MOBILITY IN AGING: TRAVEL BEHAVIOR AND IMPLICATIONS FOR PHYSICAL ACTIVITY

MOBILITY IN AGING: TRAVEL BEHAVIOR AND IMPLICATIONS FOR PHYSICAL ACTIVITY

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ABSTRACT

Rapid demographic aging in countries around the world has prompted an interest in understanding the mobility patterns of seniors. While much research has been conducted in terms of motorized modes, the promotion of healthy aging argues for new research to investigate the multi-modal travel behavior of seniors including active travel. It is generally agreed that walking is a convenient, safe, and adequate activity for all ages and particularly for seniors, because it places the right amount of stress on their joints. It also is an inexpensive mode of transportation under a wide range of circumstances and can help achieve physical activity guidelines without imposing additional time demands.

The objectives of this dissertation are fourfold. The first two objectives investigate the factors that influence use, length, frequency of two motorized (transit and car) and one active mode of transportation (walking) of seniors. The third objective is to introduce a concept of Compliance Potential Mapping (CPM) that produces maps to show spatial variation in percentage of physical activity requirements seniors obtain from their regular walking for transport. Finally, the dissertation implements a street segment sampling approach and investigates the attributes of walkable environments from the perspective of seniors.

A joint discrete-continuous modeling framework was used to model mode use and trip length simultaneously and, on the other hand, a trivariate ordered probit model was used for estimating the multi-modal trip generation of seniors. CPM concept used simple map algebra operations on maps of spatial variations in trip length and frequency in order to produce potential maps of physical activity compliance. Lastly, the street sampling approach used multinomial spatial scan statistic to detect cluster of street segments where walkability audits can be conducted. Data were drawn from Montreal's Household Travel Survey of 2008. A broad array of covariates related to personal, mobility tools (possession of driver's licence and automobile), neighborhood, and accessibility variables were considered in the models of mode use, trip length, and trip frequency for the Montreal Island.

The results of the analyses reveal a significant degree of geographical variability in the travel behavior of seniors in the Island. In particular, estimates for seniors with different socio- demographic profiles show substantial intra-urban variability in walking behavior, and the role of neighborhood design attributes and accessibility in influencing the mobility of seniors. Demonstration of CPM indicates that seniors in the central parts of Montreal Island obtain higher percentage of physical activity guidelines from walking, but with variations according to gender, income, possession of driver's licence and vehicle. The results of the walkability analysis suggest that, other factors being equal, walking is more prevalent in street segments with marked cross–walks, horizontal and vertical mixtures in land uses, and low traffic volume. Other factors being equal, walking was less prevalent in segments with unmarked cross–walks, single residential and/or vacant land use, and high traffic volume.

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PREFACE

This dissertation is composed of six chapters that are based on four major research papers and an introduction, and conclusion. The research papers have either been accepted or submitted in four different peer-reviewed journals according to their contents and suitability. The first and third papers have already been published whereas second paper is in second round of revisions and fourth one has just been submitted. This dissertation primarily focused on *walking* as a means of physical activity and used same travel diary and built environment databases and, therefore, contains some overlaps in chapters. Those overlaps are mainly in introductions and description of databases. Various research activities including literature review, data manipulation and analysis, modeling, interpreting the results, and writing of the papers were done by the dissertation author. However, Dr. Antonio Páez is co-author of all four papers for his continuous guidance in developing research methodologies, critical appraisal, and editorial reviews. Dr. Catherine Morency provided the travel diary database used in this dissertation. Dr. Khandker Habib and Dr. Darren Scott helped in writing programming script to estimate models of this dissertation. The four research papers in the dissertation are as follows:

Chapter 2:

Moniruzzaman M, Páez A, Habib KM, Morency C (2013) Mode use and trip length of seniors in Montreal, Journal of Transport Geography, 30, 89-99.

Chapter 3:

Moniruzzaman M, Páez A, Scott D, Morency C (2014) Trip generation of seniors and the geography of walking in Montreal, Environment and Planning A (Revised and resubmitted).

Chapter 4:

Moniruzzaman M, Páez A, Morency C (2014) Compliance Potential Mapping: A Tool to Assess Potential Contributions of Walking Towards Physical Activity Guidelines, BMC Public Health, 14(1), 511.

Chapter 5:

Moniruzzaman M, Páez A (2014) An investigation of the attributes of walkable environments from the perspective of seniors in Montreal, Journal of Transport Geography, (Submitted).

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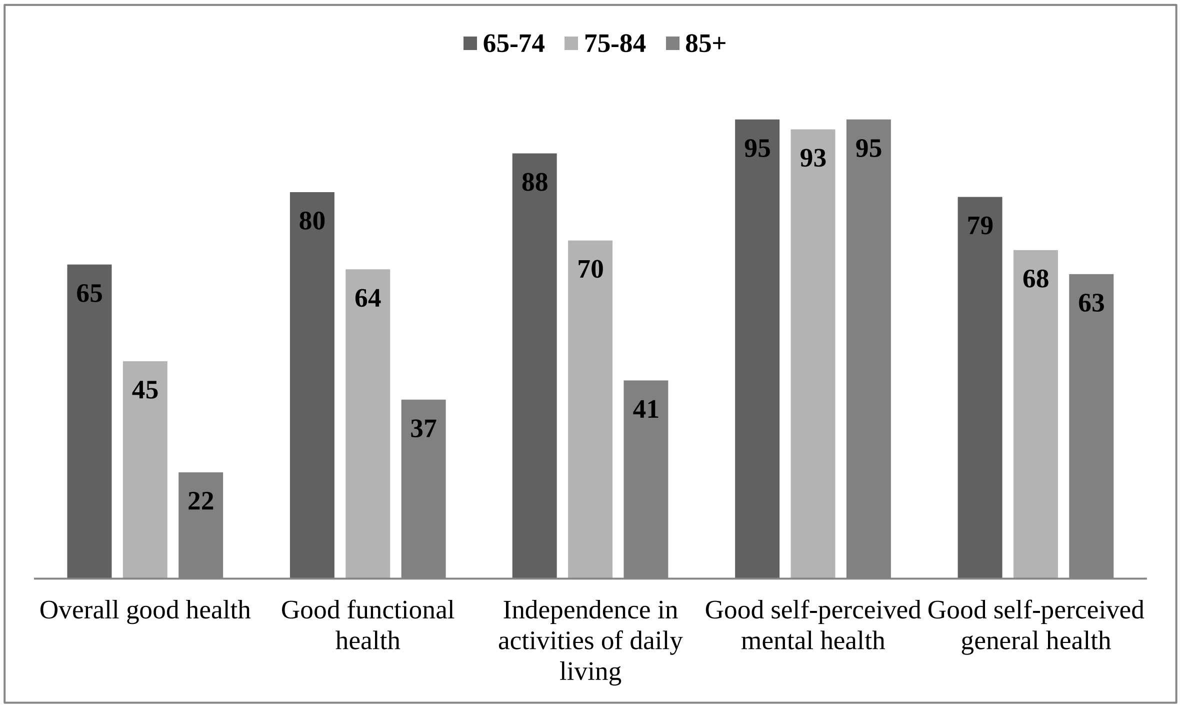
Chapter 1 Introduction

1.1. Justification of research topic

In Canada, people aged 65 years or over are usually considered seniors. The country has been experiencing a more dramatic change in the percentage of the senior cohort than it has faced ever before, as a result of the aging of the baby boomers. For instance, one in four people in Canada is projected to become a senior by 2036 (Statistics Canada, 2010a). Seniors are important for a society because of their knowledge, experience, support and love to newer generations. They are also involved in voluntary and economic sectors (Department of Health and Community Services, 2006). About 10% of seniors in Canada participated in the labor market in 2006 (Uppal, 2010). Ensuring healthy aging among seniors is therefore necessary to continue their involvement in voluntary and economic sectors. Health Canada defines healthy aging as “a lifelong process of optimizing opportunities for improving and preserving health and physical, social and mental wellness, independence, quality of life and enhancing successful life-course transitions”(Health Canada, 2002, p1). The definition encompasses a wide range of health perspectives including seniors’ independence, and quality of life. However these factors are interdependent. For instance, one can maintain good quality of life and independence by being physically, socially, and mentally well and vice-versa. Now the question is how many Canadian seniors are healthy. As seen in Figure 1, 65% of seniors aged 65-74 reported their overall health condition as good and the percentage sharply decreases in subsequent age cohorts. A similar trend was found among seniors for good functional health, and independence in activities of daily living.

