

A historical collection of impedance functions for 1

MM

```
library(knitr)
library(glue)
library(gt)
if(!require(webshot2)) warning("you'll need this")
```

Loading required package: webshot2

Registered S3 method overwritten by 'webshot2':

```
method      from
print.webshot webshot
```

```
knit_print.gt_tbl = function(x, ...) {
  f <- glue("{opts_current$get('label')}-gt_tbl.png")
  x |> gtsave(filename=f)
  knitr::asis_output(glue(""))
}
```

```
registerS3method(
  "knit_print", "gt_tbl", knit_print.gt_tbl,
  envir = asNamespace("knitr")
)
```

```
head(iris) |> gt()
```

Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species
5.1	3.5	1.4	0.2	setosa
4.9	3.0	1.4	0.2	setosa
4.7	3.2	1.3	0.2	setosa
4.6	3.1	1.5	0.2	setosa
5.0	3.6	1.4	0.2	setosa
5.4	3.9	1.7	0.4	setosa

Abstract

urban planning as cities strive to become more sustainable. Accessibility analysis employs different methods such as gravity-based models, potential models, etc. An important component of these methods is the impedance function used to represent the responses of travelers to the friction of distance separating origins and destinations. The objective of this study is to investigate active travel behavior in Canada using time use data. Empirical estimates of impedance functions are calibrated to assess the time-willingness to reach different destinations such as work, school, grocery stores, restaurants, and sports places by walking and cycling. This research makes use of Canada’s General Social Survey Cycles 2, 7, 12, 19, 24, 29 thus giving a historical perspective on active mobility over the past 35 years. The focus of these surveys is on time use and the datasets contain information on travel time by active modes (cycling and walking) as well as the type of activity at the end of the trip which allows us to classify trips by purpose. Our focus is on Canadian Census Metropolitan Areas (CMAs) and the results indicate that the most common destinations for walking trips after work or school are grocery stores, other stores or malls are the most destinations for walking travels respectively. For trips by bicycle the most common destination after traveling to work or school, is sports centers, field or arena. Strong distance-decay effects are evident from the results. The impedance functions, in addition to providing information about the behavior of active travelers in Canada for the period of time under study, are a valuable resource for implementing active accessibility analysis in Canadian applications.

Keywords: Impedance function, Accessibility, Active travel mode

1. Introduction

Urban and transportation planning has witnessed a growing interest in the idea that cities possess the capacity to shape travel behavior. This is achieved through the establishment of environments that prioritize accessibility and present a variety of transportation choices, ultimately encouraging individuals to adopt sustainable modes of transportation which is more convenient and appealing, such as walking, cycling, and utilizing public transit. In this context, accessibility refers to the ease with which individuals can reach desired destinations, access essential services, and avail themselves of various amenities within their urban environment (Iacono, Krizek, and El-Geneidy 2008). As a result, In the past few decades, active transportation modes have garnered significant interest in urban mobility research and policy-making, primarily for their prospective role in enhancing urban sustainability (**hino2014built?; lamiquiz2015effects?**). To elucidate, there has been a surge in investigations focused on non-motorized transportation methods, including walking, cycling, and public transit, recognizing their significance in promoting sustainable mobility solutions (S. Handy 1993; Clifton and Handy 2001; Frank and Engelke 2001; Krizek 2005; Sallis et al. 2004; **vandenbulcke2009mapping?**; Wu et al. 2019). It is important to note that walking and cycling accessibility are closely intertwined and both modes of active transportation contribute to the overall concept of “active accessibility” or “non-motorized accessibility.” By considering and improving active accessibility in urban and transportation planning, cities can create environments that facilitate and encourage active modes of transportation. This approach not only helps reduce dependence on private vehicles but also promotes healthier and more sustainable travel behaviors among residents.

A significant body of literature has contributed to the assessment of accessibility levels for active modes of transportation in recent decades. These studies generally agree on two primary components for measuring accessibility include: (1) the location and attractiveness of urban opportunities (benefit side), and (2) the impedance of travel from origins in the network to the destinations (cost side). Specifically, the calculation of accessibility using impedance functions has emerged as a crucial research topic that has garnered substantial attention from scholars in the fields of transport planning, urban geography, and sustainable development (Frank et al. 2005; Krizek 2005; Currie 2010; Iacono, Krizek, and El-Geneidy 2010; Yang and Diez-Roux 2012; Millward, Spinney, and Scott 2013; Nassir et al. 2016; Saghapour, Moridpour, and Thompson 2017; Wu et al. 2019). The impedance function, in its various forms, serves as a measure of the willingness to travel a certain distance to reach desired destinations and is a valuable tool for analyzing spatial patterns of travel behavior and can be used for any mode of transportation planning Millward, Spinney, and Scott (2013). According to these definitions, areas with higher accessibility are those characterized by lower impedance when traveling to desirable destinations. In other words, as the distance to a destination increases, the likelihood of walking or cycling decreases (Hansen 1959; Pirie 1979; S. L. Handy and Niemeier 1997; K. T. Geurs and Ritsema van Eck 2001; Bhat et al. 2002; Church and Marston 2003; Kwan et al.

