris 2001; D. de S. Vale 2009; Paez et al. 2010; Fan, Guthrie, and Levinson 2012; Legrain, Buliung, and El-Geneidy 2015, 2016).These two approaches are related, and individual-based measures can in fact be seen as a special case of placed-based measures, where the impedance function and cost are a constant by destinations.

The use of location-based accessibility has the significant advantage of being easily computed(Bhat et al. 2000).for calculating placed-based accessibility, researchers require data such as average travel time between two points, population data, and aggregated activity data.As a result, cumulative-opportunity accessibility is one of the most widely used methods of calculating accessibility.Following that, space-time accessibility assesses how individuals can carry out desired activities while facing constraints(Miller 1991; Kwan 1998; M. S. Lee and McNally 1998). This framework is based on Hagerstrand’s (1970) time geography model.He discussed three factors that influence individual accessibility. Capability constraint means that people can only do things when they are awake. People cannot go wherever they want because travel impediment exists at all times. Coupling is the second and most important constraint. People must perform specific tasks at specific times.People, for example, may remain at their workplace during working hours (e.g. 8 AM to 5 PM). The final constraint is the authority constraint. This constraint includes activity opening hours. People, for example, cannot use a park late at night because it is closed. The number of activities that can be performed under various constraints is measured by space-time accessibility(Ilägcrstrand 1970).According to this study, space-time accessibility (i.e. person-based accessibility) is a better measurement than cumulative-opportunity accessibility (i.e. place-based accessibility) because it captures individuals’ actual travel behavior. This is due to the fact that space-time accessibility takes into account temporal variations in transportation systems and activities, as well as individuals’ unique travel behavior. In other words, because place-based accessibility does not fully address temporal constraints, it may be inaccurate when measuring accessibility.

On the one hand, space-time accessibility takes into account temporal variations in transportation and activities(Fransen et al. 2015; Boisjoly and El-Geneidy 2017). In place-based accessibility, temporal variations in transportation systems have been ignored. Travel time between two points varies depending on the time of day because traffic volume varies. However, average daily travel time is used in place-based accessibility.

On the other hand, space-time accessibility considers temporal variations in activities. Place-based accessibility assumes that all activities are carried out during hours chosen at random by researchers. However, activities are only available during their regular business hours.

To write a general formula for accessibility for active transportation modes, we can modify the formula, by taking into account factors that are specific to active transportation. Here is one possible formula:

With functions for the opportunities that allow this formulation:

as well as possibly agglomeration effects as in:

This kind of accessibility measure was obtained from Hansen, 1959,which measures accessibility by the number of opportunities reachable via an impedance (or spatial decay) function.The impedance function reduces opportunities as travel costs rise (time, money, etc.).The impedance function computes using a variety of formulas, including negative power, exponential, lognormal, and log-logistic (Hansen (1959); Ingram (1971); Reggiani, Bucci, and Russo (2011); Geurs, Eck, et al. (2003); D. S. Vale, Saraiva, and Pereira (2016)).A\_i, O\_j, and C\_ij in this formula represent matrices of accessibility opportunities and costs, respectively. Following the development of Levinson and Wu (2020), the functions (g and f) discount opportunities and costs based on diminishing value of opportunities with both number and cost.In principle, the matrix of weighted opportunities (O\_j) can take into account different activity types, times of day, and all available modes, as well as the matrix of all relevant cost elements (C\_ij), which may be the full social costs or generalized internal costs, depending on the purpose.

The decay function’s cumulative opportunities (rectangular) formulation is as follows:

In addition, The widely used exponential decay formulation in gravity models is frequently given by [Equation 5](#eq-exponential-distance-decay):

Generally, close opportunities are preferred over distant ones (Miller 2004), and fewer trips are made between distant locations than between nearby ones(Ingram 1971).As a result, interaction is less likely in remote locations. In most cases, travel impedance functions are calibrated using observed trip likelihood or trip rate data from travel surveys(Geurs and Ritsema van Eck 2001; Ingram 1971).So, the impedance functions show reduced interaction between places. The trip rates can be used to calibrate the travel impedance function (f (C\_{ij})).

Individual-based accessibility in active mode (e.g., walking, cycling) can also be difficult to calculate due to a variety of factors. Some of the major constraints for calculating individual-based accessibility in active mode are as follows:

1. Individual preferences for modes of transportation can have a significant impact on accessibility. Some people prefer to walk or ride their bikes, while others prefer to take public transportation or drive. Factors such as distance, time, safety, and comfort can all have an impact on personal preferences.
2. Physical ability: Similar to place-based accessibility, personal physical ability can greatly impact individual-based accessibility in active mode. People with disabilities or health issues may find it difficult or impossible to travel by foot or bike, reducing their accessibility.
3. Time constraints: In order to save time, people may choose faster modes of transportation such as driving or taking public transportation, reducing accessibility in active modes. While individual-based accessibility is measured, it should be recognized that every individual has a different opportunity set available (Miller 1991). Effectively, the available time threshold (t) varies for each person as a function of individual constraints, such as time of day, purpose, and so on. Constraints arise for a number of reasons. Time geography acknowledges that spatial and temporal characteristics limit an individual’s choice of activities (Chi et al. 2013; Pred 1977; Miller 1991; Miller and Bridwell 2009). Time constraints can be visualized using a time-space diagram, the size of which is determined by both the amount of time available and the performance of the transportation system (Ilägcrstrand 1970). The space-time prism accounts for an individual’s activity schedule and can be used to measure access to multiple activities and activity participation time using simple behavioral rules (Miller 1991). Accessibility is measured by the total number of opportunities available within the space-time prism encompassing all possible paths under the time constraint (Tong, Zhou, and Miller 2015). So, while opportunities may be spatially accessible, the amount of time available in a day for people to reach and engage in these activities is limited. This line of thought leads to the constraints-based or people-based accessibility measure(Y.-H. Wu and Miller 2001).
4. Weather conditions, like place-based accessibility, can have an impact on individual-based accessibility in active mode. In extreme weather, people may be less likely to walk or cycle, reducing their ability to choose these modes.
5. Infrastructure: The quality and availability of infrastructure such as sidewalks, bike lanes, and pedestrian crossings can greatly impact individual-based accessibility in active mode. People may be less likely to choose active modes of transportation in areas with poor infrastructure, reducing there ability to choose these modes.

Accessibility measures in active modes include activity-based measures, distance-based, topological or infrastructure-based measures, utility-based measures, as well as, walkability, and bikeability. Activity-based measures (includes gravity-based and cumulative opportunities measures) are based on the gravity model and weight opportunities according to a travel impedance function and the accessibility of a place is assessed as the combined effect of the size of opportunities and the cost of traveling to them. Distance-based measures analyze the closest facilities and include: 1) distance to the closest opportunity, 2) the number of opportunities within a defined distance or time, 3) the mean distance to all opportunities, and 4) the mean distance to a defined number of closest opportunities. Infrastructur -based measures are based exclusively on features of the street and transportation network and are insensitive to the location of activities in space. utility-based measures (also designated benefit measures) are developed from microeconomic random utility theory and describe accessibility as the result of a (rational) choice from a set of destination transportation alternatives (Kwan 1998; Halden et al. 2000; Geurs and Ritsema van Eck 2001; Apparicio et al. 2008). Walkability and bikeability measure the number of people, households or jobs distributed over a unit of area or measures how many types—offices, housing, retail, entertainment, services, and so on—are located in a given area (L. Frank, Engelke, and Schmid 2003; Leslie et al. 2007). Indeed, using accurate accessibility measures for walking or cycling trips can assist transport planners in making more rational decisions in infrastructure provision for non-motorized transportation (Iacono, Krizek, and El-Geneidy 2010; Devkota, Dudycha, and Andrey 2012).

Moreover, calculating ATB accessibility in both approaches requires multiple data sets relating to travel behavior and land use. Unfortunately, this has suffered from a lack of appropriate data(Iacono, Krizek, and El-Geneidy 2010). In particular, little information is available on the geography of walking and cycling behavior such as travel episode origins and destinations, routes, and lengths (durations and distances). So, in most cases, required data is obtained from local/national questionnaires and local maps (Iacono, Krizek, and El-Geneidy 2010; Levine 2010; Devkota, Dudycha, and Andrey 2012; Yang and Diez-Roux 2012; Millward, Spinney, and Scott 2013) . In addition, available data are extremely location specific or cover a small geographic area and are not adequately covered in most large-scale survey instruments, such as national transportation survey (Ulmer and Hoel 2003; Achuthan, Titheridge, and Mackett 2007).

## Methods for ATB accessibility analysis

Measures of ATB accessibility can either be location-based, focusing on the distances to opportunities from particular locations, or individual-based, taking into account the limitations of people’s time and space. Vale et al (2016) categorized location-based accessibility measures into four main groups: first, activity-based, which includes gravity-based (also designated attraction-accessibility or potential) and cumulative opportunities measures (also known as isochrones or contour measures). In addition, these measures have been widely used in non-motorized accessibility studies (Iacono, Krizek, and El-Geneidy 2010; Lowry et al. 2012; Millward, Spinney, and Scott 2013; Prins et al. 2014; Li, Huang, and Axhausen 2020); second, topology infrastructure-based, which include topological measures of the network (Hull, Silva, and Bertolini 2012; Lundberg 2012); third, distance-based, which include analyses of the closest facilities (Apparicio et al. 2008; Sadler, Gilliland, and Arku 2011), and the last category being utility-based measures which are also known as benefits measures (Geurs and Van Wee 2004; Hunt and Abraham 2007; D. de S. Vale 2009; El-Geneidy and Levinson 2011).

One important reason why location-based measures are widely used instead of individual-based measures for active transport modes is their potential compatibility with regional travel forecasting models. These models rely on data from various sources to predict travel patterns and demands across different areas. By using location-based measures, such as coded networks, it becomes easier to extract travel times and distances between one area to another (Iacono, Krizek, and El-Geneidy 2010; Saghapour, Moridpour, and Thompson 2017).

There are some limitations of using location-based measures for active travel modes. first, active travel modes are less sensitive to travel times and levels of network congestion rather than motorized modes. as well, walking and cycling route choices tend to include qualitative, experiential, or difficult to measure factors (Hunt and Abraham 2007; Tilahun, Levinson, and Krizek 2007; Iacono, Krizek, and El-Geneidy 2010). second, measuring active transport accessibility is mostly dependent on travel diary data. besides, The methods applied so far to measure cycling accessibility have not focused on the accessibility of cycling destinations in terms of service areas (Landis, Vattikuti, and Brannick 1997; Harkey, Reinfurt, and Knuiman 1998; Harkey et al. 1998; Landis et al. 2003). some studies have investigated the level of services such as Bicycle Compatibility Index (BCI) or Bicycle Level of Service (BLOS) for a bicycle network. indeed, these measures focused on measuring the performance of a bicycle network using various geometric measures such as the width of the bicycle routes, pavement, route types, and connectivity. Nonetheless, there are other methods that consider bikeability in terms of how accessible different destinations are for bicycles as a transport mode. Such methods measure the potential for cycling using travel behaviour data (Espada and Luk 2011; Wahlgren and Schantz 2012; Rybarczyk and Gallagher 2014; Milakis et al. 2015).

##### Activity-based measures

Activity-based measures include both gravity-based (also known as Hansen-type (Hansen 1959) and cumulative opportunities measures. Gravity-based measures designated attraction –accessibility or potential and consider the number of opportunities weighted by the cost of traveling to them – using a travel impedance function that values closer opportunities higher. Researchers underlined the importance of choosing a suitable impedance function and it can be observed that a large variety of functions are applied. Commonly used functions are power, negative exponential, logistic and Gaussian functions (Iacono, Krizek, and El-Geneidy 2010; Lowry et al. 2012; Vasconcelos and Farias 2012; D. S. Vale and Pereira 2017). More recently Vale and Pereira (2017) conducted a study testing 20 pedestrian accessibility measures and identified the modified Gaussian and exponential function as the most robust ones for modeling walking accessibility. Cumulative opportunities (also known as isochrones or contour measures), measures count the number of opportunities within a defined catchment area.

Gravity-based measure derived from the gravity model’s denominator and weighted opportunities according to an impedance function, which is given by the following expression: (D. S. Vale, Saraiva, and Pereira 2016):

This equation gives the accessibility from the origin location i, W\_j are relevant opportunities found at j, f(c\_{ij}) is the cost of moving between i and j. Function f() defines a kernel around location i. Activity-based measures are useful when opportunities are complementary (e.g., jobs, people, services, parks) and when access to more opportunities and being closer (with gravity-based models) is advantageous.

