A Historical Analysis of the Evolution of Active Travel Behaviour in Canada

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Abstract

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It consists of two paragraphs.

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1. Introduction

The idea that travel behaviour can be influenced by the city form has attracted growing interest urban and transportation planning. Cities intend to encourage their residents to adopt more sustainable modes of transportation, including walking, cycling, and public transit, by developing an environment with a variety of transportation alternatives and, at the same time, increasing accessibility - understood as the ease of reaching destinations and opportunities (Iacono, Krizek, and El-Geneidy 2008). Because of their significant role in enhancing and promoting urban sustainability (Hino et al. 2014; Lamiquiz and Lopez-Dominguez 2015), active transportation modes, such as walking and cycling, are playing a central role in urban mobility research and policy-making (S. Handy 1993; Clifton and Handy 2001; Frank and Engelke 2001; Krizek 2005; Sallis et al. 2004; Vandenbulcke, Steenberghen, and Thomas 2009; Wu et al. 2019). Walking and cycling accessibility are closely related, contributing together to the concept of "active accessibility" or "non-motorized accessibility", and, when considered in the urban and transportation planning process, reducing dependence on private vehicles and promoting healthier and more sustainable travel behaviour among residents.

There are two main components when measuring accessibility: (1) the location and power of attraction of urban opportunities (trip benefit) and (2) the barrier in travel from the origin in the network to the destination (trip cost). A way for measuring the cost of travel when calculating accessibility is using impedance functions, a methods that is receiving attention from transportation planning scholars, 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 functions have different forms and all of them serve as a tool to understand the travel behaviour and as measure of the willingness to travel a certain distance to achieve a desired destination, where a service or an opportunity is located (Taylor 1975; Fotheringham 1981; Kwan 1998; Eldridge and Jones III 1991; Luoma, Mikkonen, and Palomaki 1993; Papa and Coppola 2012; Yang and Diez-Roux 2012; Millward, Spinney, and Scott 2013; Vale and Pereira 2017). In this concept, areas with higher accessibility are those characterized by a lower impedance when traveling to desirable destinations. When talking about active accessibility, increasing the distance between

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two points generally implies in a decreasing in the probability of that trip being done by walking or biking (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, Carteni, and Montanino 2013). However, more information about the willingness of some individuals to walk or cycle greater distance is needed, as well as more data on how distance affects the type and feasibility of the activity, destinations desirability, and the characteristics of those embarking on the trip in different contexts. In this context, investigate the evolution and dynamics of impedance function over time becomes important, since they're easily impacted by changes in the transportation network or in urban spatial configurations (Iacono, Krizek, and El-Geneidy 2008; Iacono, Krizek, and El-Geneidy 2010). Luoma, Mikkonen, and Palomaki (1993) evidenced a decreasing in the distance decay parameter over time, attributing this trend to improvements and maturation of the transportation system (Luoma, Mikkonen, and Palomaki 1993), and Mikkonen and Luoma (1999) argues that this difference was mainly caused by the establishment of new big retail store units, elucidating the factors behind these temporal patterns in the gravity models patterns (Mikkonen and Luoma 1999).

Since the beginning applications of the gravity-accessibility models, a range of impedance functions have been applied to describe the distribution of walking and cycling trips, wether for general or 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).

Selecting an appropriate impedance function can be challenging and results in a diverse range of cost decay functions that are employed as impedance functions in accessibility measures, including **threshold functions** (e.g., binary Step Function and multiple Step Function) and **smooth cost decay functions** (e.g., log-normal, normal, gamma, and exponential function) (De Vries, Nijkamp, and Rietveld 2009; Reggiani, Bucci, and Russo 2011; Osth, Lyhagen, and Reggiani 2016; ITF. 2017). The variety of functions relies in how scholars approach the influence of distance, with 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 is due to its ability to assign decreasing influences to more remote opportunities, giving a more accurate estimate for shorter trips (Iacono, Krizek, and El-Geneidy 2010; Kanafani 1983; Fotheringham and O'Kelly 1989). However, in addition to determine the form of the impedance function, scholars also need to specify the variable used to measure impedance, which can be either time, distance, monetary cost, a combination these last variables or even a generalized cost concept. Among these options, the choice between time and distance as the impedance has been found to be most used based on previous studies (Iacono, Krizek, and El-Geneidy 2010; Hull, Silva, and Bertolini 2012; Sun, Lin, and Li 2012; Lowry et al. 2012; Vasconcelos and Farias 2012), with distance being more adopted in non-motorized applications since extracting accurate travel times from existing network models is challenging (S. L. Handy and Niemeier 1997; Iacono, Krizek, and El-Geneidy 2010; Yang and Diez-Roux 2012; Arranz-Lopez et al. 2019). Additionally, estimate impedance function to active transportation modes requires appropriate travel survey data that is able to capture pedestrian and cycle behaviour, resulting in researchers recurring to retrospective questionnaires to assess subjective aspects such as the frequency and duration of walking and cycling activities. Notably, regional household travel surveys that include trips made by non-motorized modes have been employed for this purpose (Iacono, Krizek, and El-Geneidy 2010; Millward, Spinney, and Scott 2013). In opposition to these specific surveys, some data sets provides a nationwide perspective, including travel for different purposes and detailing the trip with valuable information, named episodes, regarding the origins, destinations, and time-based lengths. Besides this type of data can provides a deeper comprehension about the active transportation behaviour, only few studies have examined travel behaviour nationally.