2003; K. T. Geurs and Van Wee 2004; Levinson and Krizek 2005; Cascetta, Cartenì, and Montanino 2013). So, there is a limited information scarce on the willingness of some individuals to walking or cycling greater distances. Equally, there's a paucity of data on how distance affects the nature of the activity, the desirability of the destinations, and the characteristics of those embarking on the trip in different context . Hence, it is imperative to investigate the evolution of impedance function over time due to its inherently dynamic nature, which fluctuates in response to the evolution of transportation networks and shifts in urban spatial configurations (Iacono, Krizek, and El-Geneidy 2008; Iacono, Krizek, and El-Geneidy 2010). Luoma, Mikkonen, and Palomaki (1993) provided evidence highlighting a diminishing distance decay parameter over time, attributing this trend to enhanced travel velocities and the maturation of transportation infrastructures (Luoma, Mikkonen, and Palomäki 1993). Subsequent research by Mikkonen & Luoma (1999) delved into elucidating the factors behind these noted shifts in the parameters of gravity models over periods (Mikkonen and Luoma 1999).

Various impedance functions have been utilized to describe the distribution of walking and cycling trips, both in general and for specific purposes (Iacono, Krizek, and El-Geneidy 2008; Iacono, Krizek, and El-Geneidy 2010; Larsen, El-Geneidy, and Yasmin 2010; Yang and Diez-Roux 2012; Millward, Spinney, and Scott 2013; Vale and Pereira 2017; Li, Huang, and Axhausen 2020). When assessing accessibility using impedance functions, different cost decay functions have been employed, including **threshold functions** (e.g., step function) and **smooth cost decay functions** (e.g., inverse-potential, log-normal, logistic, exponential square-root, and half-life function) (De Vries, Nijkamp, and Rietveld 2009; Reggiani, Bucci, and Russo 2011; Östh, Lyhagen, and Reggiani 2016; ITF. 2017). Scholars place significant emphasis on the selection of an appropriate impedance function, leading to a diverse range of functions being employed. These various specifications primarily vary in their treatment of the influence of distance, consequently impacting the measurement of accessibility. However, negative exponential distance-decay functions are commonly used in assessing non-motorized accessibility, capturing the willingness of individuals to walk or cycle to destinations (S. L. Handy and Niemeier 1997; K. T. Geurs and Ritsema van Eck 2001; Iacono, Krizek, and El-Geneidy 2010; Vega 2012; Millward, Spinney, and Scott 2013; Vale and Pereira 2017; Li, Huang, and Axhausen 2020). The merit of this function lies in its ability to attribute decreasing influences to more remote opportunities, thereby offering a more accurate estimation for shorter journeys, especially those undertaken by non-motorized modes (Iacono, Krizek, and El-Geneidy 2010; Kanafani 1983; Fotheringham and O'Kelly 1989).

In addition to determining the form of the impedance function, the analyst must also specify the variable used to measure impedance, which can be either time, cost, or a combination of both. Previous studies have employed both of these measures, and there are instances where the generalized cost concept has been applied as well. The choice between time and distance as the impedance variable has been found to be acceptable based on previous research (Iacono, Krizek, and El-Geneidy 2010; Hull, Silva, and Bertolini 2012; Sun, Lin, and Li 2012; Lowry et al. 2012; Vasconcelos and Farias 2012). However, when it comes to non-motorized travel modes, extracting accurate travel times from existing network models can be challenging, which limits the options and makes distance a more practical choice (S. L. Handy and Niemeier 1997;

Iacono, Krizek, and El-Geneidy 2010; Yang and Diez-Roux 2012; Arranz-López et al. 2019). Furthermore, researchers specializing in active modes of transportation have faced challenges stemming from a dearth of objective data concerning walking and cycling behavior. Because Estimating specialized impedance functions specific to non-motorized modes requires appropriate travel survey data that can capture pedestrian and cycle behavior. Often, researchers have resorted to relying on retrospective questionnaires, which assess subjective aspects such as the frequency and duration of walking and cycling activities. Notably, regional household travel surveys, including trips made by non-motorized modes, have been employed for this purpose (Iacono, Krizek, and El-Geneidy 2010; Millward, Spinney, and Scott 2013). In contrast to these localized surveys, there are some dataset that provides a nationwide perspective, encompassing travel for various trip purposes and offering insights into details like travel episode origins, destinations, and time-based lengths. This comprehensive approach furnishes a more holistic understanding of active transportation behavior. Nevertheless, only a few studies have examined active travel behavior in national scale, such as Yang et al (2012).