Cumulative opportunities (also known as isochrones or contour measures), measures count the number of opportunities within a defined catchment area. In contrast to the utility measure, which measures accessibility by the ‘net utility’ from travel, the cumulative measure represents accessibility with the total number of opportunities. This measure counts both the number of reachable opportunities and the associated travel costs.

in a cumulative measure the distance decay function is binary:

In [Equation 8](#X9a5d005bdcc13f2a81b5fe78e7de06d7a0ea12d) is the threshold value. According to this formula, all opportunities located within the threshold are considered accessible. In addition, f(c) is an indicator function that returns 1 if the logical statement in the function’s argument is true (i.e. if the cost of reaching j from i does not exceed the bandwidth parameter value) and 0 otherwise. Other distance-decay functions (for example, inverse distance or negative exponential) generate smoother map patterns (O’Kelly and Horner 2003), but they require more parameters and introduce distance- (or cost-) discounted schemes that are more difficult to interpret. Previous research has shown that cumulative opportunity measures are highly correlated regardless of the distance-decay function used (Kwan 1998), and we ultimately prefer simplicity and interpretability in our accessibility indicator selection.

##### Distance-based measures

Distance-based measures consider accessibility in terms of proximity, either by travel distance, time, or a generalized cost measure between locations. A distance measure analyses the closest facilities, including 1) distance to the closest opportunity, 2) the number of opportunities within a defined distance or time, 3) the mean distance to all opportunities, and 4) the mean distance to a defined number of closest opportunities (Apparicio et al. 2008). These measures are applicable when destinations are regarded as substitutes for one another (i.e., hospitals, transit stops, convenience stores etc.), under the assumption that individuals want to access the nearest facility.

Distance is considered as the travel impedance and four types of distances are usually used in distance-based accessibility measures: 1) Euclidean distance, that has been mainly used for walkability measures, particularly in health studies (Apparicio et al. 2008). 2) Manhattan distance, 3) shortest network distance (Lundberg 2012; Hochmair 2015) 4) shortest network time (Pearce, Witten, and Bartie 2006; Páez, Scott, and Morency 2012). As well, there are two different ways for measuring distance, first calculates the distance to the closest facility of each type. The first method calculates the distance from each zone centroid to the closest or the first n closest facilities (e.g. medical centers).and second, calculates the distance to all facilities close by. This approach is based on floating catchment areas that finds the closest facility regardless of distance and measures the distance from each zone centre to the closest or the first n closest different facilities (e.g. medical centres, shopping centres, etc.).

Distance to nearest location is calculated based on [Equation 9](#eq-distance-based-accessibility):

In this equation, is accessibility of zone i to location of type p, is set of locations of type p, and is distance (or travel time for a given mode) from i to location j in set . This measure is consistent with an extremely simple location model in which the nearest location is always chosen with probability 1.0. (2)

In equation 2, is the probability of choosing location j for purpose p given that one is located in zone i. This measure has two limitations, first, doesn’t consider the size/attractiveness of locations and second, doesn’t investigate the cumulative effect of multiple accessible locations. So, it is not recommended to calculate accessibility using this method as an independent measure.

##### Topological or infrastructure-based measures

Topological-based measures consider accessibility in terms of the street network, rather than access from origins to destinations. Topology measures may evaluate network connectivity, the quality of infrastructure within a catchment area, or some combination of connectivity and infrastructure quality. Indeed, this measure emphasizes on infrastructure evaluation. Such approaches are applicable in the context of planning – for example, in identifying priorities for development, or identifying potential impacts of redevelopment.

There are three types of topological measures: the first group evaluates the level of service (LOS) within a floating catchment area (FCA)(Sisson et al. 2006). The second type is similar the first one. however, this one used a pre-defined spatial unit to evaluate LOS, and this is based on the segment instead of the point (Emery and Crump 2011; Horacek et al. 2012; Lowry et al. 2012). The third one is very different, since traffic is not considered as a relevant parameter (Hoedl, Titze, and Oja 2010; Zielstra and Hochmair 2011; Jabbari, Fonseca, and Ramos 2021). These measures are based on and the evaluation of network segments, infrastructure characteristics, and include variables such as sidewalk or bike path availability, quality, and length among others.

##### Utility-based measures

Utility-based measures evaluate accessibility based on individual preferences and the log-sum of discrete choice models applied to destination choice analysis (M. Ben-Akiva and Lerman 2021). This measure, which is known as benefit measure, can better represent individual accessibility than location-based measures. In addition, individual-based accessibility yields more representative measures than placed-based accessibility and reflects population access. It is a common method of aggregating accessibility (Geurs, Eck, et al. 2003; Wachs and Kumagai 1973).

Utility-based measure can be calculated using two methods:

1. Assume that a decision-maker perceives the utility of a destination as: where is the individual’s idiosyncratic deviation in terms of how s/he perceives the utility of alternative j relative to the population average utility, . The person chooses the alternative that generates the maximum perceived utility, . Under very common assumptions, the probability that j is the maximum utility alternative and so is chosen is given by the multinomial logit (MNL) model(Train 2009):

In this equation, : The systematic utility of alternative j; is a Vector of explanatory variables and Β is a (Row) vector of parameters.

1. The actual perceived maximum utility is unobservable, but, for the case of the MNL model, it can be shown (M. E. Ben-Akiva et al. 1985) that the expected maximum utility associated with this choice is given by [Equation 12](#eq-maximum-utility):

That is, it is the natural logarithm of the denominator of the logit choice model (sometimes referred to as the “logsum” term). Further, it can also be shown that this expected maximum utility is the consumer’s surplus for this choice. Thus it is a standard measure of economic benefit. Given this, Ben-Akiva and Lerman (1985) argue that it also provides a behaviorally and economically sound definition of accessibility: accessibility for a given activity is the expected utility that would be derived from participation in this activity, which is also the consumer surplus associated with this participation. That is:

{eq-accessibility-maximum-utility}

In the following, Tables 1 and 2 have categorized recent studies based on the accessibility by walking and cycling. However, Vale et al. (2016) found relatively few studies examining cycling-specific accessibility in comparison to walking. For a comprehensive review of all 84 papers on walking and cycling accessibility (published by September 2013) refer to Vale et al. (2016).

**Table 1.** Studies employing cycling-specific accessibility measures

| **Type of metric** | **Study** | **Measure** | **Travel time / distance threshold** | **Origins / Destinations** | **Geographic scale** | **Travel time / distance calculation** | positive / normative implementations |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Activity-based | Murphy and Owen (2019) | Cumulative job opportunities Access gap: comparing LTS 1-4 Weighted accessibility by a number of workers | 20 mins (Tested 5 to 6 mins) | Census block centroids | Neighbourhoods -> city level | Network travel time 15 km/h | Normative |
|  | Faghih Imani, Miller et al. (2019) | Cumulative opportunities: jobs & population access Calculated isochrones for LTS 1-4 | 30 mins | Dissemination area centroids | Dissemination areas | Network travel time | Normative |
|  | Wu, Lu et al. (2019) | Gravity-based measure: accessibility to POIS at metro stations Lognormal distance decay function (confirmed using distribution of bicycle-metro trip data) | 2.5 Km | Metro stations (origins) POIs (destinations) | 2.5 km buffer | Euclidean distance | Normative |
| Distance-based | Houde, Apparicio et al. (2018) | Proximity of bike paths: 1. Network distance to nearest section of cycling network 2.Network distance to cyclist-only bike path |  | Census tract centroids (origins) Bike paths (destinations) | Census tracts | Network distance | Positive |
|  | Pérez, Buck et al. (2017) | 1.the dedicated cycling network - The distance from census tract centroid to nearest bike network segment was measured to estimate the accessibility of each tract. 2. Level of traffic stress (LTS network) was used to assess accessibility in the district. |  | census tract centroid to nearest bike network | The District of Columbia | Euclidean distance | Positive |
| Topology-based | Mekuria (2012) | Network connectivity by LTS 1-4: percent trips connected percent nodes connected |  | Home-to-work O-D pairs from regional trip table Land parcel ‘attraction strength’ (size and land-use attraction) (destinations) | Census blocks | Network | Positive |

**Table 2.** Studies examining walking-specific accessibility

| **Type of metric** | **Study** | **Measure** | **Travel time / distance threshold** | **Origins / Destinations** | **Geographic scale** | **Travel time / distance calculation** | positive / normative implementations |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Activity-based | Cheng, Caset et al. (2019) | Cumulative opportunities: chess/card rooms and urban parks for older and younger adults Park spaces weighted by their size | Adaptive distance thresholds (based on location and socio-economic variables) | locations from travel survey (origins) Parks and chess/card rooms (destinations) | Traffic analysis zones | Network distance | Positive |
|  | eyes, Páez et al. (2014) | Cumulative opportunities to urban parks for children parks spaces weighted by their size: 1. Accessibility based on all individual attributes from travel survey 2. Accessibility based on scenario profiles (gender, age, income,etc) | Based on statistical model of travel behavior | Locations from household travel survey Rasterized parks 25\*25 m (destinations) | Dissemination areas (weighted average) | Euclidean distance | Normative |
|  | García-Palomares, Gutiérrez et al. (2013) | Access quality indicator for metro stations: population served Access by age group Distance decay function by age group | 1500m & Distance thresholds calculated for different age groups | Metro stations (origins) Transport-zone level populations | 1500m metro station catchment areas | Network distance | Normative |
|  | Papa, Carpentieri et al. (2018) | Contour accessibility measure: bus catchment areas Number of inhabitants served by age group Catchment areas calculated with and without network slope | Dependent on frequency of bus service | Bus stops | Hexagonal cells 50m | Network distance Walking speeds dependent on age | Normative |
| Utility-based | Blecic, Ivan, et al |  |  |  |  |  |  |
| (2013) | modeling how residents from various points in space can walk to places of interest in an urban area using utility based accessibility |  | all the points of origin of trips to accessible destinations | creating 100 m x 100 m cell grids that covering the whole map | Network distance | Normative |  |

##### Walkability measures

Walkability indices can be defines based on the both the social and physical environment, a predictive indicator of active travel and physical activity to access facilities; based on indicator of the usability of the built environment to people (L. D. Frank, Andresen, and Schmid 2004; L. D. Frank et al. 2006) who walk to different destinations and for different purposes (i.e., from a clear origin to a clear set of destinations) (Saelens and Handy 2008; Blečić et al. 2015; D. S. Vale, Saraiva, and Pereira 2016; Dovey and Pafka 2020). There is a difference between gravity- and distance-based accessibility measures and the walkability index so that for measuring walkability, area characteristics around the origins and destinations are also taken into account in the calculation, but still, this index does not consider route characteristics.

Walkability measures are divided into 4 categories including Frank’s Walkability Index, Walk score, Objective Walkability Index (OWI), and Graz Walkability Index. In the Frank’s index, a walkability score is calculated by summing the normalized scores across factors that are identified based on a definition of the concept of walkability. This index uses residential density, land use mix, retail floor area ratio, and intersection density as variables to measure walkability. Then Grasser, Van Dyck et al. (2013) improved Frank’s index for assessing Europe cities by considering population density, household density, and entropy index for land-use mix, and three-way intersection density in order to construct the Graz walkability index (Grasser et al. 2013). In addition, some other theory-based methods such as Objective Walkability Index (OWI) are also proposed. Weiss, Maantay et al. (2010) constructed the OWI, which includes street connectivity, land use mix, pedestrian safety, neighborhood aesthetics, neighborhood safety, and neighborhood infrastructure(Weiss, Maantay, and Fahs 2010). In 2011, Duncan, Aldstadt et al. (2011) developed Walk Score for measuring walkability of neighborhoods. Indeed, Walk Score recognizes eight types of walking attractors: Errands, Culture, Grocery, Park, Dining and Drinking, School, and Shopping. Walk Score can be assessed for any location worldwide, however, locations outside the US, Canada, Australia, and new zealand should be additionally validated, since the geolocated data is not always complete [Duncan et al. (2011); WalkScore 2020].

Most of the studies assessed walkability using two Frank’s index and walk score (L. D. Frank et al. 2005, 2006, 2010; D. S. Vale, Saraiva, and Pereira 2016). The major difference between these approaches is that Walk Score uses a gravity-based methodology. Opportunities are weighted using a distance decay function, while the Walkability Index is based on a cumulative opportunities measure. In the following, Table 3 provides a summary of this categorization.