Figure 1.1 Percentage of seniors in good health, by age group



(Data source: 2003 Canadian Community Health Survey)

Chronic diseases and/or conditions such as high blood pressure, cardiovascular disease, arthritis, osteoporosis, type-2 diabetes, colon cancer, depression, and anxiety among seniors are the primary reason for their deteriorated health conditions (Colditz, 1999; Dietz et al., 1994; Public Health Agency Canada, 2010; Seguin et al., 2012). For instance, 89% seniors across Canada reported that they had at least one chronic condition in 2009 whereas it was only 60% for the 45-64 year old age group (Public Health Agency Canada, 2010). The high percentage of seniors with chronic condition is actually triggered by increasing physical inactivity among them (Department of Health and Community Services, 2006). In 2010, 58.1% seniors across Canada reported themselves as inactive during leisure-time (Statistics Canada, 2010b). Katzmarzyk et al. (2000), on the other hand, reported that physical inactivity causes 10.3% of total death in Canada with an additional $2.1 billion direct cost in health care expenditures. Older adults that were sedentary or lightly active were found to have higher odds of having heart disease (5 and 3.7, respectively) compared to moderately active individuals (Chen and Millar, 1999). It was also found that seniors in general are at a very high risk (odds of 12.6) relative to younger age cohort (20-44 years) in developing heart diseases. It is evident that seniors are more likely to have heart diseases and the risk is even higher for inactive seniors.

Regular physical activity has numerous health benefits that include reduced risk of chronic diseases, increased life expectancies, better cognitive function, and psychological and overall well-being of seniors (Kruk, 2007; McAuley and Katula, 1998; McAuley et al., 2006; Paterson et al., 2007). It also helps to palliate physiological changes in sedentary individuals as well as assists in the prevention and treatment of disability (Singh, 2002). In sum, increasing physical activity has been identified as a key factor in reducing chronic conditions and diseases, disability, and premature death and therefore holds eminent potential in cutting down the associated health care costs (U.S. Department of Health and Human Services, 1996, 2002).

According to the New Canadian Physical Activity Guidelines, a senior 65 years and older should accumulate at least 150 minutes of moderate-to-vigorous physical activity per week, in bouts of 10 minutes or more (Canadian Society for Exercise Physiology, 2012; Tremblay et al., 2011). Unfortunately, despite the enormous benefits of physical activity, as noted earlier, more than half of seniors in Canada do not meet this minimum physical activity guideline. Further, it is challenging to change behavior and engage seniors in high level physical activities during their leisure time (Crombie et al., 2004). Active transportation (e.g. walking and cycling) can be an alternative viable approach to meeting the minimum physical activity requirements without any additional time demand (Frank et al., 2003; Sallis et al., 2004; Simpson et al., 2003; Wanner et al., 2012). Cycling requires some skills and might not be a good choice for older seniors and therefore walking, being the most popular form of physical activity among older adults, is highly recommended by physicians for seniors of all ages (Duncan et al., 1991; Morris and Hardman, 1997; Rippe et al., 1988; Siegel et al., 1995). Walking does not require any training or preparation and can be undertaken year-round and in different settings (Morris and Hardman, 1997; Mutrie and Hannah, 2004; U.S. Department of Health and Human Services, 2008). It is also good for seniors who were involved in inactive jobs (e.g. sitting in front of computer) in their past life and did not participate in any form of leisure-time physical activities since walking places the right amount of stress on joints (Alberta Center for Active Living, 2007; Elsawy and Higgins, 2010). Past studies also reported that walking provides similar health benefits in seniors as intense physical activity does and bears a lower risk of injury and sudden death (Hakim et al., 1998; Harris et al., 1989; Siegel et al., 1995; U.S. Department of Health and Human Services, 2008). Considering the benefits of walking, it was necessary to explore different walking behaviors to improve our understanding of walking for seniors.

1.2. Research questions and objectives

The primary goal of this dissertation is to investigate elderly travel behavior with a focus on walking. The study began with two research questions. Firstly, what are the factors that influence different mobility behaviors of seniors and, secondly, to what extent can walking for transport, in particular, contribute to meeting the minimum physical activity requirements for seniors? In order to achieve the overall goal and answer the research questions, four specific objectives were addressed in this dissertation. The objectives of the dissertation are listed below:

1) To investigate factors that affect mode use and the associated trip length of seniors with a focus on walking.

However, it may well be the case that a senior in a suburb walks only rarely and therefore derives only limited benefit from walking. Hence, it was important to investigate the frequency of walking trips as well. This was addressed in the second objective.

2) To investigate factors that affect trip generation behavior of seniors with a focus on walking.

The analysis of trip frequencies complements the analysis of the first objective. The next objective used the results of walking trip length and frequency to determine the contribution of walking for transport in meeting the recommended physical activity guidelines for seniors.

3) To introduce a concept of Compliance Potential Mapping in order to assess the potential contribution of walking for transport towards meeting physical activity guidelines for seniors.

Past walkability studies showed that in addition to neighborhood-scale or meso-scale attributes of built environment, street-scale or micro-scale street–scale features are also important in determining the walkability of a neighborhood. However, street-scale built environments are usually not available from secondary sources and require field work to gather information which is usually done by means of walkability audits. The last objective of this dissertation implements an approach to sample street segments for conducting walkability audits and explores features of walkable street segments.

4) To implement a model-based approach to select street segments for walkability audits and to investigate the attributes of walkable environments from the perspective of seniors.

The above four objectives were addressed in detail in the dissertation. In doing so, this dissertation contributes towards a more complete picture of elderly mobility behaviors with an extended analysis to visualize geographic variations of the behaviors. Additionally, it demonstrates how the estimated models of walking behaviors (i.e. trip length and trip frequency) can be used to introduce the concept of CPM to estimate potential contribution of walking towards the minimum physical activity requirements for seniors. Finally the dissertation adopts and adapts the model–based approach proposed by Moniruzzaman and Páez (2012) to select street segments and examines the attributes of walkable environments from the perspective of seniors. To the best of the knowledge of the author, studies in this dissertation are the first examinations of elderly mobility behaviors that show geographic variability in the walking behaviors across space. In doing so, this dissertation significantly contributes to the understanding of elderly travel demand.

1.3. Dissertation contents

The remainder of this dissertation is organized as follows. Chapter 2 examines the socio-economic, urban form, and built environment related factors that influence seniors' trip length and mode use behavior from multi-modal perspectives. The objective of this chapter is to investigate the use of three transportation modes (car, transit, and walking) and associated trip length by seniors in Montreal Island, Canada. A joint discrete-continuous modeling framework was used to estimate the behaviors that account for possible endogeneity of those two processes. Past studies on seniors' travel behavior focused on mode use and trip length. Those studies however estimated the behaviors separately which leaves the issue of endogeneity in the estimation process. By using a joint discrete-continuous model, this study simultaneously estimated the behaviors and thus addressed the issue of endogeneity. Another important feature of this study is the use of a trend surface to visualize the variations in the estimates of mode choice probabilities and trip lengths across the study area. The findings from this study offer valuable insights pertaining to the multi-modal travel behavior of seniors. The use of spatial trend surface helps to detect significant and non-trivial intra-urban variations in the estimates of the length and probability of walking even after controlling for density and built environment variables.

Chapter 3 explores the same set of variables, with additional measures of accessibility, in determining factors that influence the propensity of undertaking different number of trips from the multi-modal perspectives. The objective of this chapter is to analyze the multi-modal trip generation of seniors. Trip frequency of one mode is likely to be dependent on the frequencies of other modes. However, earlier studies on trip generation of older adults disregarded the mode of travel or segmented (and using separate models) by trip purpose only. Therefore, relatively little was known about the walking behavior of seniors in the context of multi-modal trip generation. A trivariate ordered probit model was used to simultaneously estimate the propensity of trip frequencies by multiple modes. In addition to the estimates of observed confounding factors, the model also accounts for common unobserved factors which contribute in the synergistic decision processes. Similar to the model of mode use and trip length, the models of trip generation were also expanded by means of trend surfaces to assess variations in the geography of walking among seniors in Montreal Island. The findings of this study complement the analysis of Chapter 2 by providing a complete picture of seniors' walking behavior from geographic perspectives.

Chapter 4 introduces the concept of a CPM tool to demonstrate how the models of walking behaviors, estimated in Chapter 2 and 3, can be used to estimate the potential contribution of walking towards physical activity guidelines for seniors. The tool uses simple map algebra operations to produce the maps of physical activity compliance. Considering an average walking speed of 68.4 m/min (Montufar et al., 2007) for seniors, 150 min of physical activity is equivalent to 10.26 km of walking per week. Based on estimates of walking trip length and frequency, estimates of expected total daily walking distance are obtained. These estimates are converted to weekly walking minutes, which are in turn compared to the recommended physical activity guidelines for seniors. Compliance Potential Maps offer valuable information for public health and transportation planning and policy analysis by identifying areas where higher level interventions are necessary in order to obtain higher benefits from walking for transport.