Aiming to address the mentioned challenges, this study has as the main goal identifying appropriate impedance functions for active transportation modes for various destinations and time periods in Canada. Additionally, the present paper realizes a comparative analysis of travel behaviors associated with these two modes. To do achieve this objective, we utilize the {ActiveCA} R package. {ActiveCA} is an open data product in the form of an R data package with information about active travel in Canada. This data product is based on Public Use Microdata Files of Statistics Canada's General Social Survey (GSS) program with a focus on the Time Use Survey cycles. To build this package, Santos and Paez [*include the reference*] extracted all walking and cycling episodes and their corresponding episode weights for GSS cycles, Cycles 2 (1986), 7 (1992), 12 (1998), 19 (2005), 24 (2010), and 29 (2015), spanning a period of almost thirty years. Origins and destinations were categorized, enabling the investigation of active travel for broad destination categories and purposes.

We recognize that non-work travel encompasses a range of trip purposes and diverse traveler behaviors, which makes impedance functions essential analytical tools for studying non-work accessibility. Grengs (2015) emphasizes the importance of elaborating distinct functions for each travel purpose, a principle that guides this analysis (Grengs 2015). Our investigation covers a variety of trip goals, ranging from commutes to homes, workplaces, or educational institutions to social visits, outdoor activities, business trips, shopping, cultural outings to libraries, museums, or theaters, dining out, and engaging in religious practices. Our research aims to enhance the current knowledge about active travel behaviour and provide empirical data about frequency and duration of typical pedestrian and cycling trips for different purposes, by applying the methodology on a nationally representative samples of Canadian residents. Lastly, this comprehensive analysis seeks to contribute to the ongoing conversation on active transportation, highlighting its role in influencing transportation plans to a more sustainable alternative.

2. Background

Accessibility is understood as the potential to access spatially distributed opportunities, taking into account the challenges associated with this access (Paez, Scott, and Morency 2012). Usually, the effect of travel costs is expressed by "impedance functions" or "distance decay functions" (Hansen 1959; Koenig 1980; Fotheringham 1981). In general, they are derived from estimates based on distributions of sample data that reflect variations in the willingness of individuals to travel different distances to reach opportunities (Hsiao et al. 1997; Zhao et al. 2003; Iacono, Krizek, and El-Geneidy 2010; Li, Huang, and Axhausen 2020). The main objective of the impedance function is to describe the decrease in the intensity of interaction as the cost of travel between locations increases and, in general, the cost of travel is measured in terms of the distance between the places of origin and destination or in terms of the time spent reaching the destination from the point of origin. In general, these functions describe how an increase in the associated distance/travel time inversely affects the potential for making the trip; in essence, distant facilities are less likely to be used compared to closer ones (Hansen 1959; Koenig 1980; Fotheringham 1981; Skov-Petersen 2001). Thus, the "distance decay" effect suggests that adding a unit of distance to a long trip is less significant than adding a unit to a shorter trip (Carrothers 1956), since the farther location already has a lower probability of access for the person willing to travel Carrothers (1956). Examining the impedance functions related to different modes of transport and destinations is a good way to understand the travel behavior attributed to each mode. When segmenting modal trips by destinations, it is possible to compare the distribution of trips between multiple finalities for each mode of transport (work-related and non-work-related) and examine any allegations about travel behavior. For example, current interest in creating "livable" communities revolves around vague assumptions about individuals' willingness to walk or bike to different destinations, such as the assumption that people are generally willing to walk up to a quarter mile to access most places (Untermann 1984). However, there is still little information on whether certain individuals are willing to walk or cycle longer distances and, if so, how far they are willing to go. In addition, more evidence is needed on the influence of trip characteristics, destination attractiveness and individual characteristics on the impact of distance on walking and cycling behavior (K. Geurs 2006).

2.1. Impedance functions in accessibility measures

Since Hansen's (1959) research, different categories of accessibility measures have been developed, such as indicators based on actives, infrastructure, individuals and utilities (Hansen 1959; K. T. Geurs and Van

Wee 2004). The family of gravity-based accessibility have been widely used in active modes (Miller 2005). Many gravity-based accessibility measures derive from the work of Hansen (1959), represented in (Equation 1), in which an impedance function weights opportunities:

$$A_i = \sum_{j=1}^{J} O_j . f(c_{ij}) \tag{1}$$

The accessibility score A_i at each origin i is obtained by summing up the opportunities O available at destination j, where i and j are sets of spatial units in a region. However, the number of opportunities in each destination is gradually discounted as travel costs become higher and the the rate at which this weight decreases is determined by a decay function. $f(c_{ij})$ represents the impedance during the trip from origin i to destination j and c_{ij} reflects the generalized travel cost, potentially encompassing factors such as time, distance and effort. In this way, the impedance function $f(c_{ij})$ allows the accessibility analyst to define a measure of travel behavior with precision: the relationship between the "population" at an origin and where they normally want to or can go to reach "opportunities" at destinations. The definition of the impedance function $f(c_{ij})$ is very important from this perspective.