**Table 3.** Studies examining walkability

| **Methods** | **Author** | **Variables** | **Data** | **Descriptions** | positive / normative implementations |
| --- | --- | --- | --- | --- | --- |
| Methods based on a theory-driven approach |  |  |  |  |  |
| Frank’s Walkability Index | Frank, Schmid et al. (2005), Frank, Sallis et al. (2010) | Net residential/ Population density | · travel data from both Census Journey to Work for both regions |  | Normative |
|  |  | · Retail floor area ratio | · Household Travel Survey Data |  |  |
|  |  | · Intersection density | census-based demographic data |  |  |
|  |  | · Land use mix |  |  |  |
|  | Manaugh and El-Geneidy (2011) | · Net residential/ Population density | · Retail information (shopping and school) was obtained from the Dun and Bradstreet business database and combined with a weighted intersection index. | · nine models were generated for each trip purpose using a different walkability measure in every run (Walkscore, walk opportunities, the WI at four scales and three sizes for the pedshed connectivity measure) | Normative |
|  |  | · Retail floor area ratio | · used a database of over 100,000 postal code points from Walkscore.[1] | · The walkability index generated at four scales: 400, 800 and 1200 m network buffers as well as at the census tract level. |  |
|  |  | · Intersection density | · Household level data and travel behavior characteristics are obtained from the 2003 Montréal Origin–Destination survey. | · used a simple gravity-based measure to weight nearby locations higher than those more distant. |  |
|  |  | · Land use mix | · census tract level demographic data derived from Statistics Canada |  |  |
|  |  |  |  |  |  |
|  | Adhikari, Delgado-Ron et al. (2021) | · residential density | · demographic characteristics of participants | · The walkability index uses 1 km pedestrian “walksheds” that map pedestrian-accessible roads around each postal code centroid. | Normative |
|  |  | · the commercial floor-to-area ratio |  | · Each walkshed corresponds to approximately 10–15 min of walking time, a commonly used time frame to assess perceived proximity to amenities and services. |  |
|  |  | · land-use mix |  |  |  |
|  |  | · intersection density |  |  |  |
|  | Azmi, Karim et al. (2013) | · Mixed-use planning | · data was gathered by using the questionnaire survey | · the type of community facilities or services selected was based on the availability of the services provided within a radius of 400 meter (approximately 5 minute of walking) | Normative |
|  |  | · Density | · asking the accessibility of residents walk from their home to community facilities or services provided within the walkable catchment | · There are a total of 13 community facilities and services such as grocery store/supermarket, park or recreational facility (indoor or outdoor), elementary school, other school, community center, restaurant or other places, bank, medical clinic/pharmacy, personal shop (laundry, salon), workplace, bus stop, post office and place of worship. |  |
|  |  | · Street connectivity | · indicated the amount of time they thought it would take for them to walk from their home to the nearest destination. |  |  |
|  | Liao, van den Berg et al. (2020) | · The variables of this section are divided into four parts: | · as a source of walking frequency data, the Dutch national travel survey. | · density variables: population density, intersection density, and business property density | Normative |
|  |  | ü density | · neighborhood data as a source for socio-demographic and physical neighborhood variables and used as control variables include gender, age, income status, work status, household status, and migration background. | · facilities variables: a range of facilities the distance to the nearest facility (average distance from the center of the neighborhood) and the number of facilities available within a 1 km radius (from the center of the neighborhood) |  |
|  |  | ü facilities | · All walkability variables were derived from the Esri-open postcode plane and the CBS data. | · green space variables: total area of different types of open green space and recreational space. |  |
|  |  | ü green space |  | · land use mix variables: the separate lower-level land-use variables in the form of a percentage of the total land covered by the land-use were used |  |
|  |  | ü land use mix |  |  |  |
|  | Arellana, Alvarez et al. (2021) | · intersection density | · latest household Origin Destination survey. | · Calculated potential accessibility. | Normative |
|  |  | · land use entropy score | · Land use data, the location of commercial zones, the population, and the characteristics of the walking trips from each zone (TAZ). | · The measure evaluates the access to shop, job, study, and institutional opportunities |  |
|  |  | · population density |  |  |  |
|  |  | · commercial density |  |  |  |
|  | Ruiz-Padillo, Pasqual et al. (2018) | · Public Security | · Census tracts were used that including size and number of households | all census tracts were classified according to three variables: | Normative |
|  |  | · Traffic Safety |  | ü motorization rate |  |
|  |  | · Convenience and attractiveness: |  | ü density of commercial and service establishments |  |
|  |  | ü Street connectivity |  | ü average slope |  |
|  |  | ü Destination’s proximity (number of shops and services) |  |  |  |
|  |  | ü Mix of uses proximity (number of shops and services) |  |  |  |
|  |  | ü attractiveness |  |  |  |
|  |  | · Characters of the roots: |  |  |  |
|  |  | ü Pavement Quality |  |  |  |
|  |  | ü Pavement width |  |  |  |
|  |  | ü Slope |  |  |  |
| Walk Score (Walk Score calculates a score by determining the walking distance to amenities in nine different amenity categories) | Duncan, Aldstadt et al. (2011) | · Walking distance to amenities | · Google AJAX Search application program interface (API) provides data for the Walk Score. |  | Normative |
|  |  | · Intersection density metrics |  |  |  |
|  |  | · Average block length |  |  |  |
| Graz Walkability Index (based on American city and Frank’s walkability index) | Grasser, van Dyck et al. (2017) | · Net residential/ Population density/ household density | · Outcome data were derived from the representative cross-sectional survey | present study reported the results of the 1000 m circular buffer and the 1500 m street network buffer[2]. | Normative |
|  |  | · Intersection density | · Walking (for at least 10 min) and cycling (in the warm season) |  |  |
|  |  | · Land use mix (entropy index for land-use mix) |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| [1] Walkscore.com. |  |  |  |  |  |
| [2]most studies (conducted mainly in USA and Australia) use 1000 m buffers. The European environmental questionnaire ALPHA used a distance of 10- to 15-min walk (i.e. \_1–1.6 km) as a neighborhood scale. |  |  |  |  |  |
|  |  |  |  |  |  |

##### Bikeability measures

Bikeability can be defined as the ability of a person to bike or the ability of the urban landscape to be biked or as a baseline definition of the likelihood that individuals or groups of people will choose the bicycle as a mode of transport or leisure (Krizek, Handy, and Forsyth 2009; Winters et al. 2013; Nielsen and Skov-Petersen 2018) .However, It should be noted that the bikeability index described by several scientists: in 2012, Lowry, Callister et al explained the Bikeability index as the comfort and convenience of an entire bikeway network for accessing important destinations. Then they referd that this index is the only methodology exclusively dedicated to bicycle travel (Lowry et al. 2012). In additional, The Bikeability Index described by Winters, Brauer et al. (2013)includes the three basic measures, but adds the length of bicycle routes, slope, and the separation from car traffic. Each variable is given a score of 1 to 10, which is then summed to produce the final score (Winters et al. 2013).

Explaining the Bikeability of an environment has included the following characteristics:

* Single principles of the townscape or the infrastructure, such as bicycle tracks, crossings, and parking facilities, which are referred to by Lowry, Callister et al. (2012) as “bicycle suitability”(Lowry et al. 2012).
* Neighbourhoods are delineated based on airline/Euclidean distance rather than network distance (Greenberg and Renne 2005; Nielsen and Skov-Petersen 2018)
* Explicit polygon features generated around specific trajectories of individual respondents – e.g., as recorded by GPS. Such features can be purely geometric, such as buffers or ellipsoids, or be based on the topology of a transport network (Madsen et al. 2014; L. D. Frank et al. 2017).
* Connected infrastructures as a functional component of entire towns and urban fabrics (Lowry et al. 2012). According to Lowry, Callister et al. (2012), this is in fact what covers the term “Bikeability”. In the following, Table 4 prepares some of the studies that used bikeability index.

**Table 4.** Studies examining bikeability

| **Author** | **Study area** | **Measure** | **Data** | **Descriptions** | positive / normative implementations |
| --- | --- | --- | --- | --- | --- |
| Lowry, Callister et al. (2012) | Moscow, Idaho | · proposed calculation for bikeability was developed on the basis of a common accessibility equation (Hansen’s model). | · bikeway is any roadway where bicycle travel is permitted regardless of the presence of a bike lane | · Assessment of bikeability considers comfort and safety of the entire bikeway network for access to important destinations. | Positive |
|  |  | · calculation finds the shortest routes between zone i and every destination j | · Complete entire bikeway network and important destinations in the case study community | · impedance functions were estimated based on a negative exponential function. |  |
|  |  |  | · only arterials, collectors, and shared-use paths were considered part of the major bikeway network. | · bikeability was assessed for all commercial destinations |  |
| Nielsen and Skov-Petersen (2018) | Denmark | · presented a micro-level analysis of the Bikeability variables included density/accessibility, | · cycling data obtained from the Danish National Travel survey |  | Positive |
|  |  | infrastructure provision and terrain measured | · a classification of all roads and paths into seven classes is provided: roads without bicycle infrastructure, roads with bicycle lanes, roads with bicycle paths (protection by kerb and/or separating strip), fully separated bicycle and foot paths, fully separated foot paths, roads without access for pedestrians or bicycles, and roads without public access. | · The survey’s account of cycling includes cycling as the main mode of transport as well as cycling as a stage mode, e.g., connecting to public transport and leisure cycling without a destination purpose. |  |
|  |  | · The accessibility was based on the shortest path network distance from trip origins. | · the number of residents, jobs, retail jobs, schools, high schools, and further education were counted within 1 km, 2 km, 3 km, 4 km, and 5 km of each trip origin and added to the travel survey dataset. | · The average slope of the terrain within the same distances (Euclidian measure) was applied. |  |
|  |  |  |  |  |  |
| McNeil (2011) | Portland, Oregon | · assessing a neighborhood’s bicycle accessibility or “bikeability” on the basis of 20-min neighborhood for bicycles. | · the 2009 National Household Transportation Survey | · this research focused on home-based utilitarian trips and excluded any trips to and from work. | Normative |
|  |  | · Using a scoring method in order to assessment the bikeability, | · Geocoded data for parks, schools, libraries, and transit connections (light rail stops and bus lines) were obtained from Metro’s Regional Land Information System. | · Business addresses were gathered and geocoded for all childcare providers, grocery stores, clothing stores, general goods stores, beauty services (e.g., salons, barbers), banks, mail services (e.g., post offices, private mail providers), laundries and cleaners, gyms, general entertainment (e.g., bowling, performance venues), drinking establishments, movie theaters, restaurants, coffee and snack shops, and religious organizations. |  |
|  |  |  | · Business address data for other destination types were acquired through a data clearinghouse, Reference USA. |  |  |
|  |  |  |  |  |  |
| Saghapour (2017) | · | · Introducing a new index for measuring bikeability; | database included urban centres, significant buildings, landmarks, public spaces, community facilities and indigenous locations.- considered as destinations and categorized into four groups of activities. | · Service area and OD-cost matrix analysis was undertaken for each set of destinations separately: | Positive |
|  |  | Cycling Accessibility Index (CAI) was developed for quantifying cycling accessibility using the travel distance as impedance along with cycling catchments within local areas in metropolitan area | ü A datab`ase of Mesh Blocks from the 2011 Census and contained the total usual resident population and total number of dwellings. | · 4 km buffers were calculated for education centres and health and care facilities |  |
|  |  | Using gravity-based measures of accessibility. | · Point of Interests (POIs): | · used the median desirable travel time/distance |  |
|  |  | · Network models are applied to identify acceptable cycling catchments as well as an Origin-Destination (O-D) cost matrix | ØEducation Centres | · uses the speed of 16 km/h which has been adopted from the Austroads network operation planning framework |  |

## A framework for assessing data sources and needs

For calculating accessibility in active transport mode, multiple data sources are required. Following a review of the relevant literature, it was discovered that various data sources such as Travel data (trips), Users data (Socio-economic and personal data), Origin- destination, Cycling and walking network, Spatial data (boundary, land use, postal code, . . . ), additional data (such as Traffic data, weather data, slope, Level of Traffic Stress, impedance value, speed ) are required in order to determine the accessibility of active transportation.

A particular kind of data management system is a data warehouse. Data warehousing is a topic that includes application tools, architectures, information services, and communication infrastructures to combine information from disparate heterogeneous operational data sources that is valuable for decision-making. This data is collected into a single repository known as a data warehouse, which may be used for direct querying and analysis, and as a source for creating logical data marts focused on particular parts of the organization (Kimball and Ross 2011). Important data for decision making is often retrieved from the organization’s data sources, processed (i.e., cleaned and homogenized), and then integrated within a sizable data repository (the data warehouse), in what is known as the ETL (extraction/transform/loading) process (Romero and Abelló 2010).Inconsistent data, incompatible data formats, data granularity, and other common problems with distributed heterogeneous information services are covered in the first phase (for instance, see (Zhuge, Garcia-Molina, and Wiener 1996)).Regarding the second step, creating the DW necessitates methodologies entirely distinct from those used for operational information systems.In this article, the approach used to design the data warehouse is based on the multidimensional paradigm.The fact/dimension dichotomy serves to distinguish the multidimensional view of data, which is characterized by its representation of data (i.e., the relevant fact) as though it were in an n-dimensional space (with as many axes as dimensions of analysis of interest). This paradigm makes it simple to comprehend and evaluate data illustrating the various angles from which a subject may be examined. As a result, the multidimensional model is appropriate for non-expert users such as knowledge workers (from here on, the data warehouse end-users).The third phase needs for the ability to leverage aggregate navigation (Gupta, Harinarayan, and Quass 1995), complex query optimization (Chaudhuri and Shim 1994), advanced indexing strategies (Lomet and Salzberg 1990), and user-friendly visual user interfaces for OLAP (On-line Analytical Processing) (Chaudhuri and Dayal 1997; Colliat 1996) and data mining (Fayyad, Piatetsky-Shapiro, and Smyth 1996).