Acknowledging the existing gaps highlighted earlier, as well as the gap in the utilization of uniform decay curves for both cycling and walking accessibility assessments such as the negative exponential function in previous research (Wu et al. 2019), This research seeks to provide a comprehensive solution to these deficiencies. The study delves into the intricacies of actual travel behavior, with a specific focus on active transportation modes, utilizing historical data from the General Social Survey (GSS) spanning the years 1986 to 2015 in Canada. In this pursuit, the primary objective is to calculate the impedance function for both cycling and walking trips. This study, therefore, juxtaposes the travel behavior associated with both modes. Moreover, given that non-work travel encompasses a variety of trip intentions and unique traveler behaviors, the impedance function emerges as a vital tool in analyzing non-work accessibility. This underscores the importance of devising distinct impedance functions tailored to each trip purpose (Grengs 2015). As such, our analysis will span various trip intents, including commutes to homes, workplaces, or educational institutions, social visits, outdoor engagements, business excursions, shopping expeditions, cultural outings to libraries, museums, or theaters, dining experiences, and religious observances. By incorporating a nationally representative cohort of Canadians, this research aims to bridge the existing gaps in empirical data concerning the frequency and duration of typical pedestrian and cycling ventures across various trip purposes. In doing so, it aims to provide a robust understanding of active mode travel behavior. Through this comprehensive analysis, we seek to contribute to the broader discourse on active transportation and its implications for travel behavior and accessibility.

Describe following section

2. Background

Accessibility is conceptualized as the potential to access geographically dispersed opportunities, taking into account the challenges associated with reaching them (Páez, Scott, and Morency 2012). The positioning of resources concerning users, the transportation infrastructure, and how spatial relations and distances impact the potential utilization of amenities are fundamental considerations in accessibility and mobility modeling. Typically, the effect of distance on potential use is encapsulated through “Impedance functions” or “Distance Decay functions” (Hansen 1959; Koenig 1980; Fotheringham 1981). These functions are integral in transportation planning, commonly incorporated into forecasting models to interpret urban travel behaviors for each mode. They’re typically shaped from estimates grounded in sample data distributions that mirror fluctuations in individuals’ propensity to travel over different distances to reach opportunities. This importance is underscored by their prevalent use in understanding accessibility to specific locations and areas covered by different services (Hsiao et al. 1997; Zhao et al. 2003; Iacono, Krizek, and El-Geneidy 2010; Li, Huang, and Axhausen 2020). Fundamentally, accessing opportunities is tied to the travel costs to a destination. Indeed, the main goal of the impedance function is to depict the diminishing intensity of interaction as the separation between locations augments. These functions delineate how an increase in distance or associated travel costs inversely affects potential usage; in essence, distant facilities are less likely to be used compared to those in closer proximity (Hansen 1959; Koenig 1980; Fotheringham 1981; Skov-Petersen 2001). In addition, the essence of the impedance function insinuates that adding distance or time matters less for longer trips than for shorter ones (Carrothers 1956).

The examination of impedance functions concerning different transportation modes and destinations serves as a valuable foundation for comprehending the travel behavior attributed to each mode. The parameters of impedance functions offer insights into the spatial coverage provided by each mode of transportation. By segmenting modal trips based on their purposes, it becomes possible to compare the distribution of trips between various purposes for each transportation mode (work-related and non-work purposes). Empirically derived impedance functions offer valuable evidence that can be utilized to examine and substantiate various claims pertaining to travel behavior, thus supporting urban planning endeavors. For instance, the current interest in creating “livable” communities revolves around loosely held assumptions regarding individuals’ willingness to walk and cycle to different destinations. A common belief is that people are generally willing to walk up to a quarter of a mile to access most locations (Untermann 1984). However, there remains limited information regarding whether certain individuals are open to walking or cycling longer distances and, if so, how much farther they are willing to travel. Moreover, there is a dearth of evidence concerning the influence of trip characteristics, destination attractiveness, and the personal attributes of travelers in relation to the impact of distance on walking and cycling behaviors (K. Geurs 2006).

Since Hansen’s foundational research, various categories of accessibility measures have been developed, such as active-based, infrastructure-based, individual-based, and utility-based indicators (Hansen 1959; K. T. Geurs and Van Wee 2004). Accessibility metrics, particularly those of the gravity type or potential measures have been extensively utilized in active modes (Miller 2005). These measures primarily stem from the gravity model’s denominator, where opportunities are weighed by an impedance function. In fact, these are designed by weighting opportunities within an area according to an attraction measure and then diminishing each based on an impedance measure (for example Geertman and Ritsema Van Eck 1995; S. Handy 1993). The general representation of the accessibility equation can be expressed as:

$$A_{ik}^{pt} = \sum_{j=1} g(O_{jk}^t) f(C_{ij}^p)$$

{#eq:1-general accessibility function}

Research demonstrates that two primary types of accessibility indicators are predominantly used in studies. First one revolves around **Opportunities** are weighted by an impedance (characterized by a relevant decreasing function of either travel cost or time required to access these opportunities(equation)). The accessibility measure A_{ik}^{pt} signifies accessibility from an origin i at a specific time t to a certain destination type k tailored for an individual of type p . The function $g(O_{jk}^t)$ quantifies the appeal of opportunities categorized under type k situated at destination j , accessible at time t . Simultaneously, $f(C_{ij}^p)$ represents the impedance while traveling from origin i to destination j for a person belonging to type p . It’s worth noting that the functional form $f()$ delineates an impedance decay function. Meanwhile, C_{ij}^p signifies the generalized travel cost, potentially encompassing factors such as time, distance, and exertion.