Chapter 5 adopts and adapts the model–based approach proposed by Moniruzzaman and Páez (2012) to select street segments and then investigates the attributes of walkable environments from the perspective of seniors. The discrete part of the joint models in Chapter 2 provided the basis of this study. Using the results of the mode use models, walking behavior was estimated and categorized as matched, under or over–prediction. It was hypothesized that better street–scale built environmental features will be found in the street segments where the walking behavior was under–predicted whereas limited street–scale features will be associated with the street segments where the model over–predicted the behavior. Multinomial spatial scan statistics in SaTScan (Jung et al., 2010) were used to detect possible clusters of over– and under–prediction. Street segments were sampled based on the results of cluster analysis. As a proof of principle, an in-person walkability audit using Pedestrian Environment Data Scan (PEDS) and Seniors Walking Environment Assessment Tool-Revised (SWEAT-R) was conducted in the sampled street segments in Montreal Island. The implemented sampling approach can save both time and money by systematically selecting a sample of segments from a relatively large city while capturing valuable information from street segments. Moreover, it provides a list of street-scale built environmental features that encourage seniors to choose walk. This information can provide valuable insights for transportation planners, city designers, and health policy makers interested in active travel and seniors' health.

Finally this dissertation is concluded in Chapter 6 where the findings and clear contributions of this research are summarized. Additionally, this chapter provides suggestions for extensions of this research in the future.

Chapter 2 Mode use and trip length behavior of seniors

2.1. Introduction

Between 2010 and 2031 baby boomers in Canada will become 65 years or older. Like other developed countries, Canada will face a situation of a rapidly aging population during that period. By 2036, the proportion of individuals in this age cohort will comprise between 23% and 25% of the total population and between 24% and 28% by 2061. This represents a dramatic change from 2009, when the proportion of seniors in the population was only 14% (Statistics Canada, 2010). Furthermore, current population projections indicate that by 2036 the composition of the population by age groups will remain relatively stable, upon completion of the transition of baby boomers into the senior age cohort (Statistics Canada, 2010). The prospect of a future when seniors will be more numerous both in relative and absolute terms has prompted attention in various cognate disciplines, such as health sciences and gerontology. Attention has also been drawn to the implications for transportation and urban planning as they relate to aging societies (e.g. Mercado et al., 2007; Schmocker, 2009; Schwanen and Páez, 2010).

Previous research into the travel behavior of seniors has tended to concentrate on their mobility by motorized modes (Farber and Páez, 2009; Hough et al., 2008; e.g. Rosenbloom, 2001; Scott et al., 2009; Smith and Sylvestre, 2001). Missing appears to be research that addresses the multi-modal travel behavior of seniors, including active modes. This is of particular interest, given the connections between mobility, well-being, and health (Dora and Racioppi, 2003; Jakobsson Bergstad et al., 2011). While its importance for the activity participation of older adults has been demonstrated (e.g. Páez et al., 2007; Schmocker et al., 2005), motorized mobility does not contribute to physical activity, and may in fact enable more sedentary lifestyles (Frank et al., 2004; Roorda et al., 2010) and increase the risk of depression for seniors upon driving cessation (Marottoli et al., 1997). In contrast, it is generally agreed that walking is a convenient, safe, and adequate activity for all ages and particularly for seniors, because it places the right amount of stress on joints (Alberta Center for Active Living, 2007; Cunningham and Michael, 2004; Melzer et al., 2004; Owen et al., 2004). Walking among seniors has been found to correlate with better physical function (Wong et al., 2003) and enhanced odds of preserving cognitive functions (Prohaska et al., 2009), as well as greater longevity (Manini et al., 2006; Takano et al., 2002). An advantage of walking is that it also is an inexpensive mode of transportation under a wide range of circumstances (Alberta Center for Active Living, 2007) and, if incorporated as part of daily routines, can help achieve physical activity guidelines without imposing additional time demands. Hence, walking is an inexpensive way of simultaneously adding years to life and improving their overall quality.

With these considerations in mind, the objective of this chapter is to investigate the use of various modes of transportation and associated trip length by seniors in Montreal, Canada. There are three major features to this paper. First, we examine the use by seniors of motorized and active modes of transportation. Secondly, we use a modeling framework to jointly analyze mode choice and trip length, which allows us to account for the endogeneity of these two processes. Previous studies of elderly travel behavior have concentrated separately on either mode choice (e.g. Buehler et al., 2011; Hekler et al., 2012; Pucher et al., 2011; Van Cauwenberg et al., 2012) or trip length (e.g. Mercado and Páez, 2009; Morency et al., 2011). To the best of our knowledge, this study is the first effort to simultaneously model these two behaviors for seniors. Finally, we adopt a spatial analytical approach. Spatial analysis has been identified as a fruitful route to improve the way we study transportation processes (Miller, 1999; Páez and Scott, 2004). In our case we take advantage of the availability of geo-referenced data to implement trend surfaces in the joint models. This use of spatial analysis allows us to visualize the variations in the estimates of mode choice probabilities and trip lengths across the study area.

The case study is the Montreal Island, in Canada. Data are drawn from Montreal's Household Travel Survey of 2008. The results of this research help to identify many of the factors that influence the use and range of different modes of transportation by seniors in Montreal. As an illustration of the potential of our spatial analytical approach, we examine a number of individual profiles for the case of walking. The example reveals significant geographical variations in the propensity to walk and the length of walking trips in our case study. The findings should be of interest to transportation and health planners concerned with policy measures that aim at increasing walking by members of the older cohorts.

2.2. Literature Review

2.2.1. Modal choice

Use of different transportation modes has been extensively studied in the past. However, a majority of studies mainly focus on the working age cohorts with only few researches for seniors for both work and non-work related trips. Stern (1993) in a study of rural Virginia represents an early effort to model the mode choice behavior of elderly and disabled people. Later on, Kim and Ulfarsson (2004) and Schmocker et al. (2008) studied the mode choice behavior of seniors as a function of their personal, household, neighborhood and trip characteristics and found that with increasing age seniors become less likely to drive. This finding is echoed in the study by Tacken (1998). Increasing auto ownership decreases the likelihood to use public transit and increases the likelihood of driving (Kim and Ulfarsson, 2004; Schmöcker et al., 2005). The likelihood of driving also increases with increasing income and household size (Kim and Ulfarsson, 2004; Schmöcker et al., 2005). More recently, van den Berg et al. (2011) analyzed the travel mode choices of senior citizens in The Netherlands for social trips only, and found results consistent with those reported by Kim and Ulfarsson (2004). They also found urban density as a significant variable in the mode choice models.

2.2.2. Trip length

Trip length has also previously been studied in travel behavior research (e.g. Khattak et al., 2000; Naess, 2006; van den Berg et al., 2011). This aspect of mobility is of particular interest in the case of seniors because it is considered a good measure of "everyday competence" (see Mercado and Páez, 2009, p. 65). Various studies in different national settings have found that older people travel less than younger people (Schwanen et al., 2004; Tacken, 1998). In Canada, Mercado and Páez (2009) found that motorized trip length in the Hamilton CMA tends to decrease with age, with the most dramatic loss in mobility for car drivers. The finding that individuals become less mobile as they age is corroborated by the research of Morency et al. (2011). The findings about the effect of age are moderated by other variables. For example, older people tend to travel longer distances for recreational trips (Schmocker et al., 2005) and social trips (van den Berg et al., 2011). Males are more likely to travel longer or make more trips than females (Tacken, 1998; van den Berg et al., 2011). Mercado and Páez (2009) found a mixed result for this variable when they independently regressed the distances traveled as car driver, car passenger, and bus. Females traveled longer distances as car drivers but shorter distances as car passenger and bus riders. Income and possession of a driver's licence have a fairly consistent significant positive relationship with trip length across age cohorts (Mercado and Páez, 2009; Morency et al., 2011; Páez et al., 2010b; Tacken, 1998; van den Berg et al., 2011). For those who drive, there appears to be a negative significant relationship between trip distance and household size (Mercado and Páez, 2009). Household structure also has been found to be a key variable. In a case study of Netherlands, van den Berg et al. (2011) found that older individuals living with a partner make shorter social trips when compared to single seniors. Examination of occupation status shows that seniors employed part-time or unemployed travel shorter distances relative to seniors with full time jobs, in the case of motorized transport modes (Mercado and Páez, 2009). A similar finding is reported by van den Berg et al. (2011) for the case of social trips.

2.2.3. Research Gaps

The focus of the studies cited above has been for the most part on motorized travel. In this paper we examine the multi-modal behavior of seniors, including walking. To be certain, studies exist that analyze walking by seniors. For instance Van Cauwenberg et al. (2012) used data from over 48,000 Flemish seniors collected in the period 2004-2010. Hekler et al. (2012) compared utilitarian walking and walking for leisure in 16 older adults. Kim (2011) investigated the mobility alternatives of seniors upon driving cessation using a national survey by the American Association of Retired Persons (AARPs) and Schmocker et al. (2008) used the London Area Travel Survey to study mode choice of seniors, including walking. However, none of these studies considers trip length.