In this study, the multidimensional data warehouse design and end-user requirements elicitation tasks are supported by a user-centered methodology. Three steps make up the process:

* First, our method begins by thoroughly examining the data sources to determine, without yet taking requirements into consideration, the multidimensional knowledge they capture (i.e., data likely to be analyzed from a multidimensional point of view).
* Second, we suggest using this knowledge to aid in the work of needs elicitation. By doing this, we are able to fully utilize the sources’ analytical skills while already balancing requirements with the data sources.
* Third, once the requirements are established, we automatically generate the data warehouse conceptual schema and the multidimensional knowledge extracted from the sources.

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Table 5, shows required data based on the each measure.

**Table 5.** Required data according to each active transportation accessibility of measure

| **Data / Methods** | **Travel Data** | **Users Data** | **Origin- destination Data** | **Cycling and walking network** | **Spatial data** | **additional data** |
| --- | --- | --- | --- | --- | --- | --- |
| Activity-based | Travel data is usually obtained from surveys and includes information about each trip such as duration, start point, end point, origin and destination. | travel behavior characteristics such as age, gender, income, can be considered if the data are available | The origin and destinations spatial data or a database of POIs that is obtained from local map. Indeed, a database of POIs consists of the location of all of the facilities such as home, workplace, parks, schools, groceries, etc. | Walking and cycling network data are required for calculating time or distances (using network analysis or nearest distance) that can be obtained from both the OpenStreetMap and the local government data portals. | spatial data of statistical areas such as blocks, mesh, zones, areas, etc. This data set includes some information such as population, number of dwellings, employment data, etc. This dataset is required for calculating accessibility in each area. | · Impedance functions are required that are usually estimated based on a negative exponential function and it is mostly based on the travel time. |
|  |  |  |  |  |  | · Slope can be considered for calculating accessibility. |
| Distance-based | —– | —– | Required to calculating the shortest distance to nearest facilities. | Required to calculating nearest distance or time to facilities using network analysis. | Required to census tracts data. |  |
| infrastructure-based | —– | —– | —– | Walking and cycling network data are required | Spatial data of essential services or origins/destinations are required. For example, grocery stores, hospitals, schools, bikeshare systems etc |  |
| Utility-based | Travel data is required. | travel behavior characteristics are required such as age, gender, etc. | —– | Walking and cycling network data are required | Spatial data of essential services |  |
| Walkability | Travel data is usually obtained from surveys and includes information about each trip such as duration, start point, end point, origin and destination. | travel behavior characteristics are required such as age, gender, income, car availability and etc. | The origin and destinations database is required | Walking and cycling network data are required | Spatial data of net residential/ Population density, Retail floor area, Intersection density, and Land use mix are required |  |
| Bikeability | Travel data is required and includes information about each trip such as duration, start point, end point, origin and destination. | - | The origin and destinations database is required . | Walking and cycling network data are required for calculating time or distances (using network analysis or nearest distance) | spatial data of statistical areas such as blocks, mesh, zones, areas, etc. is required for calculating accessibility in each area. | Impedance functions are required that are usually estimated based on a negative exponential function and it is mostly based on the travel time. |

## Data needs and sources

As previously stated, the computation of accessibility metrics requires data pertaining to six distinct categories. These data sets are essential to calculate the accessibility measures accurately. Canada boasts a plethora of data sources, ranging from national to regional and urban levels, which provide the necessary data required for the calculation of accessibility measures. One of the existing data sources that can be utilized for data needs is the household travel survey, which has been conducted in various regions throughout Canada. This survey provides access to relevant data pertaining to travel, users, and origin-destination, which are essential for calculating accessibility measures accurately. The household travel survey is a valuable resource for transportation planners, policymakers, and researchers who seek to gain a comprehensive understanding of travel behavior patterns and the factors that influence them. In a household travel survey, several variables are collected such as household levels, person level for each person in the household, and trip level for each trip made by each household member. The General Social Survey (GSS) is another data source that can be utilized at the national level to extract information on travel behavior. The GSS is a comprehensive survey that collects data on a range of topics, including transportation and travel patterns, social trends, and attitudes. The survey is conducted regularly by Statistics Canada.

The following is an overview of the categories of data that are obtained through the households travel surveys:

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Table 6, shows various data in Household travel survey.

| **household levels** | **person level** | **trip level** |
| --- | --- | --- |
| Home location | Gender | Origin location |
| Dwelling type | Age | Destination location |
| Household size (# people) | Driver’s licence | Trip departure time (start and end time) |
| Number of vehicles | Transit pass | Purpose of travel (destination activity) |
| Number of bicycles | Student status | Mode(s) of travel (up to 5) |
| Household income | School level | Number of vehicle occupants (if driver or passenger |
| Home parking (#off-street spots) | School location |  |
|  | Employment status |  |
|  | Workplace location |  |
|  | Parking at work and school(free or pay) |  |
|  | Other occupational status |  |
|  | Location of residence |  |
|  | Frequency of cycling, walking, and other active mode use |  |

### General social survey (GSS)

The General Social Survey (GSS) is a ***national*** survey conducted by Statistics Canada that collects information on the social trends and attitudes of Canadians. The survey has been conducted since 1985 and is conducted every two years, making it one of the longest-running surveys of its kind in Canada. This Survey (GSS) in Canada covers a wide range of topics related to social trends and attitudes. Some of the major topics covered by the survey include:Social well-being, Health, Education, Work, Family, Social networks, Crime and justice, and Time use. The survey is designed to provide a snapshot of social trends and attitudes in Canada, and is used by researchers, policy-makers, and the general public to gain a better understanding of the social issues facing Canadians.

The Time Use Survey is a component of the General Social Survey (GSS) that has been conducted since 1986.This survey is conducting every 5 years (1986, 1992, 1998, 2005, and 2015) and continued until 2020. However, the information related to the 2020 census has not been released yet. So, The most recent survey was released in 2015. It is designed to provide information on how Canadians allocate their time on a daily basis activities such as paid work, household chores, leisure activities, caregiving activities, and travel trips. Time Use Survey collects data on how individuals travel from one location to another during their daily activities. This includes modes of transportation such as walking, cycling, driving, and taking public transit.The survey collects information on the start and end time of each trip, the mode of transportation used, the purpose of the trip (e.g. work, shopping, leisure), and the distance traveled. In addition, This dataset contains travel time data for people in many of the Census Metropolitan Areas (CMAs) and non-CMA areas all over Canada. CMAs are including St. John’s, Halifax, Saint John, Montreal, Quebec City, Toronto, Ottawa, Hamilton, Winnipeg, Regina, Saskatoon, Calgary, Edmonton, and Vancouver. and the non-CMA areas of each of the ten provinces were also grouped to form ten more strata.The survey also collects information on the characteristics of individuals and their households such as age, sex, education, employment status, family composition, and income.

Based on the categories of data mentioned above, this database includes the following data:

* Travel data (trips) Travel data provides information about the trips, including the mode of travel, duration of travel, and trip origins and destinations. This dataset contains 301 bicycle and 4236 walking trips in 2015. Each trip contains pumID, start time, end time, duration, origin and destination.
* Users data (Socio-economic and personal data)

Demographic variables of pedestrian and cycling users including age, gender, and the number of households can be obtained from this Survey.

* Origin- destination data

In the GSS database, different travel destinations and locations are considered and each location is identified with a specific code, as follows: home or on the property, someone else’s home or property, work or school, in the neighbourhood, Outdoors, Grocery store, other stores or mall, Library, museum or theatres, Sports center, field or arena, Restaurant, bar or club, Place of worship, medical, dental or another health clinic, and Elsewhere.

### Transportation Tomorrow Survey survey (TTS)

The Transportation Tomorrow Survey (TTS) is a comprehensive survey (a series of population-based cross sectional travel surveys) that gathers information about how and where people travel. The survey aims to gather detailed information about the travel patterns of households and individuals.Since 1986, the Greater Toronto Area (GTA) has been implementing the Transportation Tomorrow Survey (TTS) program every five years, which has proven to be a highly effective means of collecting data on travel behavior. The Transportation Tomorrow Survey (TTS) are parts of an ongoing data collection program by the Transportation Information Steering Committee (TISC). The survey data (2016, 2011, 2006, 2001, 1996, 1991 and 1986) are currently under the care of the Data Management Group. This group is responsible for maintaining the TTS databases and making available appropriate travel information for any urban transportation study in the area.

In 1986, the survey covered the Greater Toronto and Hamilton Area (GTHA), which included the Municipality of Metropolitan Toronto and the Regional Municipalities of Durham, York, Peel, Halton, and Hamilton. In 1991, the survey area was expanded to include the municipalities adjacent to the GTHA boundary, known as the ‘fringe area.’ The 1996 survey included all of the GTHA, plus several additional regions, including Peterborough County, City of Peterborough, Victoria County, Town of Orangeville, Simcoe County, City of Barrie, Wellington County, City of Guelph, Waterloo Region, and Niagara Region. In 2001, the survey area changed again, with the addition of the whole of Simcoe County, the City of Orillia, and the exclusion of the Regional Municipality of Waterloo and Northumberland County. The 2006 survey area included the Regional Municipality of Waterloo, the City of Brantford, and Dufferin County, with interviews conducted in Brant County during interviewer training. The survey area in the 2011 and 2016 TTS was the same as in 2006, with the inclusion of Brant County.

TTS database includes ***Household attributes*** (such as Regional municipality of household, geocode of household, UTM X and Y coordinate of the household, Type of dwelling unit, Number of persons in the household, Day of week trip data, Number of vehicles, Number of persons possessing a driver’s licence in the household, Number of full or part time workers in the household, Number of full or part time students in the household, Number of household trips on trip day, and Household’s total income), ***Person attributes*** (such as person number within the household, age, gender, possession of a driver’s licence, possession of a transit pass, employment status of the person, person’s occupation type, student status of person, school codes (Starting from 2001), regional/Local municipality of person’s usual place of work, UTM X and Y coordinate of person’s usual place of work, geocode person’s usual place of work, number of trips made by the individual on trip day, and number of trips made by individual on trip day with primary mode being public transit), ***Trip attributes*** (such as trip number for persons in household, start time of the trip, Primary mode of the trip (public transit, bicycle and walking), purpose of the trip (home-based work (i.e. home-to-work or work-to-home), home-based-school, home-based-discretionary, non-Home-based), origin purpose of the trip, Regional municipality of trip origin, planning district of trip origin, 2001 and 2006 traffic zone of trip origin, UTM X and Y coordinate of trip origin, Method used to geocode trip origin, destination purpose of the trip (second and subsequent school trips, daycare (not in 1986), entertainment (1986 only), facilitate passenger, home, linked trip (1991 only), marketing/ Shopping (not in 1991), second and subsequent work trips, first school trip of the day, first work trip of the day and others), regional municipality of trip destination, planning district of trip destination, 2001 and 2006 traffic zone of trip destination, UTM X and Y coordinate of trip destination, method used to geocode trip destination, straight line trip length in kilometres, manhattan distance trip length in kilometres).

The information collected through the TTS provides valuable insights into travel patterns in a given region. It can help transportation planners and policymakers better understand the needs of travelers and make informed decisions about transportation infrastructure and services. By analyzing the data collected through the TTS, planners can identify trends and patterns in travel behavior, such as the most popular modes of transportation and the busiest travel times, and use this information to develop more effective transportation policies and programs.

### Autorité régionale de transport métropolitain survey (ARTM)

The Montreal OD (Origin-Destination) survey is a large-scale cross-sectional household travel survey conducted every five years since 1970 in the Montreal metropolitan area (1970, 1974, 1978, 1982,1987, 1993, 1998, 2003, 2008, 2013, and 2018). The survey covers 5% of the population residing in the Montreal metropolitan area and is conducted by the Autorité Régionale de Transport Métropolitain (ARTM).

Its purpose is to provide an accurate picture of all the trips made by residents of the region during an average weekday, for all modes of transportation used such as walking, cycling, bus, metro, train, and car. . They are descriptive surveys that provide a statistical portrait of the different characteristics of people’s trips. For each documented trip, the surveys identify the origin, destination, purpose, departure time, and all the different modes of transport used. Other socio-demographic variables are also collected. This is primarily a survey conducted through telephone interviews that aims to provide a general overview of all trips made by residents of the region, regardless of the mode of transport used. For the first time, the 2018 OD survey included a web questionnaire component.In addition, this survey cover an increasingly larger territory that spans the entire metropolitan region, from the major cities of Montreal, Laval, and Longueuil, to the north and south crowns.

The survey collects detailed information on each trip made by all individuals in ***each surveyed household*** (such as home location, size,vehicle ownership, and number of cars), **each person in the household** (age, gender,income,education level, driving license ownership, main occupation, public transit monthly pass ownership), and **each trip** made by each person of 5 years and older ( such as departure time, origin and destination locations, trip purpose, mode sequence, and others).