Another type of family of accessibility measures are *cumulative opportunity* metrics, commonly referred to as isochronous indices. The binary function Equation (2) forms the basis of the cumulative opportunities maeasure approach. This function determine accessibility by summing up the number of opportunities available within a specific limiar of travel time or distance from a reference point, without discounting the potential of the trip in relation to the associated cost. They use a rectangular function, categorizing the trip as "acceptable" within certain limits and "unacceptable" beyond them. One of the main complexities of these metrics is deciding what the appropriate limiar point is. This decision may be based on the prevailing mobility patterns of the population or may reflect established norms, conventions or informed projections of the researcher (Vickerman 1974). Note that the cumulative opportunity measure can be understood as a special case of a gravity-based measure in which the weight of each opportunity is defined by a binary function, rather than a gradually decaying function.

$$C_{ij} = \begin{cases} 1 & \text{if } c_{ij} \leq x \\ 0 & otherwise \end{cases} \tag{2}$$

Among the various mathematical forms that can represent impedance functions, the negative exponential function is the dominant choice in accessibility research (Meyer and Miller 1984; Gutierrez, Gonzalez, 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). Its high adoption can be attributed mainly to its ability to give greater weight to nearby opportunities, and greater weight to distant opportunities - a highly relevant characteristic for active modes of transportation, such as walking and cycling. Song (1996) noted in his examination of alternative measures of accessibility that the negative exponential form ($e^{-\beta x}$) stands out as the most suitable for explaining population distribution due to its gradual decline, which aligns with empirical data and accurately captures the influence of proximity on accessibility (Song 1996). Kanafani (1983), who highlighted the suitability of this function for modeling non-motorized modes, emphasizing its ability to better estimate shorter trips compared to the power function. In addition to Song and Kanafani, several other studies (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) use the negative exponential function after comparison with empirical trip distribution data.

Researchers can adopt other forms of impedance functions when calculating the distance decay effect in accessibility analysis. One of these options is to adopt a probability density function (PDF) [SOUKOV]. Using a PDF, $f()$ can be interpreted as the probability density of a trip occurring for each value of travel cost c_{ij}. If a graph of the PDF (y-axis) is plotted against the travel cost c_{ij} (x-axis), the probability of a trip occurring between a given range of c_{ij} is the area under the curve. In this case, the total area under the PDF curve always sums to 1, meaning that there is 100% probability that the trip will occur between the minimum and maximum c_{ij}.

Dunn et al. (2023) presented a set of distributions that serve as PDFs. From their survey, we selected some options for $f()$ commonly used in accessibility research and their impact on the number of opportunities (the sum of opportunities) at specific travel costs c_{ij}, namely: uniform, negative exponential, gamma, normal, and lognormal distributions.

- **Uniform distribution**

The uniform distribution or rectangular PDF looks very similar to the binary function, since it only returns one of two values, but ensure that area under the curve for the range of c_{ij} is 1. The uniform distribution PDF is shown in (Equation 3).

$$f(c_{ij})^{uniform} = \begin{cases} \frac{1}{c_{max}-c_{min}} & \text{for } c_{min} \leq c_{ij} \leq c_{max} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

The parameters to be calculated are c_{max} and c_{min}, which represent the maximum and minimum travel costs that describe the observed or assumed willingness to reach destinations. In this distribution, all values within the interval are equally likely, and all values outside the interval have probability 0, assuming that the population's potential to interact with these opportunities is zero.

- **Exponential distribution**

The exponential distribution PDF equation is given by Equation (4). This model suggests that impedance decreases exponentially with increasing cost (c_{ij}). The parameter β represents the decay rate, with higher values indicating a faster decrease in accessibility with increasing cost. As already mentioned, this function is widely used due to its simplicity and ability to model the rapid drop-off in accessibility over distance.

$$f(c_{ij}) = e^{-\beta c_{ij}} \text{ with } c_{ij} \geq 0 \tag{4}$$

- **Gamma distribution**

The exponential distribution PDF equation is presented by the Equation 5.

$$f(c_{ij}) = \begin{cases} \frac{1}{\sigma^{\alpha}\Gamma(\alpha)} c_{ij}^{\alpha-1} e^{\frac{-c_{ij}}{\sigma}} & \text{if } 0 \leq c_{ij} < \infty \text{ and } \alpha, \sigma > 0 \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Where $\Gamma(\alpha)$ is the gamma function to be estimated. In this case, the probability is typically low at low cost, higher at medium cost, and low again at high cost. The higher the σ (scale rate) parameter, the higher the probability that the majority of trips will be in the low cost range. So at low values of the σ (scale rate) parameter, the same probability is spread over a wider range of travel costs. For the α (shape) parameter, the higher the value, the higher the probability density of trips with a higher average cost [SOUKHOV].

- **Lognormal distribution**

The normal distribution, also often called the Gaussian distribution, is suitable when the travel cost is found to be distributed normally. The normal distribution has the PDF form displayed in Equation (6).

$$f(c_{ij}) = \frac{1}{\sqrt{2\pi}\sigma c_{ij}} e^{-\frac{(\ln c_{ij}-\mu)^2}{2\sigma^2}} \tag{6}$$

In this equation, μ and σ are the mean and standard deviation of the logarithm and need to be estimated together to control the shape of the normal curve. In this distribution, about 68% of the observations will fall within 1 standard deviation of the mean, about 95% will fall within 2 standard deviations, and about 99.7% will fall within 3 standard deviations of the mean. In this case, the values close to the mean will have the highest probability.