Other studies considered the probability of walking combined with only a very coarse description of trip length. Among these, Buehler et al. (2011), used national travel surveys from the US and Germany to investigate the probability of “any walking” and “30 minutes of walking and cycling” over two time periods. Previously, Pucher et al. (2011) analyzed the National Household Travel Survey, and considered as outcomes “any walking/cycling” and “30 minutes walking/cycling”. Lim and Taylor (2005) defined adequate physical activity as at least 30 minutes of walking (or other activities). Conversion of a continuous variable (trip length in minutes) into a dichotomous one (at least 30 minutes) involves significant loss of information.

Although a few researches have concentrated on the trip length of seniors by different modes, nonetheless they lack information about walking and do not consider the probability that trips are made by different modes of transportation. See for example Mercado et al. (2009) and Morency et al. (2011).

Less frequently, trip generation, mode choice, and/or trip length are reported in a single paper, but the analysis uses separate models for each outcome variable and/or use descriptive statistics only (see Collia et al., 2003; Schmöcker et al., 2005; van den Berg et al., 2011).

As our review of the literature indicates, previous studies of elderly travel behavior have separately modeled mode choice and trip length of seniors. To the best of our knowledge, our paper is the first effort to simultaneously investigate these two behaviors for the senior age cohorts using a tightly-coupled joint discrete-continuous modeling approach (see Habib, 2011). More specifically, we develop a joint model whereby mode choice is represented by means of a multinomial logit function, and trip length is modeled using a hazard function. One advantage of this approach is that it explicitly deals with the issue of sample selection bias (a detailed discussion of selection bias in endogenous processes can be found in Train, 1986, Chapter 5). Endogenous effects have been found, for instance, in the choice of vehicle type and mileage driven (Spissu et al., 2009). A second advantage of the modeling approach selected is that trip length can be modeled as a continuous variable without the loss of information that results from reducing this variable into a discrete form.

A second research gap that we identify is the limited geographical resolution in the study of mode choice and trip length. Some of the studies identified above use large national surveys wherein geocoding often is limited to a state, or metropolitan area, or occasionally just an indicator variable for urban and rural respondents (see Buehler et al., 2011; Kim, 2011; Pucher et al., 2011; Van Cauwenberg et al., 2012). Other studies are based on much smaller samples with limited geographical coverage and extent. For instance, Hess and Russell (2012) use a sample of 207 seniors, Hanson and Hildebrand (2011) use a sample of 60 rural seniors, and Hekler et al. (2012) use an even smaller sample of 16 participants. In our case, availability of a large, fully geocoded travel survey that includes walking means that analysis can be conducted at a much higher level of geographical resolution.

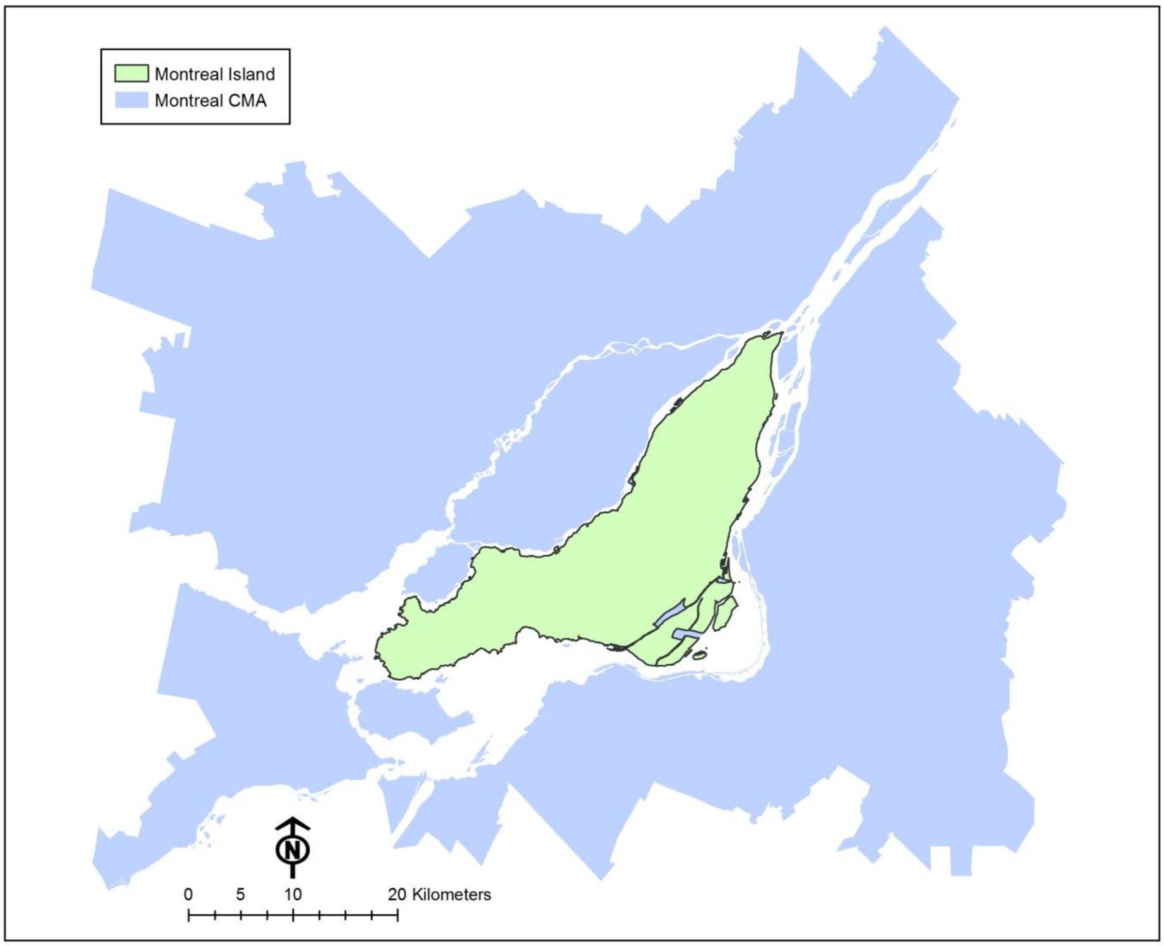
2.3. Context and Data

2.3.1. Context

The study area is the Montreal Island in the province of Quebec, Canada. Montreal is at the core of the most populous area in the province of Quebec, and the second most populous area across Canada (Figure 2.1). The Island has observed relatively high demographic growth for many years. This, however, has also been accompanied by a rapid population aging process. The proportion of seniors in the province is expected to rise to 18% in 2016, 24% in 2026, and 31% in 2051. In the Montreal region, the proportion of seniors increased from 10.6% to 13.6% in the period between 1987 and 2003. This proportion has already exceeded 60% in some census subdivisions located in Montreal

Island. Importantly, recent research indicates that the senior population is geographically dispersing at a higher rate than the general population (Morency and Chapleau, 2008), thus highlighting the importance of adopting a spatial perspective.

Figure 2.1 Map of Montreal Island with Montreal Census Metropolitan Area (CMA)



With respect to modes of travel, a report published by TCAÎM (2008) reveals that car (driver or passenger) is the preferred mode of transportation among seniors in Montreal Island, followed by transit and then walking. Despite the preference for cars, 52% of the seniors in Montreal Island do not drive and those who drive tend to avoid driving during the night, at rush hour and/or in high-traffic areas. In addition, 18% of them live in households without access to a car (Morency and Chapleau, 2008). With respect to transit, the difficulty involved in using metro services (multi-level stairs, relatively longer distances between metro stations) makes the use of buses the main preference of the public alternatives. Walking is the third preference among seniors in the Island.

2.3.2. Montreal's Household Travel Survey

The database used for this study is Montreal's Household Travel Survey of 2008. This data collection program was started in 1970 and has been conducted periodically at intervals of approximately 5 years since then. The data of 2008 is the ninth edition of the origin-destination (OD) survey conducted for the entire metropolitan area. In addition to being the largest survey of mobility in Quebec, it is one of the largest travel data collection programs in the world. The principal objective of this travel survey is to provide data to support transportation planning and operations in the region, applied and basic travel behavior research, and is increasingly being used for a variety of applications as well, including examinations of accessibility to health care (Páez et al., 2010a), accessibility to food (Páez et al., 2010b), and linguistic segregation and exposure patterns (Farber et al., 2012).