### Vancouver panel survey (VTS) (**https://vancouver.ca/streets-transportation/annual-transportation-survey.aspx?**)

The 2020 Vancouver Panel Survey is a longitudinal survey of households living in the city of Vancouver, British Columbia, Canada (Vancouver’s nine transportation zones). The survey is conducted annually, and its primary goal is to provide a comprehensive picture of travel behavior and trends over time, as well as the impact of policies and interventions on these trends.The primary component of this survey is a travel diary in which individuals record the details of the trips that they make on an assigned weekday. This trip data is then compared to the previous panel surveys conducted from 2018 to 2019 (2008,2011, 2013 and 2019), allowing analysis of transportation trends.

The survey collects detailed information on personal and household characteristics, including age, gender, income, education, and employment status. It also gathers information on travel behavior, including trip purpose (such as work, school, recreational/social/entertainment, home, work business trip, shopping, personal business, restaurant, drop off/pick up, and drive someone ), mode of transportation (Auto, transit,cycling, walking, and other), travel distance,start time for each of their recorded trips, travel time ,trip rates, VKT, origin-destination patterns (The daily origin and destination (O-D) patterns for Vancouver residents based on geocoded trip-end coordinates), average trip distances (Trip lengths were estimated using the distance matrix from TransLink’s Regional Transportation Model’s shortest distance assignment) and trip frequency.

One of the unique features of the survey is the collection of data on active transportation, such as walking and cycling. This data is used to evaluate the effectiveness of policies and interventions aimed at promoting sustainable transportation modes.

In addition to travel behavior and personal characteristics, the survey also collects information on attitudes and perceptions related to transportation and the built environment. This information is used to inform policies and interventions aimed at improving transportation options and promoting sustainable and healthy communities.

### Origin- Destination survey of National Capital Region ((**http://www.ncr-trans-rcn.ca/surveys/o-d-survey?**)/)

The Origin-Destination (OD) survey of National Capital Region (NCR) in Canada is a comprehensive travel survey that aims to gather detailed information on the travel behavior of residents in the region. This survey has been conducted in the years 1986, 1995, 2005 and 2011, and it is currently being conducted again in 2022.The Origin-Destination (O-D) Survey examines the “who, where, why, when, and how” of trips made by residents of the National Capital Region (NCR) resulting in extensive, up-to-date information on current daily trip patterns of area residents in rural areas, growing suburbs, mature neighbourhoods and downtown areas alike. The survey is a joint project of the TRANS Committee, made up of the National Capital Commission, the City of Ottawa, the City of Gatineau, the Ontario and Quebec Ministries of Transportation, and the transit agencies of Ottawa and Gatineau.

Total trip numbers account for the population of age 5 and older for the 2011 O-D survey and age 11 and older for the 2005 O-D survey. In addition, The survey did not capture commercial trips or trips generated outside of the National Capital Region. The survey is designed to capture all trips made by residents in the NCR, including the trip origin and destination (includes different districts in this region such as Ottawa Inner Area, Ottawa West, Merivale, Ottawa East, Alta Vista), purpose (such as home, work, school, shopping, leisure, personal and others(include visiting friends and family, health-related trips, and other), and pick up or drop off), time of travel, distance of travel, and mode of transportation. The survey covers a wide range of transportation modes, such as walking, cycling, public transit, and driving.

The survey also collects personal and household information such as age, gender, income, education, household size, driver’s licence, household vehicle availability and employment status. These variables are used to understand how travel behavior varies by demographic groups and to identify potential disparities in access to transportation.

### Origin- Destination survey of Capital Regional District (CRD) ((**https://www.crd.bc.ca/project/regional-transportation/origin-destination-household-travel?**))

The Capital Regional District (CRD) conducted a comprehensive trip diary (origin-destination, or O-D) survey. The survey profiles residents’ travel behavior. The profile will aid the CRD in its Regional Growth Strategy, the Regional Transportation Plan, and other ongoing sustainable planning initiatives. The 2017 survey updates surveys that were conducted in 2011, 2006, and 2001.

The 2017 study area of the survey consisted of all 13 incorporated municipalities in the CRD, the Juan de Fuca Electoral Area and Salt Spring Island. Most of the reporting described below covers the 13 incorporated municipalities and the Juan de Fuca Electoral Area: this area corresponds to the area that is covered by the Regional Growth Strategy and is defined as the “Regional Planning Area” (RPA). Households from Salt Spring Island were included in order to build a better picture of travel between these regions and the RPA, and of the travel patterns of Salt Spring Island residents. The Southern Gulf Islands and the CVRD were not included.

Demographic variables

The demographics of the RPA’s residents are important indicators of travel. The key factors are population (trips are made by people), households (members of households coordinate their trips includes households size, age, employment, type of dwelling ) and the vehicle available to each household.

Travel variables

The survey collects information on trip origins and destinations, travel modes used, trip purposes (such as Work / work-related, Post-secondary school , School, Personal business , Recreation / social , Dining / restaurant, Shopping, Pick-up / drop-off passengers, home, and others), and the time of day that trips are taken

### Origin- Destination survey of Nanaimo City

The City of Nanaimo recently initiated the Nanaimo Transportation Master Plan (NTMP) process. In preparation for the development of the NTMP, the City undertook a Pre-Plan Consultation Process in 2011, which included open houses and surveys to identify key themes and priorities to be considered during the development of the NTMP.

The Origin-Destination (OD) survey of Nanaimo City collects data on daily travel patterns of residents and visitors in the city. The survey covers a wide range of travel-related information, including the purpose of the trip (Commute, Exercise, Recreation, Shopping/Errands and others), mode of transportation, trip distance, trip duration, and demographics of the travelers.

The survey provides detailed information on the different modes of transportation used by travelers, including driving, walking, cycling, and public transit. It also documents the frequency and duration of each mode of transportation, as well as the distance traveled.

In addition to travel-related data, the survey also collects information on demographic factors such as age, gender, education level, income, and employment status. This data provides insights into how different groups of people travel within the city and helps identify any disparities in transportation access and mobility.

### Edmonton and Region Household Travel Survey (ERHTS)(**https://www.edmonton.ca/transportation/traffic\_reports/travel-pattern-analysis?**)

The Edmonton and Region Household Travel Survey (ERHTS) is a comprehensive travel survey conducted in the Edmonton Metropolitan Region, Alberta, Canada in 1994, 2005 and 2015.The ERHTS was conducted using a combination of online and paper-based surveys, with participants randomly selected from over 46,000 residential addresses in the Edmonton region.the report describes the weekday travel patterns of residents of the Edmonton Capital Region and travel between the Region and the City of Edmonton The survey collected data on travel behavior over a 24-hour weekday period, with participants being asked to report all trips taken, including their purpose, mode of transportation, and time of travel.

The survey aims to collect data on travel behavior patterns of households residing in the region, and demographic characteristics of the population.The travel variables collected in the survey include the number of trips made, trip duration, distance traveled (The length of trips taken is an indicator of the spatial characteristics of travel and the extent to which people are willing to or forced to travel to complete activities), mode of transportation (car driver, car passenger, walk, transit,school bus, bicycle, and other), travel purpose (such as Work, Post-Secondary, School, Shopping, Social / Recreation, Personal Business, Pick up/Drop off, and other), and travel time. Personal variables collected include age, gender, education level, employment status, and household income. In addition to travel and personal variables, the survey also collected information on household characteristics, including the number of household members, number of vehicles owned, and housing type.

The survey found that the most common mode of transportation for all trip purposes was driving, with 78% of all trips being made by private vehicle. Walking was the second most common mode of transportation, accounting for 10% of all trips. Public transportation was used for only 6% of all trips, and cycling for 3% of all trips. The survey also found that the average trip distance was 8.7 km, and the average travel time was 29 minutes.

### Calgary and Region Travel and Activity Survey (CARTAS) (**https://www.calgary.ca/planning/transportation/surveys.html?redirect?**, =/travelsurveys)

the Calgary and Region Travel and Activity Survey (CARTAS) conducted in 2012. Household travel surveys have been conducted approximately every 10 years since 1964 and provide key information to decision makers on how travel behavior and influences are changing over time. The CARTAS study area includes The City of Calgary, the Municipal District of Foothills, Rockyview County, Wheatland County, and all the towns and villages within those boundaries including: Airdrie, Chestermere, Cochrane, High River, Okotoks, Nanton, and Strathmore. The primary purpose for the survey is to collect information to update the Regional Transportation Model (RTM), but these surveys offer a unique insight in the characteristics of travel in Calgary and the surrounding region.

The travel data collected in the survey include information on the frequency of travel, the length of trips, and the types of transportation used, such as walking, cycling, public transit, and private vehicles. The survey also collected information on the number of people traveling together, the trip purpose, and the time of day the trip was made.

The personal variables collected in the survey include demographic information, such as age, gender, income, education level, and employment status. The survey also collected information on household characteristics, such as the number of people living in the household, the number of vehicles owned by the household, and the availability of alternative modes of transportation, such as bicycles and public transit.

The survey data were used to analyze travel patterns and trends, assess transportation infrastructure needs, and evaluate the effectiveness of transportation policies and programs. The data have been made available to the public and can be used by researchers, policymakers, and other stakeholders to inform decision-making and planning related to transportation and urban development in Calgary and the surrounding areas.

### City of Saskatoon Household Travel Survey

The 2013 Saskatoon Travel Survey is a comprehensive study of travel behavior in the city of Saskatoon, Canada. The survey was conducted in order to gather information about residents’ travel habits, including mode choice, trip purposes, and travel times.

The survey collected data from households within the city limits of Saskatoon through telephone interviews, asking questions about each individual’s travel on a typical weekday and weekend day. In addition to travel data, personal characteristics such as age, gender, employment status, and household size were also collected.

The travel data collected in the survey includes trip purpose, mode of transportation, origin and destination, time of travel, and travel distance. The survey also collected data on the frequency of travel, such as the number of trips taken by each individual in a week, and the types of destinations visited.

The survey also included a mode choice analysis to better understand the factors that influence people’s travel choices, such as personal characteristics and trip characteristics.

The data collected from the survey has been used to inform transportation planning and policy in Saskatoon, as well as to better understand the travel behavior of residents in the city. The information has been used to identify areas where improvements to the transportation system could be made, such as increasing transit service or building new cycling infrastructure.

### Okanagan Travel Survey (OTS)

The City of Kelowna, City of Vernon, Regional District of Central Okanagan, West Kelowna, Lake Country, Peachland, and Westbank First Nation, along with the BC Ministry of Transportation and Infrastructure, have collaborated to conduct the Okanagan Travel Survey (OTS). The smartTRIPS program, which is a part of the Sustainable Transportation Partnership of the Central Okanagan (STPCO), supported the survey’s execution. The OTS employs a methodology that involves conducting a household travel survey every five years in the Central Okanagan and City of Vernon region. This type of survey gathers information on the daily travel patterns of each household member who is five years of age or older, based on their travel on the previous day. This survey was conducted in 2007, 2013 and 2018. Like the objectives of the previous Okanagan Travel Surveys conducted in 2007 and 2013, the data collected through the 2018 OTS creates a repository of the travel habits of residents. This data can serve as a foundation for developing policies and transportation plans in the Central Okanagan and The City of Vernon. Additionally, the 2018 OTS contributes to the larger aim of tracking regional travel trends and establishing a regional transportation demand model for the area.

The Okanagan Travel Survey conducted in 2018 recorded the journeys taken by individuals within a specific region during a regular working day that lasted 24 hours. The survey measured the number of person-trips made for different reasons from one location to another. These trips were taken at a specific time of day and made using any of the five available modes of transportation.

The 2018 survey was a household-based survey that collected demographic information on all household members and travel characteristics. data is as follow:

* household data includes address, dwelling type, number of householders, number of vehicles available to householders, number of working bicycles available to householders, household Income.
* Person level data for each person in the household includes gender, age, driver’s license, student status, school level, employed, employment status, workplace location, and type of occupation.
* Trip level data for each trip made by each household includes origin (Geocode origin XY coordinates), destination (Geocode destination XY coordinates), trip departure time, trip arrival time, trip purpose (or activity at destination location such as travel to Work, post-Secondary School, school, restaurant, recreation (gym, swimming, etc.), social outing / meet friends, shopping, personal business, pick up and drop off a passenger, home and others ), mode of travel (such as auto driver, auto passenger, public transit, school bus, bicycle, walked, motorcycle or moped/scooter), transit route(s), number of vehicle occupants, vehicle availability for trip (if not by automobile and household has vehicles), and additional information about trip (open-ended response).

### Winnipeg Area Travel Survey (WATS)

the Winnipeg Area Travel Survey (WATS)is a travel ‘origin-destination’ survey that was conducted in autumn 2007. The survey covered the entire City of Winnipeg and all of the surrounding area within a 100-km radius of downtown Winnipeg. The 2007 WATS is the first all household based trip survey ever done in Winnipeg. In combination with traffic counts, on-board transit ridership counts and demographic and employment data from the Census of Canada and other sources, the 2007 survey provides both a reliable profile of current conditions and a means to measure trends in local travel.