Within the gravity model, the second variable concerns the cost associated with the spatial gap between a trip’s start point and its endpoint (origins and destinations). Moreover, the third pivotal variable, crucial for constructing this model, involves the mathematical formulation delineating the travel impedance between origins and destinations. This “cost” can be articulated in terms of physical distance, duration of travel, financial outlay, or a fusion of these elements. Among these, travel duration emerges as the chief measure of cost and is the metric chosen for this particular investigation(S. Handy 1993; Fotheringham and O’Kelly 1989; Grengs 2004; Hess 2005). In fact, when selecting a format for the impedance function, the researcher must determine which variable (time, cost, or both) will serve as the measure of impedance. Historically, both these measures have been employed, with certain instances incorporating the concept of generalized cost (S. L. Handy and Niemeier 1997). For non-motorized travel modes, however, the prevalent choice seems to be distance, attributed to the challenges in obtaining precise travel times from existing network models designed for walking and bicycling. Previous studies indicate that adopting either time or distance as the impedance variable is appropriate (S. L. Handy and Niemeier 1997). While the first two variables are derived from the attributes of the built environment, the impedance parameter captures aspects of human behavior, making its determination an intricate undertaking.

The second type pertains to the **Cumulative-opportunity** metrics, often referred to as **isochronic indices**, which evaluate accessibility by determining the count or proportion of opportunities available within specified travel duration or distances from a reference point. These metrics avoid making presumptions about travel decay. They utilize a rectangular function, categorizing travel as “acceptable” within certain thresholds and “unacceptable” beyond them. One of the main complexities with these metrics is deciding on the appropriate cutoff point. This decision can be based on prevailing mobility patterns of the population, or it can mirror established norms, conventions, or the researcher’s informed projections (Vickerman 1974). This metric can be interpreted as a specialized solution of Equation (1). In this context, the impedance function is designated as 1 when $C_{ij} < x$ and 0 when $C_{ij} > x$.

$$C_{ij} = \begin{cases} 1 & \text{for } c_{ij} \leq x \\ 0 & \text{for } c_{ij} > x \end{cases}$$

The domain of transportation research has seen an increased focus on various formulations related to accessibility. Pre-eminent research in this domain has been presented by the likes of Song (1996), Handy and Niemeier (1997), Handy and Clifton (2001), and Iacono et al. (2010) (Song 1996; S. L. Handy and Niemeier 1997; Clifton and Handy 2001; Iacono, Krizek, and El-Geneidy 2010). While a predominant chunk of these studies is devoted to automobile transportation, the researches by Iacono et. al. (2010), Millward et. al. (2013), and Vale et. al. (2017) uniquely distinctively explored active modes of transportation, such as walking and cycling. They determined the parameter for the computation of the impedance function. Their findings indicate a significant decline in the attractiveness of destinations positioned beyond a mile’s distance.

1. The study of travel behaviors has, over time, led to the development of various mathematical functions, meticulously crafted by juxtaposing observed walking and cycling trips with predefined mathematical distributions. The choice of the impedance function is critical, as it’s deeply intertwined with the gravitational force of travel, subsequently influencing accessibility evaluation outcomes (Breheny 1978; Kwan 1998; Talen and Anselin 1998).

While the negative exponential function remains dominant in traditional transportation planning models (Meyer and Miller 1984; Gutiérrez, González, and Gomez 1996; Kwan 1998; Apparicio et al. 2008; Iacono, Krizek, and El-Geneidy 2008; Iacono, Krizek, and El-Geneidy 2010; Larsen, El-Geneidy, and Yasmin 2010; Millward, Spinney, and Scott 2013), the best impedance function and its parameters can differ based on the specific travel mode, especially for active modes, and the underlying purpose of the trip (Iacono, Krizek, and El-Geneidy 2008; Iacono, Krizek, and El-Geneidy 2010; Larsen, El-Geneidy, and Yasmin 2010; Millward, Spinney, and Scott 2013).

Despite many overlooking the specific nuances of the impedance function, reviews have indicated a preference for exponential and power functions in Gravity models. Still, more adapt-

able functions like the Box-Cox, logistic, and the Tanner functions have been explored (Gaudry 1981; Mandel, Gaudry, and Rothengatter 1997; Tiefelsdorf 2003; Richardson et al. 1969; Dios Ortúzar and Willumsen 2011).