The instrument utilized to collect the data is a Computer Aided Telephone Survey. In 2008, the survey was conducted from September 3rd to December 19th in the year. The fall months are chosen as the travel patterns are generally more stable in the time period. The sample rate for 2008 is 4.1%, which represents a population of 3.94 million. All trips made by a respondent who performed out-of-home activities are recorded in the database. The origin and destination of these trips are geocoded using various trip identifiers such as address, nearest intersections or trip generators.

For the purposes of this analysis, a subset of trips was extracted to include only home-based trips, that is, all trips where one end of the trip was the place of residence made by the senior cohorts. It is noteworthy to mention that although the Montreal Household Travel Survey targets a sample rate of 5% of total population across the Montreal Census Metropolitan Area, the DMTI database for built environment was not so rich outside of Montreal Island and therefore we confined our analysis within the Island only. Home-based trips provide a spatial anchor for the geographical element of this study. In addition to being more systematic, they also account for a large proportion of trips among the population of interest.

With respect to the population selected for the study, research concerning seniors typically takes as a cut-off age the traditional retirement age of 65. In the particular case of Canada, individuals aged 65 years or more are officially considered as seniors (Turcotte and Schellenberg, 2006). We also include the transitional cohort of individuals aged 55-64 years.

After extracting the subset, a few observations were also removed because of extremely low variability of some attributes – for instance there were only a few dozen points corresponding to seniors who were students, or were lone parents of young children – or to remove nonsensical observations – such as trips recorded with a length of zero. The transportation modes considered are the most prevalent in the region, namely car, transit, and walking, to the exclusion of modes infrequently used by seniors in the area, such as cycling. Based on these criteria, we retrieved a total of 31,631 one-way home-based trips, for all purposes and three modes of transportation.

2.3.3. Neighborhood variables

Neighborhood design attributes i.e. density, diversity, and design (Cervero and Kockelman, 1997) have influence on the walking behavior of seniors (Borst et al., 2008; Inoue et al., 2010; Nagel et al., 2008). Compact and mixed land use development ensures the availability of various activity locations in short distances. Hence, neighborhoods with those characteristics make its residents more conducive to walk towards the nearest activity centers – for instance grocery stores, pharmacy, restaurants etc. In addition to individual's socio-demographic attributes, we consider two land variables, namely population density and employment density. These two variables are also calculated at individual level, and are categorical based on the tertiles of their corresponding distributions. On the other hand, the built environment attributes are based on the Dissemination Area (DA) of the place of residence. The DA is the smallest census geography publicly available, which in the case of Montreal is on average 0.15 km^2 (s.d.=0.55 km^2). Attributes of built environment considered are street density (based on centerline length), intersection density (based on number of four or more way intersections), and building footprint density. Intersection density is related to route directness to different destinations and, is a useful attribute for measuring walkable neighborhoods. Building square footage to land ratio is another built environment attribute which is used to measure the percentage of built up area in the neighborhood. Prior expectation is that these variables will positively contribute to the model of walking behavior.

For calculating land use mix, four types of land uses were considered in this study – namely residential, commercial, government and institutional, and parks and open spaces. The calculated parameter has values between 0 to 1, where 0 indicates perfect homogeneity and 1 indicates perfect diversity in the land uses. The following normalized entropy formula was used to calculate the land use mix:

$$-\frac{1}{ln(N)}\sum_{i=1}^{N} P_i \ln(P_i) \tag{1}$$

where P_i is the proportion of land uses i and N is the number of land uses considered.

All these attributes of neighborhood design were extracted from the geographic file 'CanMap RouteLogistics' prepared by DMTI spatial (DMTI Spatial Inc., 2009).

2.3.4. Explanatory variables

Selection of variables for the analysis of modes used and their associated trip lengths is informed by a scan of the literature pertaining to the study of travel behavior and physical activity for older adults. The dependent variable of the continuous hazard model in the analysis is the natural logarithm of trip length in km. This transformation is used to reduce the scale of the variable, and to ensure that estimated trip lengths are positive. The full list of explanatory variables considered is shown in Table 2.1.

Table 2.1 Variables with definitions and distributions (Number of seniors (N) = 13,127)

Variable name	Description	n (% of N)
Age: Younger senior	If age is 55 to 64 years =1, 0 otherwise	15812 (49.99)
Age: Senior	If age is 65 to 74 years =1, 0 otherwise	9990 (31.58)
Age: Elder senior	If age is 75 or more =1, 0 otherwise	5829 (18.43)
Gender	If female = 1, 0 otherwise	16984 (53.69)
Driver's licence	If status of driver's licence is yes =1, 0 otherwise	24282 (76.77)
Household type: Single	If household is of indicated type =1, 0 otherwise	9582 (30.29)
Household type: Couple	If household is of indicated type =1, 0 otherwise	15477 (48.93)
Household type: Other multi-person household	If household is of indicated type =1, 0 otherwise	6572 (20.78)
Occupation: Full-time	If occupation is of indicated type =1, 0 otherwise	9302 (29.41)
Occupation: Part-time	If occupation is of indicated type =1, 0 otherwise	2233 (7.06)
Occupation: Retired	If occupation is of indicated type =1, 0 otherwise	19120 (60.45)
Occupation: At-home	If occupation is of indicated type =1, 0 otherwise	976 (3.09)
Income: <20k	If income is less than $20,000 =1, 0 otherwise	3600 (11.38)
Income: 20-40k	If income is $20,000 to 39,999 =1, 0 otherwise	6197 (19.59)
Income: 40-60k	If income is $40,000 to 59,999 =1, 0 otherwise	4439 (14.03)
Income: 60-80k	If income is $60,000 to 79,999 =1, 0 otherwise	2775 (8.77)
Income: 80-100k	If income is $80,000 to 99,999 =1, 0 otherwise	1603 (5.07)
Income: >100k	If income is more than $100,000 =1, 0 otherwise	2794 (8.83)
Income: RF/DK	If income is do not know or refused =1, 0 otherwise	10223 (32.32)
Population density: Low	If population density is of indicated type=1, 0 otherwise	5455 (17.25)
Population density: Medium	If population density is of indicated type=1, 0 otherwise	11372 (35.95)
Population density: High	If population density is of indicated type=1, 0 otherwise	14804 (46.8)
Job density: Low	If employment density is of indicated type=1, 0 otherwise	18454 (58.34)
Job density: Medium	If employment density is of indicated type=1, 0	9159 (28.96)

	otherwise	
Job density: High	If employment density is of indicated type=1, 0 otherwise	4018 (12.7)
Neighborhood: Street density	Total street lengths (km)/DA area (square km)	
Neighborhood: Intersection density	Total number of intersections /DA area (square km)	
Neighborhood: BSF to DA	Total area of building square footage/DA area	
Neighborhood: Land use mix	Values between 0 to 1	
Trend surface: CBD distance	Euclidian distance from Central Business District (CBD) to home location	
Trend surface: *X*, *Y*	Coordinates of home location	

2.4. Methods

2.4.1. Joint discrete-continuous model

Analysis is based on the estimation of a joint discrete-continuous model. The discrete mode component is modeled using a multinomial logit model (MNL), whereas a continuous time hazard-based model is employed to model trip length (Day et al., 2009).

The MNL model component assumes that each individual i has a level of net utility U_{mi} associated with mode of transportation m:

$$U_{mi} = V_{mi} + \varepsilon_{mi} = \beta_m x_{mi} + \varepsilon_{mi} \tag{2}$$

According to Random Utility Maximization theory (Ben-Akiva and Lerman, 1985), the net utility is decomposed in terms of V_{mi}, a systematic utility component, and a random variable, ε_{mi}, that captures the unobservable parts of the net utility. Further, V_{mi} is a function of a set of explanatory variables (x_{mi}) and corresponding parameters (β_m). According to this theory, alternative mode m is chosen by individual i, if the utility of that mode is the maximum of all alternatives.

$$U_{mi} > \max_{n=1,2,3......M,\, n \neq m} U_{ni}$$

$$V_{mi} > \left\{ \max_{n=1,2,3......M,\, n \neq m} U_{ni} \right\} - \varepsilon_{mi}$$

$$\therefore$$

$$\begin{aligned} \Pr(U_{mi} > \max_{n=1,2,3......M,\, n \neq m} U_{ni}) &= \Pr\left(V_{mi} > \left\{ \max_{n=1,2,3......M,\, n \neq m} U_{ni} \right\} - \varepsilon_{mi} \right) \\ &= \Pr\left(V_{mi} > (V_{ni} + \varepsilon_{ni}) - \varepsilon_{mi} \right) \\ &= \Pr\left(V_{ni} \leq V_{mi} + (\varepsilon_{mi} - \varepsilon_{ni}) \right) \end{aligned} \tag{3}$$

Assuming that the error term of the utility function of equation (3) is identically and independently distributed (IID) Type I Extreme-Value (Gumbel), the implied cumulative distribution of the random error term of the chosen alternative, $F(\varepsilon_{mi})$ can be written as (Habib et al., 2008; McFadden, 1973; McFadden, 1978):

$$\Pr\left(V_{mi} > V_{ni}\right) = F\left(\varepsilon_{mi}\right) = \frac{\exp\left(V_{mi}\right)}{\exp\left(V_{mi}\right) + \sum_{n \neq m} \exp\left(V_{ni}\right)} = \frac{\exp\left(\beta_m x_{mi}\right)}{\exp\left(\beta_m x_{mi}\right) + \sum_{n \neq m} \exp\left(\beta_n x_{ni}\right)} \tag{4}$$

Equation (4) is the formula of the well-known Multinomial Logit (MNL) model.