Typical of origin-destination surveys, there are three categories: household data, person data and trip data. As noted, trip data were collected only for household members 11 years of age and older.The 2007 survey was a travel survey that collected demographic information on all household members and travel characteristics. dataset is as follow:

Household data consists of location, household size, number of vehicles, type of dwelling, and household income.

person data includes age, gender, driver’s license, occupation status (worker, student, retiree, etc.), usual place of work or school, long-term physical disability, labour force status, hours of work and education.

Trip data includes origin, destinations, purpose of travel(such as work, work-related, school, shopping, social / recreational, restaurant, medical / dental visit, drive someone somewhere / go pick someone up, return home), mode(s) of travel (such as car driver, car passenger, Winnipeg Transit, intercity bus, other transit, private transportation service, school bus, water taxi3 / ferry, taxi, handi-Transit, bicycle, walk, and motorcycle / moped), departure time, arrival time, If transit: use of park and ride lot, line(s) used, transfer point(s).

### The London Household Travel Survey

In 2016, the London Household Travel Survey was carried out to offer an in-depth understanding of the travel patterns of individuals residing in the City of London and the nearby Census Metropolitan Area. Vital data concerning travel making, preferences, and attitudes was collected during the survey to support the development of infrastructure and services for road users, public transport passengers, cyclists, and pedestrians. Earlier editions of this survey were conducted in 1987, 2002, and 2009. This Survey collected data on various variables related to households, persons, and trips.

For households, the survey collected data on location of residence, the number of people living in the household, driver’s license, their age and gender, their employment status, and their income. It also gathered data on the type of dwelling, such as whether it was a single-family home or an apartment, and the availability of cars and bikes in the household.

For persons, the survey collected data on their age, gender, and employment status, as well as their level of education and income. It also asked about their travel behavior, such as how often they traveled, what modes of transportation they used, and their travel purposes.

For trip data, the survey collected data on location of origin and destination for each trip, the purpose of the trip (work, post-secondary school, school, shopping/recreational, other discretionary), the mode of transportation used (such as auto driver, auto passenger, transit, walk/cycle and others), the time of day, the distance traveled, and the duration of the trip. It also gathered information on the origins and destinations of the trips, such as the home address and the location of the destination.

### Kingston Household Travel Survey

The 2019 Kingston Household Travel Survey (KHTS) was undertaken with a random sample of households in the City of Kingston. Previous household travel surveys of Kingston residents were conducted in 2002 and 2008. The 2019 survey builds on the legacy of the previous surveys while expanding the depth of the data collected and providing more detailed reporting on travel patterns captured by the survey. The survey gathered information on household and demographic characteristics relevant to understanding travel patterns. It also captured detailed trip information for residents aged 5+ years, providing a snapshot of the 24-hour travel patterns over the course of a typical fall weekday.

The objectives of the survey were to gather information to assist the City of Kingston in transportation planning and to promote the use of sustainable modes of transportation, such as walking, cycling, and public transit. The survey aimed to identify travel patterns and behavior and to identify opportunities to reduce the reliance on single-occupancy vehicles.

This survey collected information on various aspects of travel and socio-demographic characteristics, such as:

* Household data consists of age, gender, income, student number in a household, type of dwellings, access to car, access to bicycle,transit Passes and employment status.
* Trip data includes frequency and purpose of trips (such as usual work, work related, post-secondary school, attend K-12 school, shopping, personal business, restaurant, recreation, social, serve passenger, return home, and other), modes of transportation used (such as auto Driver, auto Passenger, Kingston transit, School Bus, Walk, Bicycle, and others), trip distances, and travel times.

### North Shore Transportation Survey

The North Shore Transportation Survey (NSTS) 2019 is a biennial survey of residents of the North Shore that tracks key transportation metrics associated with residents’ travel patterns. The survey is an initiative of the City of North Vancouver (CNV), District of North Vancouver (DNV), and District of West Vancouver (DWV). This Survey collected data on various variables related to households, persons, and trips are as follows:

* Participant Characteristics: describes the characteristics of North Shore residents and their households, as captured by the survey, including age, gender, household, employment, health status, occupation, bike access, and vehicle access characteristics. The purpose of capturing these characteristics is to better understand travellers’ needs, challenges, and patterns. The results are based on the survey sample with selected information from the 2016 census.
* Daily trip characteristics: provides a snapshot of daily (24-hour) travel patterns from the trips reported by survey participants and includes location, trip demand, purpose (such as usual work, work related, school, personal business, restaurant, recreation, social, serve passenger, return home and others ), mode share (Auto Driver, Auto Passenger, Transit, Walk, bicycle, and others), and distribution (include the trip origin and destinations).

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Table 7, available data in different households travel surveys.

| Survey | Year of Survey | Household Data | Person Data | Trip Data |
| --- | --- | --- | --- | --- |
| General social survey (GSS) | 1986 | Dwelling type | Gender | Mode(s) of travel |
|  | 1992 | Household size | Age | Purpose of travel |
|  | 1998 | Household income | Student status | Start Time |
|  | 2005 |  | School level | End Time |
|  | 2015 |  | Employment status |  |
| Transportation Tomorrow Survey survey (TTS) | 1991 | Regional municipality of household | person number within the household | trip number for persons in household |
|  | 1996 | geocode of household | Age | start time |
|  | 2001 | Type of dwelling unit | Gender | End Time |
|  | 2006 | Number of persons in the household | Transit pass | Mode of the trip |
|  | 2011 | Number of vehicles | employment status of the person | Purpose of the trip |
|  | 2016 | driver’s licence in the household | person’s occupation type | Geocode of origins and destinations |
|  |  | Household’s total income | student status of person |  |
|  |  |  | school codes |  |
| Autorité régionale de transport métropolitain survey (ARTM) | 1970 | home location | Age | Origins location |
|  | 1974 | size of household | Gender | Destination location |
|  | 1978 | vehicle ownership | Income | Trip purpose |
|  | 1982 | number of cars in households | Education level | Mode of transportation |
|  | 1987 |  | Driving license ownership | Start time |
|  | 1993 |  | Main occupation | End time |
|  | 1998 |  | Public transit monthly pass ownership |  |
|  | 2003 |  |  |  |
|  | 2008 |  |  |  |
|  | 2013 |  |  |  |
|  | 2018 |  |  |  |
| Vancouver panel survey (VTS) | 2008 | Home location | age | trip purpose |
|  | 2011 | Size of household | gender | mode of transportation |
|  | 2013 | vehicle ownership | income | travel distance |
|  | 2019 |  | education | Start Time |
|  |  |  | employment | End time |
|  |  |  |  | geocoded origin and destination |
|  |  |  |  | trip frequency |
| Origin- Destination survey of National Capital Region | 1986 | Size of household | age | Trip origion and destination |
|  | 1995 | household vehicle availability | gender | purpose of trip |
|  | 2005 | vehicle ownership | Income | Time of travel |
|  | 2011 |  | Education | mode of transportation |
|  |  |  | driver’s licence |  |
|  |  |  | employment status |  |
| Origin- Destination survey of Capital Regional District (CRD) | 2001 | Households size | age | trip origins and destinations |
|  | 2006 | type of dwelling | Gender | travel modes |
|  | 2011 | vehicle available to each household | employment | trip purposes |
|  | 2016 |  |  | Start time |
|  |  |  |  | End Time |
| Origin- Destination survey of Nanaimo City | 2011 | Household size | age | purpose of the trip |
|  |  | Type of Dwelling | gender | mode of transportation |
|  |  | Number of vehicle | education level | trip distance |
|  |  |  | income | trip duration |
|  |  |  | employment status |  |
| Edmonton and Region Household Travel Survey (ERHTS) | 1994 | household income | age | number of trips |
|  | 2005 | number of household members | gender | trip duration |
|  | 2015 | Type of dwelling | education level | distance traveled |
|  |  | Number of vehicle | employment status | mode of transportation |
|  |  |  |  | travel purpose |
|  |  |  |  | travel time |
| Calgary and Region Travel and Activity Survey (CARTAS) | 2012 | number of people in the household | age | frequency of travel |
|  |  | number of vehicles | gender | length of trips |
|  |  | Household income | income | Mode of transportation |
|  |  | Number of vehicle | education level | trip purpose |
|  |  |  | employment status | Start time |
|  |  |  |  | End time |
| City of Saskatoon Household Travel Survey | 2013 | household size | age | trip purpose |
|  |  | Household income | gender | mode of transportation |
|  |  | Number of vehicle | employment status | origin and destination |
|  |  |  |  | time of travel |
|  |  |  |  | travel distance |
| Okanagan Travel Survey (OTS) | 2007 | Location | gender | Geocode origin and destination coordinates |
|  | 2013 | dwelling type | age | Trip departure time |
|  | 2018 | number of householdes | driver’s license | trip arrival time |
|  |  | number of vehicle | student status | trip purpose |
|  |  | number of bicycle | school level | mode of travel |
|  |  | household Income | employment level |  |
|  |  |  | workplace location |  |
|  |  |  | type of occupation |  |
| Winnipeg Area Travel Survey (WATS) | 2007 | household size | age | origin and destinations |
|  |  | number of vehicles | Gender | purpose of travel |
|  |  | type of dwelling | driver’s license | mode(s) of travel |
|  |  | household income | occupation status | departure time |
|  |  |  | usual place of work or school | arrival time |
|  |  |  | labor force status |  |
| The London Household Travel Survey | 1987 | location of residence | driver’s license |  |
|  | 2002 | number of people living in the household | age | modes of transportation |
|  | 2009 | type of dwelling | gender | travel purposes |
|  | 2016 | availability of cars | employment status | Start time |
|  |  | availability of bicycle | Income | End time |
|  |  |  |  | location of origin and destination |
|  |  |  |  | distance traveled |
| Kingston Household Travel Survey | 2002 | type of dwellings | age | frequency of trip |
|  | 2008 | student number in a household | gender | purpose of trips |
|  | 2019 | access to car | income | modes of transportation |
|  |  | access to bicycle | employment status | trip distances |
|  |  | transit Passes |  | travel times |
| North Shore Transportation Survey (NSTS) | 2019 | household employment | age | location of origin and destination |
|  |  | health status | gender | trip demand |
|  |  |  | occupation | purpose of travel |
|  |  |  | bike access | mode of travel |
|  |  |  | vehicle access | origin and destination |

### The Linkable Open Data Environment (LOD)

the Linkable Open Data Environment (LODE) is an exploratory initiative that aims at enhancing the use and harmonization of open microdata primarily from municipal, provincial and federal sources. It has been compiled by the Centre for Special Business Projects (CSBP) at Statistics Canada in 2020.

This database includes variables such as address, postal code, city, province and latitude and longitude of each facility and includes a Canada-wide Open Database of educational facilities (this database covers facilities such as ***early childhood education, kindergarten, elementary, secondary, and post-secondary institutions***, and ***specific vocational training centers***. The database does not include virtual educational institutions.), healthcare facilities (including ambulatory health care services, hospitals, and nursing and residential care facilities), cultural and art facilities (such as arts or cultural centers, artists, festival sites, galleries, heritage or historic site, library or archive, museum, theatre/performance and concert hall, and miscellaneous), and recreational and sports facilities (including trails(such as urban and rural trails or pathways for walking, hiking, or biking), sports fields, arenas (facilities where sports and/or recreational activities take place), athletic parks, beaches, casinos, community centers, gyms, marinas, parks and green spaces, playgrounds, pools, race tracks, ice rinks, skate parks, splash pads, stadiums, miscellaneous), and Businesses (this database contains addresses of business, name, type of business and locations).

* The Open Database of Buildings ((**https://www.statcan.gc.ca/en/lode/databases/odb?**))

The inputs for the ODB are datasets provided by municipal, regional or provincial sources available to the general public through open government portals under various types of open data licenses. The current version of the database (version 2.0) contains approximately 4.4 million records and includes provinces and territories where open building footprints were found during the collection period.Within the original datasets, each data provider attached a different set of variables to their building footprints.The variables included in the ODB are as follows:Latitude,Longitude,Area,Perimeter, Data provider, Census subdivision unique identifier, Census subdivision, name, Unique building ID

* The Open Database of Educational Facilities ((**https://www.statcan.gc.ca/en/lode/databases/odef?**))

The Open Database of Educational Facilities (ODEF) is a collection of open data containing the names, types, and locations of education facilities across Canada, and is made available under the Open Government Licence - Canada.The inputs for the ODEF are primarily datasets provided by municipal, regional or provincial sources available to the general public through open government portals under various types of open data licences, or otherwise published on their webpages and released under an open licence with their permission.The variables included in the ODEF are as follows: Facility Name, Facility Type, Authority Name, International Standard Classification of Education (ISCED) ,Level, Official Language Minority School Status, Address, Unit, Street Number, Street Name, Municipality Name, Province, Postal Code, Province Unique Identifier, Census Subdivision Name, Census Subdivision Unique Identifier, Census Metropolitan Area Name, Census Metropolitan Area Unique Identifier, Longitude, Latitude, Geocoding Source, Source ID, Unique ID.