2. Furthermore, the literature reveals four distinct types of impedance functions highlighting spatial interaction effects, with the derived indicators seldom undergoing empirical evaluations to determine their efficacy in illustrating location attractiveness (Willigers, Floor, and Wee 2007). The distance-decay function’s shape is notably influenced by both travel mode and purpose. For instance, while Zhao et al. (2003) shed light on the walking distance’s impact on public transport accessibility, leaning towards the exponential function, other studies, such as those by Gutiérrez et al. (2011) and Mamuna et al. (2013), ventured into the complexities of multi-modal intra-urban riderships and time distances, respectively.
3. More commonly, the impedance function is represented using a straightforward inverse power function or a negative exponential function based on distance or travel time. In 1971, Ingram highlighted that both these formulations tend to wane too swiftly in proximity to the origin when compared to empirical data. He posited that a modified Gaussian function is more advantageous, primarily because of its slower decline rate near the origin and a less precipitous drop to zero at larger distances, compared to the negative exponential and inverse power functions (Ingram 1971). Although a theoretical proposition advocates for the utilization of a Gaussian function (Ingram, 1971), the reviews revealed no research applying it specifically to gauge active mode accessibility. To the best of our knowledge, only Kwan (1998) employed a Gaussian function for assessing automobile accessibility (Kwan 1998; Vale and Pereira 2017).
4. Scholarly consensus aligns with the view that inverse distance-decay functions in geographical applications rarely trace a linear trajectory. Simplistic functions often falter in mirroring observed data trends on distance-interaction intensity graphs. This discord has necessitated the development of more intricate distance-decay functions, as advocated by luminaries like Taylor (1983) and Robinson (1998). Among the various models, those characterized by bell-shaped curves, such as Tanner’s function and the Box-Cox function, have gained prominence. They are predominantly directed by two parameters, offering a more nuanced approach to spatial interaction effects.
5. Researchers, from Stewart (1941) to Haggett (2001), have reached consensus regarding the non-linear nature of inverse distance-decay functions in human geographical applications (**stewart1941?**; **goux1962?**; **taylor1971a?**; **taylor1983?**; **johnston1973?**; **wilson1974?**; **alonso1978?**; **sheppard1978?**; **robinson1998?**; **haggett2001?**). While simplistic functions may not aptly reflect the observed data on distance-interaction intensity graphs, intricate distance-decay functions have been promoted by luminaries like Taylor (1983) and Robinson (1998). Among these functions, bell-shaped curves, such as the Tanner function, March’s function, and the Box-Cox function, have gained prominence, directed by multiple parameters (**taylor1983?**; **robinson1998?**;

openshaw1977?; tanner1978?; nakaya2001?; celik2004?; langford2012?; martinez2013?). Mozolin et al. (2000) introduced an approach that integrates distance and employment numbers, visualized in a 3D diagrammatic representation (mozolin2000?). However, while these functions provide precise fits for specific scenarios, their general application across varying contexts may be limited.

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8. why using negative exponential is more popular? Although the impedance function may take many forms, the negative exponential form has been used more often than others in recent studies and is also the most closely tied to travel behavior theory.

s, it found that an accessibility measure with an exponential distance-decay function (e^{-r}) is the most useful in explaining population distribution (article?) {song1996some, title={Some tests of alternative accessibility measures: A population density approach}, author={Song, Shunfeng}, journal={Land Economics}, pages={474–482}, year={1996}, publisher={JSTOR} }

Here, we choose the negative exponential form (e^{-x}). This function has the advantage that it declines more gradually than the power function, and thus better estimates shorter trips, such as those made by non-motorized modes (Kanafani 1983). This advantage, along with a record of numerous empirical applications made it an appropriate functional form to be estimated for the set of impedance functions applied in the current study.

The negative exponential form presents an advantageous characteristic of a more gradual decline when compared to the power function. This attribute renders it particularly effective in accurately estimating shorter trips, especially those associated with non-motorized modes of transportation (Kanafani 1983; Fotheringham and O’Kelly 1989; De Vries, Nijkamp, and Rietveld 2009; Iacono, Krizek, and El-Geneidy 2010; Signorino et al. 2011; Prins et al. 2014). In a recent study by Vale and Pereira (2017), the modified Gaussian and exponential functions were found to be the most robust for modeling walking accessibility when examining 20 pedestrian accessibility measures. Additionally, the study introduced a new cumulative Gaussian function that considers cumulative opportunities at close distances (200 or 400 m) and a modified Gaussian curve for longer distances (Vale and Pereira 2017).

I #Additionally, the literature occasionally references s-shaped functions, such as bell-shaped and logistic functions (Páez, Scott, and Morency 2012; Halás, Klapka, and Kladiivo 2014; Martínez and Viegas 2013; Van Wee, Hagoort, and Annema 2001).

’0

However, this is only the case when matching the impedance function with the observed walking behavior, which might be different from the perceived behavior of the individual. Moreover, it should be noted that distance–decay is an aggregate concept based on travel frequency characteristics of a group of individuals according to distance. At the individual level, movements are much more complex, with significant variations among individuals (Golledge and Stimson,

1997), partly explaining the weak relationship between personal and place accessibility (Kwan, 1998).

The accessibility toolbox implements the five different impedance functions from Kwan (1998):

Inverse Power:

$$f(t_{ij}) = \begin{cases} 1 & \text{for } t_{ij} \leq 1 \\ 0 & \text{otherwise } t_{ij}^{-\beta} \end{cases} \quad (1)$$

Negative Exponential:

$$f(t_{ij}) = e^{-\beta t_{ij}} \quad (2)$$

Modified Gaussian:

$$f(t_{ij}) = e^{-t_{ij}^2/2} \quad (3)$$

A logarithmic normal distribution function (Wu et al. 2019):

$$f(c_{ij}) = \alpha \frac{1}{\sqrt{2\pi x\sigma}} e^{-\frac{(\ln t - \mu)^2}{2\sigma^2}}$$

where the variable “x” symbolizes the distance covered during active modes. The parameters denoted as α , μ , and σ play a pivotal role in this analysis, as they are subject to estimation. Collectively, these parameters wield influence over the configuration of the curve under examination (Wu et al. 2019).