The continuous time hazard model components are primarily concerned with the total distance traveled in one trip (considered as individual events) by travelers choosing specific modes. We consider a continuous time hazard model formulation that allows us directly interpreting the relationship between covariates and distance traveled due to their multiplicative effect on time (Day et al., 2009).

The basic formula describing event termination in hazard models is the hazard rate $\lambda(l)d(l)$, which is the conditional probability of event termination occurring between distance l and $l+dl$ given that the event has not terminated before length l. For unit length step, $dl=1$, the hazard rate is expressed simply by $\lambda(l)$. The mathematical expression of the hazard rate is: $\lambda(l)=f(l)/[1-F(l)]$. Where the cumulative distribution function $F(l)$ describes the probability of event termination before time l, $F(l)=Pr[L<l]$ and $f(l)$ is the corresponding probability distribution function, $f(l)=dF(l)/dl$. Similarly, the survivor function $S(l)$, which defines the probability that the event's duration will be greater than or equal to time l, is defined as $S(l)=Pr[L\geq l]=1-F(l)$. Therefore, the hazard function can also be re-written as: $\lambda(l)=f(l)/S(l)$. Assuming that the covariates act in the form $exp(\theta Z)$, the continuous time hazard model can be expressed as: $S(l|Z)=S0[l.exp(\theta Z)]$ and $\lambda(l|Z)=h0[l.exp(\theta Z)]exp(\theta Z)$. Following the method outlined by (Kiefer, 1988), it can be shown that the hazard model can be expressed in the following equivalent linear form:

$$\ln(l_{mi}) = \theta Z_{mi} + \alpha_{mti} \tag{5}$$

Considering normal distribution assumption that gives a log-normal hazard model, we get:

$$
\begin{aligned}
f(\alpha_{mi}) &= \frac{1}{t_{mi}\sigma_{mti}}\phi\left(\frac{\ln(l_{mi})-\theta Z_{mi}}{\sigma_{mti}}\right)\\
F(\alpha_{mi}) &= \Phi\left(\frac{\ln(l_{mi})-\theta Z_{mi}}{\sigma_{mti}}\right)
\end{aligned}
\tag{6}
$$

Joint estimation of the hazard and MNL models requires the random error terms of both models to be correlated. Following Lee's transformation technique, the marginal distributions of the two random variables, namely $F(\varepsilon_{mi})$ and $F(\alpha_{mti})$, can be expressed as equivalent standard normal variables, it can be shown that (Lee, 1983):

$$
\begin{aligned}
\varepsilon^*_{mi} &= J_1(\varepsilon_{mi}) = \Phi^{-1}[F(\varepsilon_{mi})]\\
\alpha^*_{mi} &= J_2(\alpha_{mti}) = \Phi^{-1}[F(\alpha_{mti})]
\end{aligned}
\tag{7}
$$

Here, Φ^{-1} indicates the inverse of the cumulative standard normal variable. Considering that these two transformed random variables are bivariate normal distributed, we can derive the likelihood of observing a discrete mode choice and a total positive amount of distance traveled by the chosen mode:

$$
\begin{aligned}
&\Pr\left(\text{Distance} = l_m \cap Mode = m\right) = \Pr\left(\text{Distance} = l_m \cap \varepsilon \le J_1\left(\varepsilon_m\right)\right)\\
&= \frac{1}{\sigma_{mt} l_m}\phi\left(\frac{\ln\left(l_m\right)-\theta_m Z_m}{\sigma_{mt}}\right)\Phi\left(\frac{J_1\left(\varepsilon_m\right)-\rho_{mt} J_2\left(\alpha_{mt}\right)}{\sqrt{1-\rho^2_{mt}}}\right)
\end{aligned}
\tag{8}
$$

Here $\varphi(\bullet)$ and $\Phi(\bullet)$ indicate respectively the PDF and CDF of the standard normal distribution. Based on the above formulation, the log-likelihood *(LL)* function of a sample of observations with sample size *N*, *(i=1, 2, ……..N)* can be written as:

$$\sum_{i=1}^{N}\sum_{m=1}^{M} D_{mi} \ln\left[\varphi\left(\frac{\ln\left(l_{mi}\right)-\theta Z_{mi}}{\sigma_{mti}}\right)\right] - D_{mi}\ln\left(l_{mi}\sigma_{mti}\right) + D_{mi}\ln\left[\Phi\left(\frac{J_1(\varepsilon_{mi}) - \rho_{mti}\left(\frac{\left(\ln\left(l_{mi}\right)-\theta Z_{mi}\right)}{\sigma_{mti}}\right)}{\sqrt{1-\rho_{mti}^2}}\right)\right]$$

(9)

Here, D_{mi} is the indicator variable for choosing alternative *m* by individual *i*. In this paper, parameter estimates for β, θ, ρ, and σ are obtained by maximizing the above log-likelihood function using code written in GAUSS, which applies the BFGS optimization algorithm (Aptech Systems, 2009). The parameters ρ of the joint model refer to the correlation between unobserved factors affecting the discrete and continuous outcomes. According to equation (8) a negative value of ρ implies a positive correlation and vice-versa.

2.4.2. Spatial coefficient expansion

A model with spatially-varying coefficients can be obtained through the application of the spatial expansion approach. This method, developed by Casetti (1972), codifies a set of principles to develop regression models that represent substantive knowledge about a process, and allow for the presence of contextual variation. In the case of a spatial dataset, the model can be expanded by means of a spatial trend surface, useful to investigate spatial variations in regression relationships (Fotheringham and Brunsdon, 1999; Páez and Scott, 2004). The approach is highly flexible, can be adapted to different modelling approaches, and used to capture contextual variation of model parameters and functional forms (Anselin, 1992).

In the present case, we expand the coefficients by the location of seniors' place of residence. Different functions can be used for the expansion; typically, polynomial trend surfaces are selected. In this study, we adopted a quadratic trend surface that can be written as follows:

$$\theta_1 u_i^2 + \theta_2 u_i + \theta_3 u_i v_i + \theta_4 v_i + \theta_5 v_i^2 \tag{10}$$

where u_i and v_i are the coordinates of senior's location i and θs are the corresponding coefficients. The example above is for a quadratic expansion. Implementation of a linear trend, or conversely higher-order expansions can be done in a similar straightforward fashion. It should also be clear that the expansion method can also be adopted to systematize variable interactions in regression analysis. More extended discussions of the advantages of the expansion method in this type of application can be found in the papers by Morency et al. (2011) and Roorda et al. (2010).

2.5. Results and Discussion

2.5.1. Joint discrete-continuous model results

In this section we describe and discuss the result of our analysis. The discrete part of the model contains three modes of transportation – namely car, transit, and walking. The continuous part of the model is the trip lengths made by the respective mode. A forward specification search was conducted starting with the constants only, for both the multinomial and hazard models, and the search proceeded by incorporating the list of variables in Table 2.1.

The results of the specification search are shown in Tables 2.2 and 2.3. Table 2.2 includes the multinomial logit model coefficients and Table 2.3 the hazard model coefficients for all variables. It is important to note that 'car' was taken as the reference alternative in the multinomial model. At the beginning of this study, car trips were modeled separately i.e. car trips as driver and car trips as passenger. However, the coefficients for the driver models were relatively same, both in magnitude and direction, as the coefficients for the passenger models and therefore they were combined as a single mode. Finally, note that a trend surface has only been estimated for walking trips and their lengths. For this reason, the constant should not be compared directly to those of other modes, but should be seen in the context of the trend surface (more on this below).

In terms of the specification of the model, a likelihood ratio test is significant and indicates a superior fit to the naïve (i.e. constants only) model. The correlation between the random parts of the discrete and continuous models, captured by ρ (see Table 2.3) is –0.623. This value indicates significant positive correlations between the error terms of the mode use and trip length processes. In other words, the joint unexplained components of the mode choice and trip length models tend to co-vary in the same direction.