* The Open Database of Healthcare Facilities ((**https://www.statcan.gc.ca/en/lode/databases/odhf?**))

The inputs for the ODHF are datasets whose sources include regional health authorities, provincial, territorial and municipal governments, and public healthcare and professional healthcare bodies. These datasets were available either under one of the various types of open data licences, e.g., in an open government portal, or as publicly available data. In certain cases, data were obtained directly from administrative sources. Details of the sources used are available in the ODHF metadata. This dataset includes ambulatory health care services, hospitals, and nursing and residential care facilities.The variables included in the ODHF are as follows: Index, Facility Name, Source Facility, Type, ODHF Facility Type, Provider, Unit, Street Number, Street Name, Postal Code, City, Province or Territory , Source-Format Street Address, Census Subdivision Name, Census Subdivision Unique Identifier, Province or Territory Unique Identifier, , Latitude ,Longitude.

* The Open Database of Cultural and Art Facilities ((**https://www.statcan.gc.ca/en/lode/databases/odcaf?**))

The Open Database of Cultural and Art Facilities (ODCAF) is a collection of open data containing the names, types, and locations of cultural and art facilities across Canada.This dataset includes arts or cultural centers, artists, festival sites, galleries, heritage or historic site, library or archive, museum, theatre/performance and concert hall, and miscellaneous.

* The Open Database of Recreational and Sport Facilities ((**https://www.statcan.gc.ca/en/lode/databases/odrsf?**))

The Open Database of Recreational and Sport Facilities (ODRSF) is a collection of open data containing the names, types, and locations of recreational and sport facilities across Canada. recreational and sports facilities includes trails(such as urban and rural trails or pathways for walking, hiking, or biking), sports fields, arenas (facilities where sports and/or recreational activities take place), athletic parks, beaches, casinos, community centers, gyms, marinas, parks and green spaces, playgrounds, pools, race tracks, ice rinks, skate parks, splash pads, stadiums, miscellaneous).

* The Open Database of Businesses

The Open Database of Businesses contains addresses of business name and locations. It also includes information on the type of business and legal nature of business, when supplied by the data providers.

* The Open Database of Infrastructures

The Open Database of Infrastructure contains the name and location of major transport and physical infrastructures such as airports, railway stations, bridges and elevated roads, etc. Infrastructures are classified by type. Records are compiled from both open sources and from publicly available data (with permission from the data owners).

**Cycling and walking networks**

Cycling and walking networks can be obtained from different sources such as Can-BICS, open street map (OSM), and municipal open data.

Can-BICS is a classification system of five broad bicycle facilities assigned to three categories: high, medium, and low comfort, based on the facility’s contribution to user safety and comfort while cycling. 1) High comfort includes low-stress routes that are comfortable for most people, including those of all ages and abilities, with a record for best safety. for example, cycle track, local street bikeway, and bike path. 2) medium comfort is low- or medium-stress routes that are comfortable for some people, but whose safety requires careful design, such as multi-use paths (A two-way paved path shared by cyclists, pedestrians and other users). 3) low comfort bikeways are high-stress routes that are comfortable for few people, with little or no additional safety, compared to no bicycle facility, such as painted bike lanes that are designated by bicycle and diamond pavement markings and signs as exclusively for cyclists. And 4) non-conforming bicycle facilities do not meet minimum Can-BICS standards, such as non-conforming - trail (these are multi-use trails with unpaved surface), non-conforming – major road (shared lanes on major roads provide connectivity), and non-conforming - other.

Can-BICS measured bicycle infrastructure for all communities in Canada, at the neighborhood level, using open data sources such as OpenStreetMap (OSM). Another source for obtaining cycling and walking networks is OpenStreetMap (OSM). This dataset is a collaborative global map that using for active transportation researches. OSM considered cycle lanes, tracks and sidewalks. A cycle lane lies within the roadway itself (on-road), whereas a cycle track is separate from the road (off-road). Tracks are typically separated from the road by e.g. curbs, parking lots, grass verges, trees, etc. as well, trails line that indicates the paths or routes suitable for walking, hiking, bicycling, and other outdoor activities from 2015 to 2019 can be obtained from scholars Geoportal.

As well, municipal open data is a standard source of bicycling infrastructure data that city governments are making this spatial data for bicycling infrastructure. In Canada, some cities have this dataset such as Toronto, Montreal, Vancouver, etc. However, open data of different cities use different definitions for bicycling infrastructure, and they may have different levels of timeliness, completeness, and documentation (Schoner and Levinson 2014). For example, bicycle facilities the City of Toronto Open Data portal consists of a high-resolution geospatial data set with attributes accumulated from several sources of cycle tracks or bike lanes, road classification (local, collector, minor arterial, etc.), number of lanes, directions, stop signs and signalized intersections. (City of Toronto, 2017).

**Spatial data (boundary, land use, postal code, etc)**

Spatial data such as boundary, land use, postal code, origin and destinations and etc can be obtained from scholars Geoportal and open street map (OMP).

scholars Geoportal has different shape file layers such as Land Cover Region (including seven land use categories: commercial; government and institutional; open area; parks and recreational; residential; resource and industrial; or waterbody in 2019), education Point (includes the point locations of elementary schools, high schools, colleges, cégeps and universities in 2020.There is also additional information about teaching languages and grade levels), enhanced Points of Interest (EPOI) in 2019, which indicates the locations of business and recreational points of interest across Canada in 2020, Healthcare (HCR) that contains the location of hospitals, long-term care facilities, outpatient clinics, nursing stations, and community health centres in 2020, Tourist Attractions Point that indicates the point locations for various tourist sites (such as National, Provincial, and Municipal parks, Art Galleries, Historic Sites, Museums, Science Centres, Tourist Information Booths, and Zoos) in 2020, Park sports field point in 2019 across Canada, Cinemas Point, Religious Buildings Point, Retail Point that indicates the locations shopping centers and department stores in 2020, and accommodations Point such as hotels, motels, campgrounds, inns, hostels, resorts, etc., in Canada.

In Table 6, each database was examined based on seven data categories.

**Table 8.** Availability of datasets

| Dataset | Travel Data | Users Data | Origin-Destination Data | Cycling and Walking data | Spatial data | additional data |
| --- | --- | --- | --- | --- | --- | --- |
| General social survey (GSS) | Y | Y | Y | - | - | - |
| [Transportation Tomorrow Survey (TTS) of Toronto](http://dmg.utoronto.ca/transportation-tomorrow-survey/tts-introduction) | Y | Y | Y | Y | Y | Y |
| [Autorité régionale de transport métropolitain (ARTM) survey of Montreal](https://donnees.artm.quebec/depots) | Y | Y | Y | Y | Y | Y |
| [The Linkable Open Data Environment (LODE)](https://www.statcan.gc.ca/en/lode/databases) | - | - | Y | - | - | - |
| [Can-BICS](https://www.arcgis.com/home/item.html?id=6a15224d9ea347c9898c112f974c47a2) | - | - | - | Y | - | Stress Level |
| [open street map](https://www.openstreetmap.org/#map=3/71.34/-96.82) | - | - | - | Y | Y | - |
| [Toronto open data](https://open.toronto.ca/catalogue/) | - | - | - | Y | - | - |
| [Vancouver open data](https://vancouver.ca/streets-transportation/walk-bike-and-transit.aspx) | - | - | - | Y | - | - |
| [Montreal open data](https://montreal.ca/en/articles/open-data-window-municipal-arena-32256) | - | - | - | Y | - | - |

## Important considerations and possible challenges

**Travel time/distance thresholds**

Selecting an appropriate cut-off distance for travel has been acknowledged as an important step that has the potential to significantly impact results. Different distance thresholds should apply to both cycling and walking, however, there remains considerable variation among the threshold values applied within each mode.

Some analyses choose to vary thresholds according to the destination type, or by population group. For example, Saghapour (2017) use a 10-minute travel time for retail and recreation centres and a 20-minute travel time for cycling to community services(Saghapour, Moridpour, and Thompson 2017). Applying the same threshold to all age groups also disregards the fact that certain groups (for example, seniors and children) may travel slower or require greater effort to travel the same distance. Although applicable to both cycling and walking, this distinction by age group has only been applied among walking measures. In the following, Tables 7 shows the thresholds of bicycle and walking travel time and distance in different studies.

**Table 9.** Thresholds of bicycle and walking travel time and distance

| **Distance/Time thresholds** |  |
| --- | --- |
| **walking trips** |  |
| Neilson and Fowler (1972), O’Neill, Ramsey et al. (1992), Hsiao, Lu et al. (1997), Murray and Wu (2003), Zhao, Chow et al. (2003), Kimpel, Dueker et al. (2007), Gutiérrez and García-Palomares (2008) | The most common standard measure of walking distance to transit stops and stations has been 400 m (0.25 miles). |
| Lam and Morrall (1982) | In Calgary, Canada, observed a median walking distance to bus stops of 292 m, while the average was 327 m and the 75th percentile, 450 m. |
| O’Sullivan and Morrall (1996) | distinguished between walking to light-rail transit stations in the suburbs and in the central business district. They found an average distance of 649 m and a 75th percentile equal to 840 m in the former, while the average distance was 326 metres and the 75th percentile was 419 metres in the latter (Calgary, Canada) |
| Arasan, Rengaraju et al. (1996) | an average critical trip time is 20 min for walking. |
| Nicholls (2001), Smoyer?Tomic, Hewko et al. (2004) | used a distance of 0.8 km as a reasonable threshold for walking trips (the threshold is not specific to a population group) |
| Zhao, Chow et al. (2003) | in southeast Florida, the number of riders walking over half a mile (800m) was negligible. |
| Van Herzele and Wiedemann (2003) | Maximum distance from home to: 1) Residential green (150 m); Neighborhood green (400 m); Quarter green (800 m); District green (1600 m); City green (3200 m); Urban forest (5000 m) |
| Tsou, Hung et al. (2005) | Defined varying distances that depended on the type of facility: |
|  | · the service range of municipal facilities such as town parks, universities, museums and dump sites cover the entire city. |
|  | · community facilities, including junior and senior high schools, transformer stations, etc., are typically in the 2 km range. |
|  | · The service range of neighborhood facilities like playgrounds and elementary schools is typically in the 1 km range. |
| Schlossberg, Agrawal et al. (2007) | walking distances to rail transit stations in Portland, WA, and San Francisco, were a median distance of 0.47 miles (756 m) |
| Alshalalfah and Shalaby (2007) | showed that among transit users, 60 % live within 300 m from their stop and 80 % within 500 m in Canada. |
| Larsen and Gilliland (2008) | Population within 500 m walk distance of supermarkets |
| Manaugh and El-Geneidy (2011) | used 400, 800 and 1200 m thresholds for calculating walkability score |
| Daniels and Mulley (2013) | the mean walking distance to bus service 461 m with 75th percentile at 566 m. |
|  | In the same study they found mean walking to rail around 805 m and the 75th percentile at 1,018 m. |
|  | Also, it is clear that these distances are significantly beyond the 400 m for buses and 800 for rail. |
| El-Geneidy, Grimsrud et al. (2014) | The 85th percentile walking distance to bus transit service is found to be around 524 m for home-based trip origins, 1,259 m for home-based commuter rail trip origins. |
| Azmi, Karim et al. (2013) | considered radius of 400 meter (approximately 5 minute of walking) in the neighborhood area. |
| Saghapour (2017) | considered 20-30 mins or 1.6 – 2.4 km (Based on POI type) |
| van Soest, Tight et al. (2020) | 400 or 800 m thresholds for walking to public transport |
| Adhikari, Delgado-Ron et al. (2021) | 10–15 min of walking time, a commonly used time frame to assess perceived proximity to amenities and services |
| Cycling trips |  |
| Arasan, Rengaraju et al. (1996) | found an average critical trip time of 24 min for bicycling. |
| Seneviratne (1985), Arasan, Rengaraju et al. (1994), Rastogi and Krishna Rao (2003) | proposed an average critical distance of 1100 m across the categories of trip type, and 1050 m and 750 m respectively for the categories of male and female. |
| Houde, Apparicio et al. (2018) | access to the cycling network within a 500-metre radius and the access to a cyclist-only bike path within a 500-metre radius from the centroid of the census tract. |
| McNeil (2011) | the average cyclist would be willing to travel between 1 mi and 2.5 mi for most utilitarian nonwork trips |
| Saghapour (2017) | Considered 10-20 mins or 2.5 - 4km (Based on POI type) |
| Tucker and Manaugh (2017) | A cut-off length of 7 km was used. |
| Manum, Nordstrom et al. (2019) | a travel-time threshold of 15 minutes in one direction is a reasonable value for calculating the catchment area. (bicycling speeds vary) |
| Faghih Imani, Miller et al. (2019) | calculated the 30-minute cycling thresholds to accessibility to jobs |
| Li, Huang et al. (2020) | consider the trips whose trip distance and duration are between the 1st (301m and 180 s) |
| Chen and Wang (2020) | five thresholds (10-, 20-, 30-, 45-, and 60-minute) by cycling. |
| Mora, Truffello et al. (2021) | Access to bicycle lanes from the blocks was modeled in consideration of three critical distances: 300 m, and 500 m or 1000 m (Average minimum distance to bicycle lane) |

**Impedance functions**

Impedance function is used to describe willingness of cyclists and pedestrian to travel to a destination as a function of cost (distance, time, etc.); it is a component of accessibility (Iacono, Krizek, and El-Geneidy 2010; Yang and Diez-Roux 2012; Arranz-López et al. 2019). The impedance function obtained by fitting to a real dataset provides a continuous description of cycling and walking probability at different costs. The spatial distribution of bicycle and pedestrian travel can be expressed using distance decay functions (Iacono, Krizek, and El-Geneidy 2010) as travel distance is a limiting factor for implementing use(Larsen and El-Geneidy 2011). Distance decay functions describe the effect of distance on spatial interactions and typically express distance as a function of travel impedance (time or cost). Rybarczyk and Wu (2010) identified the importance of the spatial patterns of bicycle facilities and connectivity of a local network when studying accessibility. Furthermore, increased connectivity within a network also allows for increased accessibility(Rybarczyk and Wu 2010).