- **Lognormal distribution**

In many cases, the logarithm of the travel cost is found to be distributed normally. The lognormal distribution has the PDF form displayed in Equation (7).

$$f(c_{ij}) = \frac{1}{\sqrt{2\pi}\sigma c_{ij}} e^{-\frac{(\ln c_{ij} - \mu)^2}{2\sigma^2}} \tag{7}$$

It this equation, μ and σ are the mean and standard deviation of the logarithm, and need to be estimated for together control the shape of the log-normal curve. Similar to the gamma function, the probability is typically low at low cost, higher at medium cost, and low again at high cost.

As the complexity of the PDF increases, so does the flexibility to explain travel behaviour. However, the estimation of the impedance function parameters needs to be calibrated if the accessibility estimates are to be representative of people's travel behaviour. This requires additional travel behaviour data to be used in the calibration process. In our case, we will use the ActiveCA package to obtain the impedance functions, as the package contains ready-to-use data from GSS cycles.

2.2. The GSS survey

The GSS provides a comprehensive cross-sectional snapshot of the Canadian population through telephone surveys established in 1985. The survey coverage area includes both metropolitan and non-metropolitan regions, ensuring a diverse and representative sample of the Canadian population. Specifically, the ten provinces of Canada were divided into distinct geographic strata for sampling purposes. Many Census Metropolitan Areas (CMAs), such as St. John's, Halifax, Saint John, Montreal, Quebec City, Toronto, Ottawa, Hamilton, Winnipeg, Regina, Saskatoon, Calgary, Edmonton, and Vancouver, were treated as separate strata. Additional strata were formed by grouping other CMAs within Quebec, Ontario, and British Columbia, and by categorizing non-CMA areas within each province into their own strata.

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 concentrates in the daily activities of Canadians. This cycle captures the amount of time individuals allocate to various tasks and the sequence, location, and concurrent activities, offering a wide 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.

In order to investigate the historical active travel behavior in Canada, Six GSS cycles were thoroughly considered for this study: Cycles 2 (1986), 7 (1992), 12 (1998), 19 (2005), 24 (2010), and 29 (2015). The 1986 cycle is notable because it was the first national random sample examining Canadian time-use patterns. Data filtering was essential given the research focus on travel behavior, particularly walking and cycling. It required an exhaustive extraction of entries relevant to these two travel modes. Each GSS Cycle is derived from two microdata sources: the Main and Episode files. The Main file comprises questionnaire responses and associated data from participants, while the Episode files furnish detailed insights into every activity episode reported by the respondents. For 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 represents 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.

3. Materials and Methods

We can summarize the methodology in three main steps. The first step preprocess the chosen GSS survey cycles, based on Public Use Microdata Files of Statistics Canada's GSS program. The second step evolves calibrating the best impedance function for every combination of cycle, destination, and active travel mode. The third stage involves evaluating the impedance functions, comparing their temporal evolution.

To facilitate collaboration and further analysis, we created the ActiveCA R data package, an Open Data Product that provides analysis-ready data from Cycles 2 (1986), 7 (1992), 12 (1998), 19 (2005), 24 (2010), and 29 (2015) of the GSS regarding active travel. The Rmarkdown code needed to obtain these outputs from the raw data files is available through a Zenodo repository linked to our GitHub page, in line with the best practices of spatial data science. These contributions improve our understanding of active travel behaviour in Canada and provide a basis for future research and policy-making.

3.1. Preprocessing the GSS surveys

For each selected cycle of the GSS surveys, we reviewed the episode files to identify cases with activities listed as walking or cycling, selecting the locations immediately before and after the mobility episode. Doing this, we were able to identify the origin and the destination of the active travel episode. We labeled the code variables with their appropriate descriptions, identifying the transportation mode, activity/reason of the travel, as well the province and urban classification of the respondent's residency (if the respondent lives in a Census Metropolitan Area or in a Census Agglomerations).

Additionally, it was necessary to guarantee the data consistency across the surveys, since they have employed a variety of variable coding schemes. The range of activities and destinations considered in the surveys changed from 1986 to 2015. In the first survey (in 1986), there were only three options of origin/destination location available to the respondent: their home, other's home and work or studt. In its turn, the most recent survey (2015) counts with more than 10 possible destination, including sport centre, restaurant, health clinics and more. In order to achieve uniformity, the activity categories from 2005, 2010, and 2015 were synchronised, and a similar process was employed for those from 1986, 1992, and 1998. For the preceding years (1986, 1992, and 1998), the trip origins and destinations were classified as "Home," "Other's home," and "Work or School." In the subsequent years (2005, 2010, and 2015), these categories were expanded to include "Business," "Restaurant, bar or club," "Place of worship," "Grocery store, other stores or mall," "In the neighbourhood," "Outdoors," "Library, museum or theatre," and "Sport centre, field or arena". It is also important to note that the 1986 dataset exclusively contains data on walking trips, with no records of cycling trips for that year.