Cumulative Opportunities Rectang:

$$f(t_{ij}) = \begin{cases} 1 & \text{for } t_{ij} \leq \bar{t} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Cumulative Opportunities Linear:

$$f(t_{ij}) = \begin{cases} 1 - t_{ij}/\bar{t} & \text{for } t_{ij} \leq \bar{t} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Gamma formula:

$$f(c_{ij})^{***} = \begin{cases} \frac{1}{\sigma^\alpha \Gamma(\alpha)} c_{ij}^{\alpha-1} \cdot e^{-c_{ij}/\sigma} & \text{for } 0 \leq c_{ij} < \infty; \alpha, \sigma > 0 \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

log-logistic decay functions: (**article?**)`{geurs2016multi, title={A multi-modal network approach to model public transport accessibility impacts of bicycle-train integration policies}, author={Geurs, Karst T and La Paix, Lissy and Van Weperen, Sander}, journal={European transport research review}, volume={8}, number={4}, pages={1–15}, year={2016}, publisher={SpringerOpen} }`

$$f(c_{ij}) = \frac{1}{1 + \exp(a + b \ln t_{ij})}$$

In this context, the variable t_{ij} denotes the travel time between locations i and j , while parameters a and b are the subject of estimation (Thorsen, Ubøe, and Naelig; vdal 1999).

9. The inverse power, negative exponential, and modified Gaussian functions continuously discount the weight of opportunities as travel time increases using an impedance parameter that accounts for the cost of travel. With a foundation in early gravity models of spatial interaction (Stewart 1948; Zipf 1949), the inverse power function produces a rapid decline in the weight of opportunities as travel time increases. While power functions draw analogs to Newtonian physics, their theoretical relevance to human travel behavior has been questioned (Sen and Smith 1995). The negative exponential function is more gradual and based on its strong theoretical foundations in entropy maximization (Wilson 1971) and choice behavior theory (Fotheringham and O’Kelly 1989), this function appears to have become somewhat of a de facto standard in applied accessibility analysis. The modified Gaussian function exhibits a much more gradual rate of decline around its origin and a slower rate of decline overall. While Ingram (Ingram 1971) argues that these properties make the function superior to its inverse power and negative exponential counterparts for explaining observed travel behavior, it appears to be rarely used in the applied literature.

This set of impedance functions is by no means exhaustive. Numerous alternatives have been proposed, such as the exponential–normal, exponential–square root, and log–normal functions reviewed by Reggiani, Bucci, & Russo (Reggiani, Bucci, and Russo 2010) and the Box-Cox, Tanner, and Richards functions reviewed by Martínez & Viegas (Martínez and Viegas 2013). Although these functions could be implemented in future iterations of the tool, the present article’s focus on the functions specified in Kwan (1998) introduces some of the most widely used measures of impedance in applied accessibility analysis.

Kwan (1998) sets four impedance parameters for each continuous function designed to produce a weight of about 0.1 at travel times of 5, 10, 15, and 20 min respectively. Figure 1 recreates a figure from Kwan (1998) to visualize parameter values for the five functions: the inverse power

function with $\alpha = 2$ (POW2_0), the negative exponential function with $\alpha = 0.15$ (EXP0_15), the modified Gaussian function with $\alpha = 180$ (MGAUS180), and the cumulative rectangular (CUMR40) and linear (CUML40) functions with τ set to 40 minutes.

Third, people’s sensitivities to increases in travel distance or time vary depending on travel purposes and their personal and household characteristics. Variation in the magnitude of the parameters in the impedance function indicates such variation in sensitivity to spatial separation.

mention to maghalehayeh ghabli: (Sagharpour et al., 2018)

EX:(Gutiérrez et al., 2011) stations. Untermann (1984) found a distance-decay relationship in which most people were willing to walk 500 ft, 40% would walk 1000 ft, but only 10% would walk a half mile. Zhao et al. (2003) conducted an onboard transit survey to determine the effect of walking distance on transit use, showing that transit use deteriorates exponentially with walking distance to transit stops. Levinson and Brown-West (1984) classified bus riders by walking distance and car ownership rates, and compared them to the number of dwelling units in each status. A series of ridership penetration curves were calculated, showing that patronage declines linearly with increasing walking distance.

EX: Millward, Spinney, and Scott (2013) analysed active-transport behaviour focusing on distance, duration, purposes and destinations of trips, while other studies have focused on calculating non-motorized accessibility. For instance, Iacono et al. (2010) developed an accessibility measure for non-motorized modes, namely bicycling and walking. Mavoa, Witten, McCreanor, and O’sullivan (2012) also introduced a combined public transit and walking accessibility index, highlighting the importance of accessibility for the potential use of non-motorized modes of transport

EX:Prins et al. (2014) investigated bicycle and walking accessibility to grocery stores or markets for the elderly, estimating distance decay model parameters based on factors such as gender, age, and functional limitations (Prins et al. 2014). Iacono et al. (2010) calibrated the distance-decay model for five different trip purposes (work, shopping, school, restaurant, and recreation) and developed accessibility measures for both walking and cycling (Iacono, Krizek, and El-Geneidy 2008).