Some researchers have argued that – like maximum travel thresholds – distance-decay rates should differ according to trip purpose and different population groups (Garcı́a-Palomares, Gutiérrez, and Cardozo 2013; X. Wu et al. 2019). Similarly, researchers also argue that walking and cycling impedance functions should be calculated separately due to their differing travel speeds and maximum travel ranges (Cheng et al. 2019). For example, the distance-decay curve for work trips shown in Figure 1 assumes that cyclists are half as likely to reach a work destination 20 minutes away than one 10 minutes away, and therefore, any jobs 20 minutes away would be applied half the weight of jobs 10 minutes away. These cycling weights differ slightly from walking trips since fewer people are willing to walk a longer distance to work. While adjusting the distance-decay functions by mode has the potential to improve accuracy, it can also be said that a consistent approach to measuring accessibility across modes is preferable due to the possibility of causing one mode seem less accessible when applying different decay functions (State Smart Transportation Initiative, 2021).

In terms of the types of impedance functions considered, a negative exponential curve is common (Saghapour, Moridpour, and Thompson (2017); X. Wu et al. (2019)] – example shown in Figure 1. However, some studies have also calculated study-specific distance-decay curves based on trip data rather than assuming a standard function. Wu, Lu et al. (2019) calculated a distance-decay function using data from Shenzhen’s dockless bicycle-sharing system. Their findings show that a lognormal distance decay best fit the distribution of bike-sharing trips, with the willingness to cycle increasing up to ~500m and decreasing thereafter. García-Palomares, Gutiérrez et al. (2013) took a similar approach for measuring walking accessibility to metro stations and found a linear distance-decay trend that varied significantly by age (Garcı́a-Palomares, Gutiérrez, and Cardozo 2013; X. Wu et al. 2019).

|  |
| --- |
| Figure 1: Example travel time decay functions by mode for work vs. non-work trips. (Source: State Smart Transportation Initiative - based on data from 2017 National Household Travel Survey) |

**Slope**

One of the factors associated with the natural environment and has an effect on bicycle and walking trips is slope. hence, pedestrians and cyclists will travel out of their way to by-pass segments with steep slopes. because, For them, small positive increments in slope decrease travel speeds while increasing energy use and travel time. Besides, due to the differences in efforts to go up-slope versus down-slope, pedestrians and cyclists may not select the same way. This is referred to as anisotropic movement (Ebener et al. 2005).

There are few studies that have considered slope in measures of active accessibility, yet it is acknowledged as an important factor to include since people will often avoid routes with significant elevation gain, and routes with steep slopes may significantly impact accessibility. Often, network analyst tools use the shortest path from the road network, which may not reflect actual cycling or walking behavior. Vale, Saraiva et al. (2015) concluded that slope should always be included in accessibility of bicycling and that it is also important for walking, however it is largely absent from walking accessibility measures (D. S. Vale, Saraiva, and Pereira 2016). However, the greater availability of elevation data and advances in research in various disciplines offer opportunities to better understand the behavior of individuals when travelling in infrastructure-poor contexts and challenge assumptions surrounding the most important costs to be minimized. Papa, Carpentieri et al. (2018) also highlighted a significant difference in catchment areas when including versus excluding the slope attribute (~33% km2 difference for adults over 75) (Papa, Carpentieri, and Guida 2018). Wood, Jones et al. (2018) studied the sensitivity in distance calculation to variations in three travel-time modeling approaches, taking as reference a model that accounted for variations in land cover and directionality in slope (anisotropy). They found that an approach based on measuring Euclidean distances on a flat surface underestimated the distance traveled, relative to the reference. The second approach, which calculated the distances constrained to a road network, also varied substantially from the reference, underestimating it in some areas and overestimating in others. Finally, the third approach, which accounted for land cover and elevation but ignored the directionality of slopes slightly underestimated travel times (Wood et al. 2018).

Lundberg (2012) examined the local cycling and walking networks through Geographic Information Systems (GIS) using accessibility. They extracted a percent slope raster layer from DEM layer that was obtained from part of the National Elevation Dataset (NED). the percent slope of the DEM ranged from 0 to 360. In Arc Map, when the slope angle equals 45 degrees, the rise is equal to the run. Expressed as a percentage, the slope of this angle is 100%. As the slope angle approaches vertical (90o), the percentage slope approaches infinity. An X,Y coordinate was first calculated for the start point of each line segment. Next an X,Y coordinate was calculated for the end point of each line segment. Arc Map’s 3D Analyst extension was used to convert the street network into a 3D layer, at which point percent slope could then be calculated as the Z-value for each of the line segments in the network. A Z-value (elevation) was calculated at the start points and end points of each line segment. The following equation was used to derive percent slope for each line segment:

slope values indicate uphill travel while negative slope values indicate downhill travel. In this regard, they proposed different walking and cycling speeds based on the different slopes using Parkin and Rotheram (2010) findings on the impact of slope on bicycle travel speeds(Parkin and Rotheram 2010).Table 8. summarizes the various bicycle travel speeds used in the GIS modeling.

**Table 10.** Bicycle travel speeds used in GIS modeling

| **Slope** | **Speed(mph)** |
| --- | --- |
| -10 | 18.8 |
| -7 | 17.1 |
| -5 | 16.1 |
| -2 | 14.5 |
| 0 | 13.4 |
| 2 | 11.7 |
| 5 | 8.9 |
| 7 | 7.2 |
| 10 | 4.5 |

Pedestrian travel speeds were also calculated based on the effect of slope. Tobler’s hiking function was used to identify the effect of slope on travel speed. The following equation represents the modified Tobler’s formula adjusted for percent slope:

Where v is velocity, e is the base for natural logarithms, and s is the slope in percent. Table 9. summarizes a pedestrian’s travel speed used in the modeling in GIS.

**Table 11.** Pedestrian travel speeds used in GIS modeling

| **Slope** | **Speed(mph)** |
| --- | --- |
| 10 | 1.6 |
| 7.5 | 2.1 |
| 5 | 2.4 |
| 2.5 | 2.8 |
| 0 | 3.1 |
| -2.5 | 3.6 |
| -5 | 3.1 |
| -7.5 | 2.6 |
| -10 | 2.3 |

In another study, Paez et al (2020) calculated the slope from the vertical and horizontal displacements. The instantaneous slope (m) is given by the derivative of with respect to x. this is given by the following expression (Páez et al. 2020):

In a DEM layer, two physical aspects of the landscape that relate to resistance can be obtained directly from the grid, namely the vertical displacement and the horizontal displacement between nodes i and j. and $h $ are vertical and/or horizontal displacements respectively. This slope is linked to speed via Tobler’s formula for hiking travel (Tobler 1993):

where the speed s is in m/min. The amount of speed can be converted into travel time in minutes if it is divided the distance by speed as follows:

where can be the distance on the surface as discussed above or can be approximated by the horizontal distance . As seen in Fig. 2, travel time tends to increase as the slope in creases.

|  |
| --- |
| Figure 2: Relationship between surface distance/travel time and slope |

**Weather**

Other factors that are associated with the natural environment and have also been shown to affect cycling and walking trips are as follows: weather, temperature, shade, and aesthetics. The type of weather an individual has to travel through has been identified as a principal factor in the decision process for employing non-motorized travel modes. The pinnacle conditions that individuals consider using non-motorized travel include dry weather and pleasant temperatures (60 to 75) (Zacharias 2001). High amounts of shade cover over a network and available aesthetics along a route increase the rates for non-motorized travel (Zahran et al. 2008).

**Level of Traffic Stress**

Several of the cycling accessibility approaches incorporate bicycle infrastructure using level of traffic stress (LTS) (Imani, Miller, and Saxe 2019; Murphy and Owen 2019). The LTS method was first proposed by Furth, Mekuria et al. (2016) to categorize street segments into 4 categories based on the number of lanes, presence of a parking lane, the speed limit, the bike lane and parking lane width, and any bike lane blockage (Furth, Mekuria, and Nixon 2016).Faghih Imani et al. (2019) and Murphy and Owen (2019) compare cycling accessibility measures using different LTS categorizes to calculate service areas. Both studies exclude highways and high-volume roads from the network and classify into LTS categories using attribute information available from the network dataset and used the City of Toronto open data and OSM data respectively(Imani, Miller, and Saxe 2019; Murphy and Owen 2019).

The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System aims to provide a common nomenclature for bicycle facilities based on user safety and comfort. The Can-BICS classification designates bicycling facilities into three categories: high, medium, and low comfort infrastructure. There is some general alignment between Can-BICS categories and LTS criteria, however, there are a few main differences:

Local street bikeways are classified as high comfort using Can-BICS, but either LTS 1 or 2 depending on the number of lanes.

Painted bike lanes may be assigned LTS 1 to 4 depending on the speed, width, and presence of parking lanes, whereas in Can-BICS, painted lanes are low comfort facilities.

Trails and walkways in parks are LTS 1 but may be categorized as non-conforming Can-BICS facilities depending on the trail surface (e.g., gravel or dirt vs. paved).

**Table 12.** The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System

| **Facility Type** | **Can-BICS Class** | **LTS Category** |
| --- | --- | --- |
| Cycle tracks | High comfort | 1 |
| Local street bikeway | High comfort | 1 or 2 |
| Bike paths | High comfort | 1 |
| Multi-use paths | Medium comfort | 1 |
| Painted Bike lanes | Low comfort | 1 to 4 |
| Park trails and walkways | Non-conforming | 1 |

**Origins/destinations & applying weights**

Typically, the way in which opportunities are measured depends on the type of opportunity and whether one or multiple opportunity types are considered. For example, the studies measuring job accessibility or number of people served by transit consider a total count, whereas for urban park access, Reyes et al. (2014) and Cheng et al. (2019) consider cell counts to account for park area(Reyes, Páez, and Morency 2014; Cheng et al. 2019). Among walkability and bikeability indices it is also common to apply weights to the variables depending on the goals for analysis (L. D. Frank et al. 2010; D. S. Vale, Saraiva, and Pereira 2016; Arellana et al. 2021).

The majority of studies focus on origin-based accessibility (access to destinations), however, as argued by Vale et al. (2015), accessibility at destinations is also important. For example, individuals may reside in high accessible areas, but work in low-accessibility areas. In this respect, topology-based measures, may be preferred, or it may be useful to consider accessibility in terms of the population served around destinations of interest(D. S. Vale, Saraiva, and Pereira 2016).

## Summary

Overall, there remains considerable variation in the types of accessibility measures applied in the context of walking and cycling. Among the four main types of active accessibility measures identified, the majority of recent studies use an activity-based approach, either measuring cumulative opportunities (within a catchment area / weighted by distance from the origin) or measuring gravity models. The activity-based approaches mainly vary in terms of the travel time and distance thresholds, and weighting impedance functions considered.

Many of the walking approaches, for instance, aim to incorporate a variable walking threshold (depending on age or location), while this is not seen within the context of cycling – where a prioritization of measures by route infrastructure is more apparent. Conversely, attention to infrastructure type, or comfort and safety, is not seen among pedestrian-focused studies.

When selecting an accessibility measure, there is evidently a trade-off between complexity and measure interpretability. While adding more complexity or multiple indices for different population groups, may increase accuracy, a simple, and easy to implement measure may be more important for widespread use.

## Discussion

Eliciting user needs data is the process of discovering requirements for a project by accessing available knowledge sources, and by communicating with the stakeholders who have a direct or indirect influence on the requirements.Among the available requirements elicitation technique, the most common and effective elicitation techniques is interviews with stakeholders(Engelbrektsson, Yesil, and Karlsson 2000; Browne and Rogich 2001; Friedrich and Van Der Poll 2007; Hadar, Soffer, and Kenzi 2014).As a result, in this section, we discuss some of the questions required to extract data users’ requirements.

|  |
| --- |
| Flowchart of interview questions |

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