3.2. Estimating impedance function parameters

The objective of this research was to compute the appropriate impedance functions for each destination, mode of transportation and survey year. We applied the "fitdistrplus" package to calculate the best PDF for every destination, mode of transportation and survey year, between the options: uniform, negative exponential, gamma, normal, and lognormal distributions.

In order to calculate the impedance functions, two filters were applied in the GSS data set. The first is that we excluded all trips with travel times higher than 100 minutes (1.5 hours). An exploratory data analysis showed that, taking into account all the walking and cycling episodes (17401 in total), less than 0.01% of the episodes have a trip duration higher than this limit. It was also possible to know that trips with a duration higher than 100 minutes are mainly composed of hiking and camping episodes. The second filter was realized to select only the population living in a larger urban population centre (a Census Metropolitan Area (CMA) or Census Agglomeration (CA)). We decided to apply this restriction because the travel behaviour of residents of CMA and CA areas tends to be very different from those outside these large urban centres in terms of active travel.

3.3. Analyzing the active travel behaviour evolution

4. Results and discusion

4.1. Descriptive analysis of walking and cycling trips from 1992 to 2015

After applying the filters to the GSS surveys, we obtained a total of 1.2115×10^4. Table 1 contains the number of episodes about walking and cycling trips between 1992 and 2015, obtained from the GSS cycles.

The year 2005 is the year with the most episodes, 4472, representing approximately 37% of all active travel episodes. The year 2005 is followed by 2010, with 3543 episodes (representing 29% of the total), then 2015 (2900 episodes, 24% of the total), 1998 643 episodes, 5% of the total), and 1992, with only 557 episodes, representing 5% of the total.

When analyzing the two active transportation modes, walking episodes account for 93%, while the remaining 7% are cycling episodes. However, it is worth mentioning that, while in 2015 cycling episodes represented only 7% of the active travel episodes for that year, in 1992 the cycling episodes represented 12% - the highest share of this mode across all years. In the next survey (1998), it drops to around 9%, stabilizing at around 7% thereafter.

Table 1: Number of episodes identified in each active transportation mode by year

	Year					
Mode	1992	1998	2005	2010	2015	Total
Cycling	67	56	290	209	215	837
Walking	490	587	4182	3334	2685	11278
Total	557	643	4472	3543	2900	12115

Tables 2 presents statistic on travel time, which is used as the travel cost to calculate the impedance functions, by active transportation mode. The maximum time spent on walking trips varied between 90 and 100 minutes across the years. It is important to remember that trips with duration greater than 100 minutes were excluded from the analysis. The mean walking time also varies, starting at 21 minutes in 1986, dropping to 12 minutes between 1992 and 2010, and increasing again to 16 minutes in 2015. However, it is known that the mean is a statistic that is highly influenced by extreme values. For this reason, we analyze the median travel time, as it is more representative of the typical travel time. The median time spent walking is 15 minutes in 1992, then drops to 5 minutes in 1998 and remains constant at 10 minutes from 2005 to 2015.

However, the analysis of travel time statistics alone does not fully explain the reasons behind these fluctuations in travel time over the years. We can affirm, however, that there was a reduction in the time spent walking during the analyzed period, with a one-third reduction in the median walking travel time since 1992.

For cycling trips, the maximum travel time varies from 90 to 100 minutes, similar to walking, except in 1998 when the maximum travel time recorded was 80 minutes. The average cycling travel time is more constant, ranging from 19 minutes in 2005 to 25 minutes in 1992 and 1998. Again, when we analyze the median travel time, we see that the typical cycling travel time dropped from 20 minutes in 1992 to 15 minutes in 2005, 2010, and 2015, possibly reflecting advancements in bicycle technology or changes in cyclists' behaviors.

As highlighted in Figure 1, over the 30 years studied, the typical duration of walking trips was consistently lower than that of cycling trips. As already mentioned, both medians decayed when compared to 1992, and various factors might have precipitated this trend, such as urban sprawl, increased reliance on motorized transport, or societal preferences for faster modes of transportation.

Table 2: Descriptive statistics for episodes with active transport records

		Year				
Mode	Statistic	1992	1998	2005	2010	2015

Walking	count	490	587	4182	3334	2685
	max	90	100	100	90	95
	mean	21	12	12	12	16
	median	15	5	10	10	10
	min	5	1	1	1	5
Cycling	count	67	56	290	209	215
	max	90	80	95	100	90
	mean	25	25	19	20	23
	median	20	18	15	15	15
	min	5	2	1	2	5

Figure 1 shows the percentage of each destination by year and by mode of transport. For all the years analyzed, 'Home' is the most common travel destination, regardless of whether the mode of transport considered is walking or cycling, with levels above 42%. After that, 'Work or school' appears as the second most common destination, especially for journeys by bicycle, with a peak of almost 34% of trips by bicycle in 1998, a high drop to 22% in 2005, rising again to levels close to 30% in 2015. Along with the two destinations already mentioned, 'Other's home' is the only other destination present in the GSS surveys since 1992. This last destination seems to be a destination with a higher share when it comes to walking trips, but for both modes of transportation it seems that respondents are going less and less to other people's homes - a fact that can be explained by new communication technologies, in which a person doesn't need to visit another person's home to keep in touch with them.