The highlights of the analysis are as follows. First, we note that the probability of using transit and walking decreases with age. Age was introduced as three categories in the model. Compared to the younger seniors (i.e. age 55 to 64), seniors (65 to 74) and elder seniors (75 or over) are less likely to choose walking as their mode of travel, and their walking trip length tends to decrease as well. The overall reduction in the likelihood of walking with increasing age is offset to some extent by being employed part time, being retired, or staying at home for the case of walking, but not for the case of transit. This stands in contrast to previous research whereby the progression of mode choice among the elderly is firstly car, then public transit, and then walking (Rosenbloom, 2003). Females are slightly less likely to walk. They also tend to undertake shorter trips by transit. Possession of driver's licence significantly, and quite substantially, reduces the propensity of seniors to use transit and walk, and also is associated with longer trips by car, but shorter trips by transit and walking.

Household structure is also found to significantly affect mode usage and trip length. Seniors living with a partner or in other types of multi-person households have a reduced tendency to use transit and walk, perhaps because of sharing responsibilities, or a greater need or facility to use a car. Trip length when traveling by car tends to increase when living with others, but the effect is negative for transit and walking trips, which tend to be shorter. Individuals who work part-time, are retired, or stay at home are less likely to use transit, but more likely to walk than to use car. More relaxed time constraints would suggest the ability to make longer trips. However, this is the case only for walking, as it can be seen that individuals employed full time tend to make longer trips by car or transit, relative to other occupation types. This suggests that relaxed time constraints are associated with both a higher preference for walking and longer walking trips.

Higher income is associated with a reduced probability of using transit and walking. In the case of transit, the effect is monotonic, with the negative effect being consistently stronger at higher income levels. The results for walking indicate negative bumps at lower middle incomes and higher incomes. A possible explanation for this is that individuals with lower middle income levels may be more limited in their ability to select walking as a mode, or for higher incomes a reduced preference for this mode. Trip length for seniors traveling by car increases with income, but tends to be shorter for higher income seniors traveling by transit. Higher income seniors traveling on foot, on the other hand, also display a tendency towards longer trips.

Table 2.2 Estimation results of joint discrete-continuous model: multinomial logit component (car is the reference mode)

	Transit		Walking	
	Estimates	Prob.	Estimates	Prob.
Constant	1.3160	0.0000	8.4455	0.0000
Age: 55-64	Reference		Reference	
Age: 65-74	-0.1732	0.0001	-0.2834	0.0000
Age: 75+	-0.5085	0.0000	-0.3967	0.0000
Gender (female)	0.0154	0.6669	-0.0708	0.0494
Driver's licence	-2.4086	0.0000	-1.8781	0.0000
Household structure: Single	Reference		Reference	
Household structure: Couple	-0.8210	0.0000	-0.6202	0.0000
Household structure: Other	-0.6586	0.0000	-0.7680	0.0000
Occupation: Full-time	Reference		Reference	
Occupation: Part-time	-0.2082	0.0024	0.3553	0.0000
Occupation: Retired	-0.6317	0.0000	0.5412	0.0000
Occupation: At home	-0.5611	0.0000	0.4857	0.0000
Income: <20	Reference		Reference	
Income: 20-40	-0.3369	0.0000	-0.4644	0.0000
Income: 40-60	-0.7476	0.0000	-0.8228	0.0000
Income: 60-80	-0.7496	0.0000	-0.7057	0.0000
Income: 80-100	-0.9474	0.0000	-0.5094	0.0000

Income: >100	-1.2462	0.0000	-0.8003	0.0000
Income: RF/DK	-0.6427	0.0000	-0.5462	0.0000
Population density: Low	Reference		Reference	
Population density: Medium	0.1291	0.0256	0.0839	0.1868
Population density: High	0.5021	0.0000	0.3890	0.0000
Employment density: Low	Reference		Reference	
Employment density: Medium	0.4287	0.0000	0.0125	0.7561
Employment density: High	1.6401	0.0000	0.3645	0.0000
Neighborhood: Intersection density	-0.0007	0.1445	-0.0002	0.7181
Neighborhood: BSF to DA	0.7164	0.0000	1.8931	0.0000
Neighborhood: Street density	0.0114	0.0172	0.0127	0.0081
Neighborhood: Land use mix	-0.0192	0.8066	0.1789	0.0219
Trend surface: CBD distance	-	-	-2.4645	0.0000
Trend surface: X^2	-	-	0.4668	0.0000
Trend surface: X	-	-	-3.5789	0.0000
Trend surface: XY	-	-	0.1223	0.1757
Trend surface: Y	-	-	-1.7657	0.0000
Trend surface: Y^2	-	-	0.8180	0.0000

Note: gray cells indicate $p>0.05$

Table 2.3 Estimation results of joint discrete-continuous model: continuous component (dependent variable is natural logarithm of trip length in km)

	Car		Transit		Walking	
	Estimates	Prob.	Estimates	Prob.	Estimates	Prob.
Constant	Reference		1.5988	0.0000	2.1000	0.0005
Age: 55-64	Reference		Reference		Reference	
Age: 65-74	-0.0228	0.2762	-0.1259	0.0009	-0.1352	0.0004
Age: 75+	-0.0772	0.0029	-0.3431	0.0000	-0.2533	0.0000
Gender (female)	-0.0110	0.5004	-0.0682	0.0213	0.0107	0.7317
Driver's licence	0.7643	0.0000	-0.3607	0.0000	-0.2026	0.0000
Household structure: Single	Reference		Reference		Reference	
Household structure: Couple	0.2284	0.0000	-0.1201	0.0003	-0.0576	0.0954
Household structure: Other	0.2511	0.0000	-0.0570	0.1520	-0.1193	0.0096
Occupation: Full-time	Reference		Reference		Reference	

Occupation: Part-time	-0.1155	0.0006	-0.2137	0.0002	0.1117	0.0971
Occupation: Retired	-0.2619	0.0000	-0.6224	0.0000	0.2781	0.0000
Occupation: At home	-0.3478	0.0000	-0.6755	0.0000	0.2446	0.0029
Income: <20	Reference		Reference		Reference	
Income: 20-40	0.3088	0.0000	-0.0027	0.9503	-0.1003	0.0326
Income: 40-60	0.4848	0.0000	-0.0698	0.1902	-0.0721	0.2220
Income: 60-80	0.4259	0.0000	-0.0747	0.2626	-0.0610	0.3911
Income: 80-100	0.5543	0.0000	-0.1865	0.0285	0.2055	0.0125
Income: >100	0.5116	0.0000	-0.3287	0.0000	0.2213	0.0037
Income: RF/DK	0.3708	0.0000	-0.0975	0.0222	0.0186	0.6735
Population density: Low	Reference		Reference		Reference	
Population density: Medium	-0.1024	0.0000	-0.0541	0.3000	-0.0759	0.2121
Population density: High	-0.2813	0.0000	-0.1387	0.0069	-0.0878	0.1538
Employment density: Low	Reference		Reference		Reference	
Employment density: Medium	-0.1055	0.0000	0.0702	0.0317	0.0306	0.3881
Employment density: High	-0.0650	0.0419	0.5793	0.0000	0.0170	0.7563
Neighborhood: Intersection density	-0.0004	0.1207	-0.0004	0.3549	-0.0005	0.2383
Neighborhood: BSF to DA	-0.6872	0.0000	-1.4888	0.0000	-0.1821	0.2501
Neighborhood: Street density	0.0071	0.0016	-0.0030	0.4424	0.0079	0.0613
Neighborhood: Land use mix	0.0755	0.0388	-0.1187	0.0663	-0.0375	0.5721
Trend surface: CBD distance	-	-	-	-	-1.1754	0.0000
Trend surface: X^2	-	-	-	-	0.2376	0.0001
Trend surface: X	-	-	-	-	-1.7088	0.0000
Trend surface: XY	-	-	-	-	0.0031	0.9727
Trend surface: Y	-	-	-	-	-0.5917	0.0259
Trend surface: Y^2	-	-	-	-	0.3472	0.0000
Correlation between discrete and continuous models			-0.6229 (p<0.0001)			
Observations			31,631			
Log likelihood (constants only model)			-77,468.43			
Log likelihood (full model)			-69,282.01			
Likelihood ratio test			16,372.28 (p=0.0002)			

Note: gray cells indicate *p*>0.05

The effect of urban structure is to increase the probability of traveling by transit or foot as the density of employment and population increases. However, this effect is only observed for high density in the case of walking. In this regards, 53% of seniors lived in high density urban areas in 2008 (down from 55% in 2003). Higher density also tends to decrease the length of trips by car, but increase the length of trips by bus. On the other hand, while high density makes walking more likely, it does not have an impact on trip length by this mode. Something similar is observed for other neighborhood characteristics. Thus, higher built density (BSF to DA), street density, and land use mix increase the probability of walking, but not distance traveled by this mode. Higher built density and street density also increase the probability of using transit. Of the three different modes examined, trip length by car appears to be most influenced by neighborhood characteristics. Higher built density tends to decrease the length of car trips, whereas street density and land use mix tend to increase it.