3. Materials and Methods

ino mitunam baraye canada dorost konam = Historical analysis

##3.1. The GSS survey

To derive impedance functions tailored for non-motorized modes, it’s imperative to have suitable travel survey data that encapsulates pedestrian and cycling activities. The optimal approach would involve a dedicated survey, intricately designed to predominantly capture these specific behaviors, or data garnered from Global Positioning Systems—an option that usually

incurs higher costs. When these specific datasets are not available, a broader regional household travel survey can be employed, provided it encompasses trips made by non-motorized means (Iacono, Krizek, and El-Geneidy 2010). In this research, we utilized data from the General Social Survey (GSS) to delve into active travel behavior in Canada, which is administered by Statistics Canada. The GSS provides a comprehensive cross-sectional snapshot of the Canadian populace through telephone surveys which is established in 1985. The study area for the GSS encompasses the entirety of Canada, from the bustling urban centers of cities like Toronto, Vancouver, and Montreal to the more serene and remote locales in provinces like Newfoundland and Labrador, Nunavut, and Yukon. By casting such a wide net, the GSS ensures a diverse and comprehensive representation of the Canadian demographic and lifestyle mosaic. These surveys encompass an array of socio-demographic inquiries, combined with questions concentrating on specific core themes, such as health, time use, and aspects like social support and aging (Statistics Canada, 2015). One of the standout features of the GSS is its recurring “time use” cycle, which delves into the daily activities of Canadians. This cycle not only captures the amount of time individuals allocate to various tasks, but also the sequence, location, and concurrent activities, offering a holistic view of Canadians’ daily lives. The questions within this cycle have been adapted and refined over the years to reflect the changing dynamics of daily life, ensuring that the data remains pertinent and contemporary.

For the purpose of this study, six cycles of the GSS were meticulously examined, namely those from the years 1986, 1992, 1998, 2005, 2010, and 2015. A salient feature of these selected cycles is their emphasis on time use, collected in the form of detailed diaries. Of notable significance is the 1986 cycle, as it stands out as the inaugural national random sample that delved into Canadian time-use patterns. Given the research focus on travel behaviors, particularly walking and cycling behavior, data filtering was imperative. This entailed an exhaustive extraction of entries relevant to these two travel modes. Estimates from each GSS Cycle are derived from two microdata sources: the Main file and the Episode file. The Main file comprises questionnaire responses and associated data from participants, while the Episode files furnishes detailed insights into every activity episode reported by the respondents. For the purposes of this study, we employed the episode files to establish a comprehensive dataset for impedance function analysis. This dataset encompasses variables such as individual ID, start time, end time, time duration, origins and destinations of each walking and cycling trip, and weight. It should be noted that each record epitomizes a single activity in a respondent’s day, ensuring that all episodes collectively span twenty-four hours (or 1440 minutes). The weight parameter signifies the number of time use episodes that a particular record in the Episode File represents.

Prior to the in-depth analysis, a series of preparatory steps were indispensable to guarantee the consistency across the data sets. It was observed that different time-use surveys employed varied activity and contextual coding schemes. This called for the imperative of standardizing these schemes across the various surveys in question. Over the years, the coding categorizations for various activities have experienced shifts. To standardize the data and accurately determine the origin and destination of each trip, we aligned the activity categories from 2005, 2010, and 2015 with each other, and similarly, the classifications from 1986, 1992, and 1998 were made

consistent with each other. Consequently, for the years 1986, 1992, and 1998, trip origins and destinations were defined as “home”, “other’s home”, “work or school”. In the subsequent years of 2005 and 2010, and 2015 these categories were broadened to encompass “home”, “other’s home”, “work or school”, “Restaurant, bar or club”, “Place of worship”, “Grocery store, other stores or mall”, “outdoors”, and “Library, museum or theater”. It’s pertinent to highlight that the 1986 dataset is exclusively focused on walking data, devoid of any cycling trip records for that particular year.

The decision to tap into the time series data of the GSS is motivated by the opportunity it offers to discern and analyze evolving patterns over an extended time frame. By spanning three decades, this approach facilitates a comprehensive longitudinal assessment of walking and cycling trends in Canada. This depth of temporal coverage is instrumental in capturing the nuances and shifts in travel behaviors over time.