After 2005, the expansion of the destination highlights some new popular locations. For example, 'Grocery store' appears as the third most chosen destination, varying from 10% in 2005 to 6.5% in 2015 for cycling trips and from 13.3% to 12.6% for walking trips. When considering walking trips, 'Restaurants' appears as another well chosen destination and, in the case of cycling trips, 'Outdoors' appears as a well chosen destination.

Figure 2 present the box plot graphs showing the travel time distribution for active transportation modes over the years, categorized by destination. Some destinations are presented in only one survey, such as 'Sport area', 'Neighbourhood,' and 'Business'. These new destination exhibit typical walking travel times 10 minutes. For cycling trips, 'Business' recorded no trips, while 'Sport area' and 'Neighbourhood' registered typical travel times of 30 and 15 minutes, respectively.

For destinations included in more than one survey, we can compare the temporal evolution of travel times. Starting with the walking trips, we can note that there is a tendency of increasing travel times for 'Restaurants' and 'Outdoors' (both increasing from 5 in 2005 to 10 minutes in 2015) and 'Place of worship' (rising from 10 in 2005 to 15 minutes in 2015). In contrast, some destinations presented a decline in travel times, where the case of 'Cultural venues,' which had a median travel time of 2005 and drop to 5 minutes in 2015, and 'Home' which start the time series with a minutes in 1992 and dropped to 10 minutes by 2015. Other destinations maintained an almost constant travel time. In general, while 'Place of worship' displayed the maximum median travel time of 15 minutes, the general median walking time cuttoff appears to be 10 minutes, with most of trips occurring below this limit.

For cycling trips, an increasing trend in travel times is evident for destinations such the destinations 'Grocery store' (rising from 10 to 15 minutes between 2005 and 2015), 'Outdoors' (increasing from 15 in 2005 to 20 minutes in 2015), and 'Home' (retuning to the 1992 typical travel time of 20 minutes after dropping to 10 minutes in 2010). However, travel times decreased for destinations like 'Other's home' and 'Place of worship', where the typical cycling travel time declined from 20 minutes in their first recorded surveys to 15 minutes by 2015. Other destinations remained with a constant travel time.

Figures 3 and 4 show walking and cycling trips from 1992 to 2015 through heat maps. These maps use color gradients to represent the percentage of trips between origins and destinations, with darker colors indicating higher percentages and lighter colors representing less frequent routes. In 1992, walking trips with 'Home' as both the origin and destination made up the majority, accounting for almost 31% of all walking trips. These trips often involved leisure activities, like short walks or dog walking. Following this, trips from

Figure 1: Percentage of walking and cycling trips categorized by destination and year

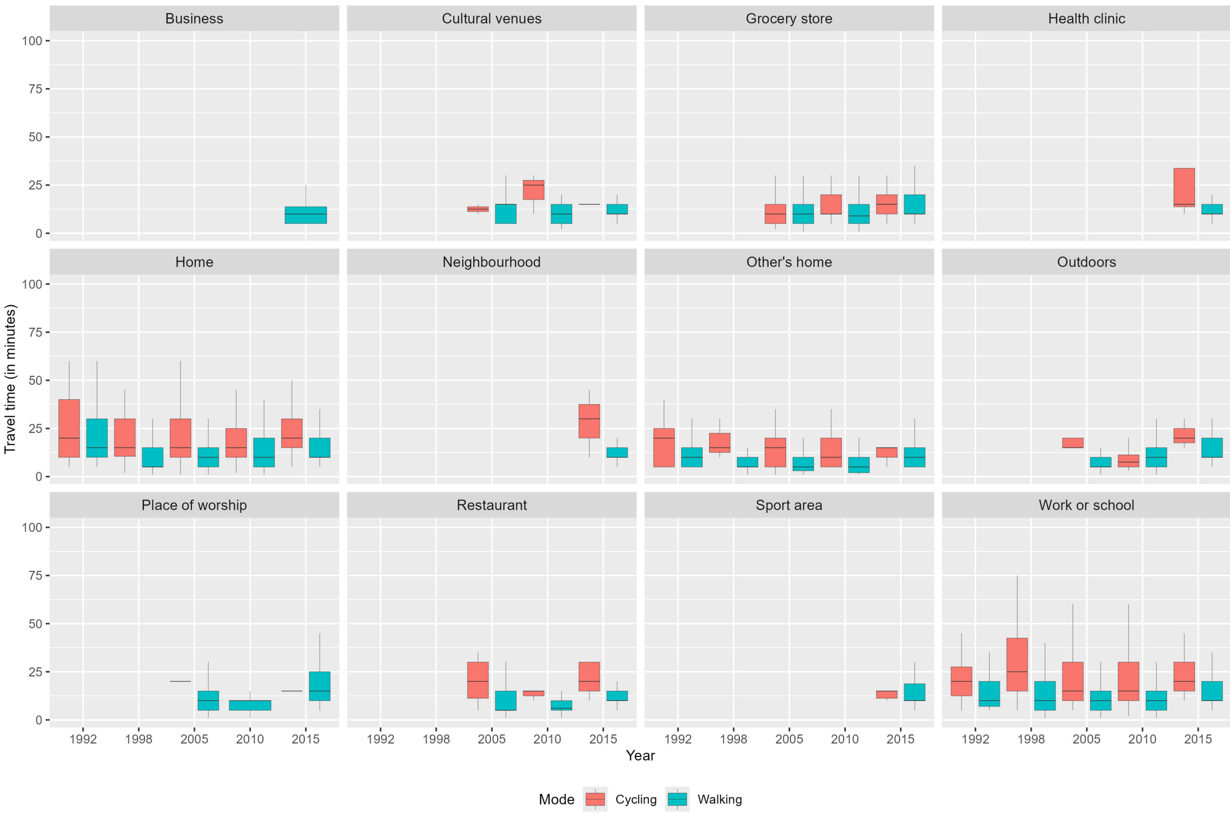

Figure 2: Percentage of walking trips categorized by origin and destination

'Home' to 'Work or school' comprised 18% of walking trips. Overall, 'Home' is the principal hub, either as an origin or destination, with only 5% of trips not involving 'Home.' By 1998, more than half of walking trips were between 'Home' and 'Other's home,' with 'Home' to 'Other's home' and 'Other's home' to 'Home' each representing 26% of trips. During this year, 'Home' to 'Home' accounted for only 10% of trips. In 2005, trips with origins or destinations involving 'Home' and 'Work or school' remained as the most common, but the introduction of new destinations led to a more dispersed trip distribution. Together, these two combinations accounted for 25% of all trips. In 2010, trips between 'Home' and 'Work or school' continued as the most common type, representing 18% of trips, tied with trips from 'Grocery store' to 'Home' (9%). Finishing the walking trip descriptive analysis, in 2015, the highest proportion of trips were from 'Home' to 'Work or school' (12%) and vice versa (11%). Trips from 'Home' to 'Home' accounted for 8% of trips, and 'Grocery store' became a notable destination for trips originating from 'Home' (8%).

For cycling trips (Figure 4), in 1992, the most common trip was from 'Home' to 'Work or school' (26%), followed by trips from 'Other's home' to 'Home' (22%). In all following years, the most frequent trip were between 'Home' and 'Work or school' in both direction. This combination accounted for 65% of the trips in 1998, 40% in 2005, 52% in 2010, and 58% in 2015. Additionally and unlike walking trips, 'Home' to 'Home' trips were not a common cycling trip in any of the surveys. This suggests that leisure trips, such as activities around the home, are predominantly done by foot rather than by bicycle.

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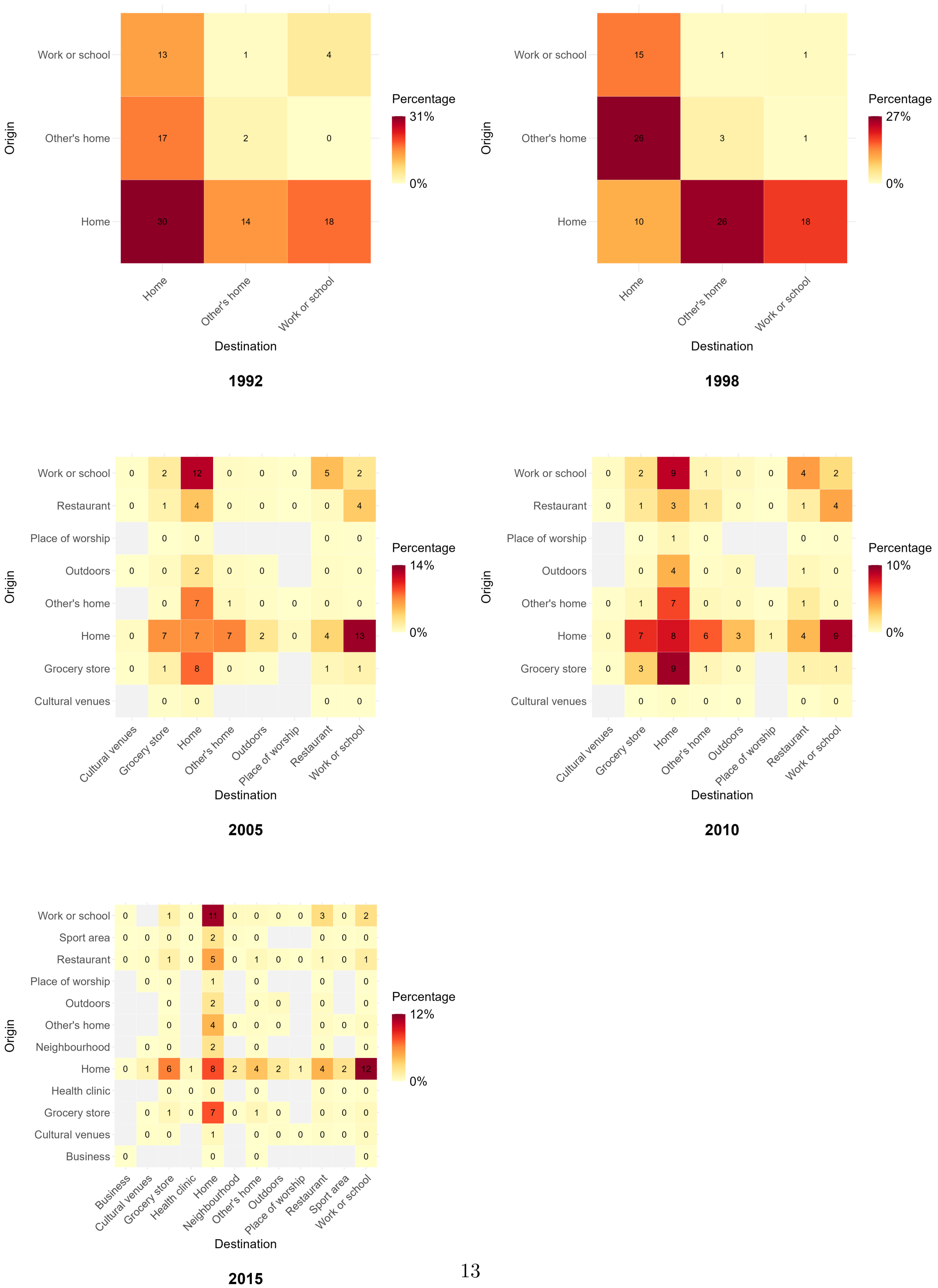