3.2 Estimating impedance function parameters

The foundation of our study rested upon the calculation of impedance functions for walking and cycling trips in each of the six years (1986, 1992, 1998, 2005, 2010, and 2015) under investigation. As before mentioned, the impedance function is a fundamental construct for examining travel behavior, encapsulating the factors that influence the ease or difficulty of traversing a particular route. Diving deeper into travel behavior variations, we acknowledged that behaviors are shaped by mode of travel (such as walking or cycling), the trip’s purpose, and the location specifics of the trip’s origin and destination (K. Geurs 2006; Iacono, Krizek, and El-Geneidy 2008; Iacono, Krizek, and El-Geneidy 2010; Larsen, El-Geneidy, and Yasmin 2010; Millward, Spinney, and Scott 2013). This insight underscored the challenge in generalizing a single impedance function, given that different travel modes and purposes necessitate differing functions. So, in this research, we endeavored to compute the impedance function individually for each destination and mode of transportation. To initiate this process, we employed the R programming language and leveraged the “fitdistrplus” package. Our approach was methodical, commencing with a comprehensive exploratory analysis. We generated skewness and kurtosis graphs, providing valuable visual representations of the distributional characteristics inherent in the travel time duration for walking and cycling trips in each year.

The selection of an appropriate probability distribution played a pivotal role in our analysis. By closely scrutinizing the skewness and kurtosis graphs, we aimed to identify the probability distribution that most faithfully mirrored the empirical characteristics of our data. This step was crucial to ensure the subsequent calculations accurately captured the underlying travel behavior. In the quest for the optimal distribution, we systematically evaluated various probability distribution models, including but not limited to the normal, gamma, exponential, and Weibull distributions. Our choice of the most suitable distribution hinged on statistical metrics, including the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). These criteria facilitated a quantitative assessment of the goodness of fit for different distributional models. Additionally, we leveraged the maximum likelihood estimation (MLE)

method, utilizing the Nelder-Mead optimization algorithm available within the `{fitdistrplus}` package (Delignette-Muller and Dutang 2015). This ensured precise estimation of distribution parameters, underlining the rigor of our impedance function calculation.

After the comprehensive model selection and parameter estimation process, we advanced to compute the impedance function. This integral construct calculated the resistance or challenges linked with walking and cycling trips for each year and destination, factoring in the varying weights of determinants. To delineate the impedance function, travel time emerged as our pivotal measure to gauge trip impedance (cost), rooted in the understanding that walking and cycling typically have no direct monetary expenditures (Hamidi 2014).

#Results and discussion

##mitunam natayeje bedast amade baraye travel behavior dar Canada ro ba natayeje khodam moghayese konam. masalan una ta chand min ro baraye walking va cycling dar nazar gereftan va natayeje man chi ro neshun mide mesle introduction Yong 2012

In our quest to understand active travel behavior in Canada, we relied on the General Social Survey (GSS) data. This dataset enabled us to meticulously determine the impedance function, shedding light on possible deterrents or incentives for active travel. We concentrated on walking and cycling trips over a significant duration from 1986 to 2015. This period was selected for its importance in reflecting changes in urban development, societal perspectives, and transportation dynamics. Our inquiry began with an exhaustive descriptive analysis, methodically examining the statistical trends of walking and cycling trips during these thirty years.

Descriptive statistics pertaining to walking and cycling trips from 1986 to 2015						
Statistic	1986	1992	1998	2005	2010	2015
cycling						
Count	NA	135	119	328	219	221
max	NA	240	90	180	135	120
median	NA	20	15	15	15	15
min	NA	5	2	1	1	5
walking						
Count	439	1500	1670	5533	4379	2822
max	660	300	255	515	480	900
median	20	10	5	10	8	10
min	1	1	1	0	0	5

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median	20	10	5	10	8	10
min	1	1	1	0	0	5

#limitations

Estimating an impedance parameter in the absence of information about the spatial distribution of activities (as is provided in the gravity model) is equivalent to assuming that activities are evenly distributed in space (Sheppard 1995). Clearly this assumption is not reasonable for most metropolitan regions and can lead to biased results. (krizek et al., 2009)

(**article?**)`{krizek2009access, title={Access to destinations: Application of accessibility measures for non-auto travel modes}, author={Krizek, Kevin J and Iacono, Michael and El-Geneidy, Ahmed and Liao, Chen Fu and Johns, Robert}, year={2009}, publisher={Minnesota Department of Transportation, Research Services Section} }`

Calculating accessibility measures requires multiple data sets relating to travel behavior and land use, each of which presents unique challenges for analysts addressing non-motorized modes. For example, robust accessibility measures are built around models representing human behavior (e.g., who shops where and how far they travel for such). Unfortunately, the data necessary to reliably build such models are often in short supply for walking and cycling. User and trip characteristics at a suitable level of aggregation, along with user preferences for facility design characteristics are currently of limited quality and are considered a high priority

for improvement (USDOT 2000). Characteristics about non-motorized mode users and their trips are typically aggregated to the same level as motorized trips, rather than being assigned to smaller aggregation units. Information on preferences toward different facilities is typically incomplete at best, and often entirely absent. These data items are not adequately covered in most large scale survey instruments, such as metropolitan travel surveys or the Nationwide Personal Transportation Survey (NPTS).

limitation estefade az GSS dataset for analysing impedance functions for active mode: A limitation of this approach, however, is the variety of destinations that can feasibly be studied. Given that walking and bicycling tend to be less heavily-used and often under reported modes in many U.S. cities, any further partitioning of the data can lead to small samples and less robust inferences.

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