Figure 3: Percentage of walking trips categorized by origin and destination

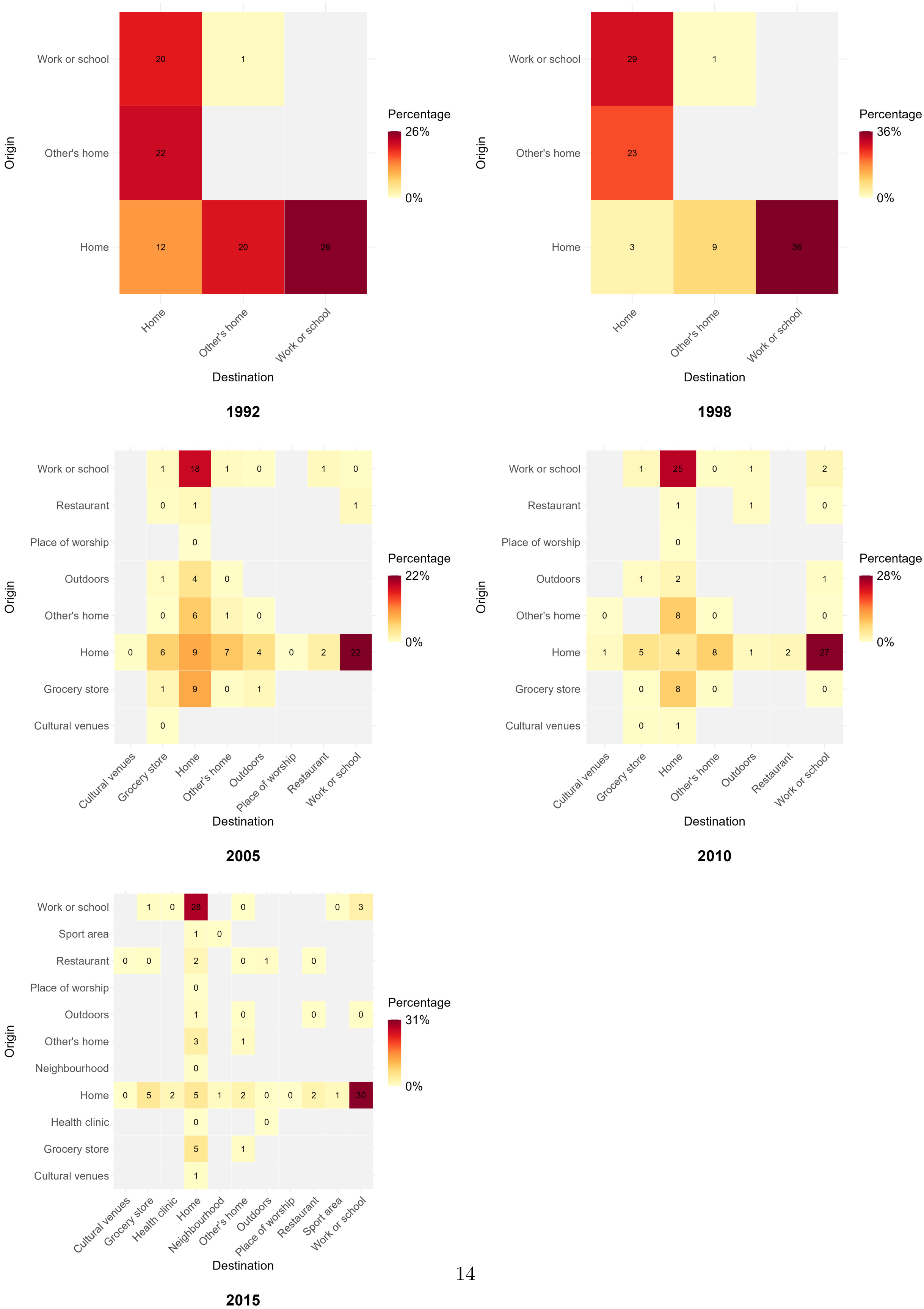

Figure 4: Percentage of walking trips categorized by origin and destination

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