2.5.2. Geographical perspective on walking behavior by seniors

The effect of individual variables was discussed in the preceding section. The findings confirm previous research which indicates that trip length decreases with age, and the probability of using specific modes of transportation changes with age. A key feature of our analysis is to make it clear that these changes may not be uniform, but rather can display important variations over space, even within an otherwise uniform cohort. The key to this is the use of a trend surface, which in our model combines distance from CBD and a quadratic function for the coordinates shown in Table 2.1. The fact that the components of the trend surface are significant implies that the probability of walking and the length of walking trips vary over space. In other words, even identical seniors (e.g. same income, same age, same gender, etc.) have different probabilities of walking and of making shorter or longer trips, depending on their location. Given the number of covariates used in the model, a useful approach to understand the net effect of various variables (including location) on walking behavior is to map the estimated values for the behavior of interest (see Morency et al., 2011; Roorda et al., 2010). For instance, a question of interest is the change in the probability of selecting walking as travel mode for low income and high income seniors, living in the central city and in the suburbs. Also of interest is the effect of age, income, and place of residence on the estimated length of walking trips. Other attributes can be explored as desired, for instance variations between two genders, possession of driving licence, and so forth.

In order to visualize the estimated probability and length of walking trips, we superimpose a regular grid-cell of size 1 km^2 over the entire study area. This grid-cell is used for visualization purposes only, and the size of the cells has no impact whatsoever on the preceding analysis. To illustrate the effect of some key variables on the behaviors of interest, we created five individual senior profiles, which define a set of variables to input into the model to obtain estimates of the probability of walking and the length of the associated trip. The profiles are summarized in Table 2.4. The coordinates of centroid of the grid-cells are used for the spatial attributes in the following analysis. In each profile, there are, excluding location, twelve attributes. Of these, six attributes are associated with socio-demographic characteristics, and remaining six are neighborhood characteristics. All neighborhood attributes are variable across grid-cells, and derived from the nearest senior or DA from the centroid grid-cells. To compare the spatial variations among the profiles, we have also created a basic senior profile by conducting frequency analysis among the attributes; this renders the typical senior (Profile 0), consisting of the characteristics most frequently found in the dataset (note that there are slightly more females than males in the population, and that most of the seniors in the dataset have income range 20-40 thousand of dollars). In this respect, Profile 0 was compared with other senior profiles to visualize variations in spatial behavior. It is also noteworthy to mention that, while estimating the propensity and trip length of the walking mode, only the parameters significant at *p*-value less than 0.1 were considered.

Profiles 0 through 2 correspond to a senior female and are identical in all respects but age. This set of profiles is intended to illustrate the effect of age in the walking behavior of females of different ages. Similarly, Profiles 3 and 4 are identical to Profile 0, but with variations in the level of income. The following subsections describe the results of this analysis.

Table 2.4 Individual profiles for estimating the probability of walking and walking trip length

Variables	Base Profile	Age Profiles		Income Profiles	
	0	**1**	**2**	**3**	**4**
Age	**55-64**	**65-74**	**75+**	55-64	55-64
Gender	Female	Female	Female	Female	Female
Household structure	Couple	Couple	Couple	Couple	Couple
Occupation	Retired	Retired	Retired	Retired	Retired
Income	**20-40k**	20-40k	20-40k	**<20k**	**40-60k**
Driver's licence	Yes	Yes	Yes	Yes	Yes
Population density	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior

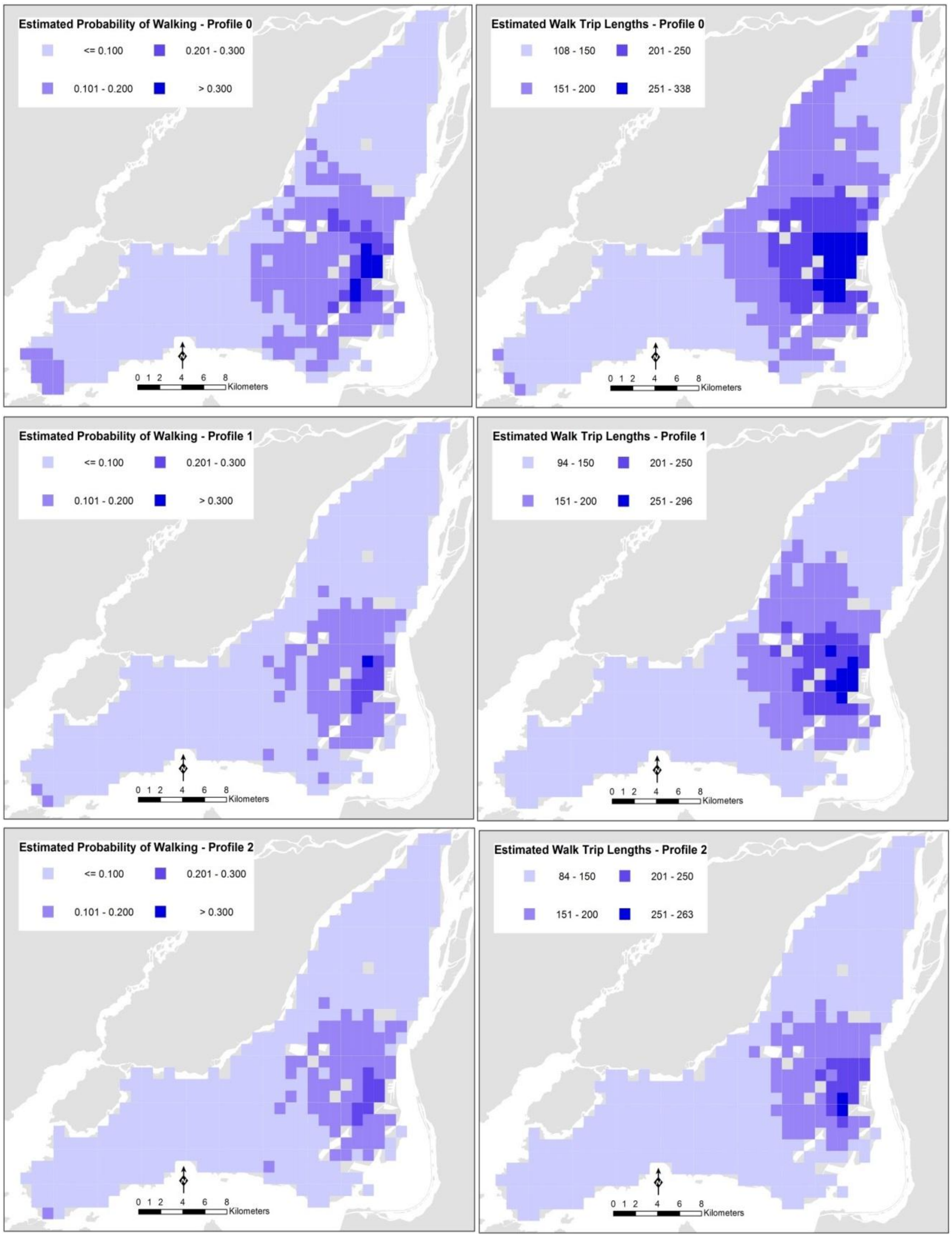
Job density	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior
Street density	Nearest DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA
Intersection density	Nearest DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA
BSF to DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA
Land use mix	Nearest DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA

N.B. Text in bold indicates respective change in the profiles

Geographical Variations by Age

Figure 2.1 shows the spatial variation in estimated probability of walking and the length of corresponding trips for Profiles 0, 1, and 2. The only difference among these profiles is age. Initially, we observe that there are important geographical variations in the probability of walking among otherwise identical seniors. As seen in the figure, individuals corresponding to the profiles under analysis are more likely to walk in the central part of the city than in most suburbs. For instance, for the youngest of the three cohorts analyzed (age 55 to 64) there are numerous locations where the estimated probability of walking exceeds 0.1, and in some cases is above 0.3. The probability of walking and the geographical variability in this behavior tend to decrease with increasing age. The number of locations where the probability of walking is less than 10% increases for the older seniors in Profiles 1 and 2.

Figure 2.2 Geographical variations in estimated probability of walking (left) and walking trip length (right) as a function of age.



As seen in the figure, the general pattern of spatial variations is consistent between age groups. For seniors of all age categories, the estimated probabilities indicate a greater propensity to walk in the central part of the Montreal. These probabilities drop to levels below 10% away from the central core of the city, with the exception of the southwestern tip of the Island, where the probability of walking tends to be slightly higher than the surrounding suburban locations.

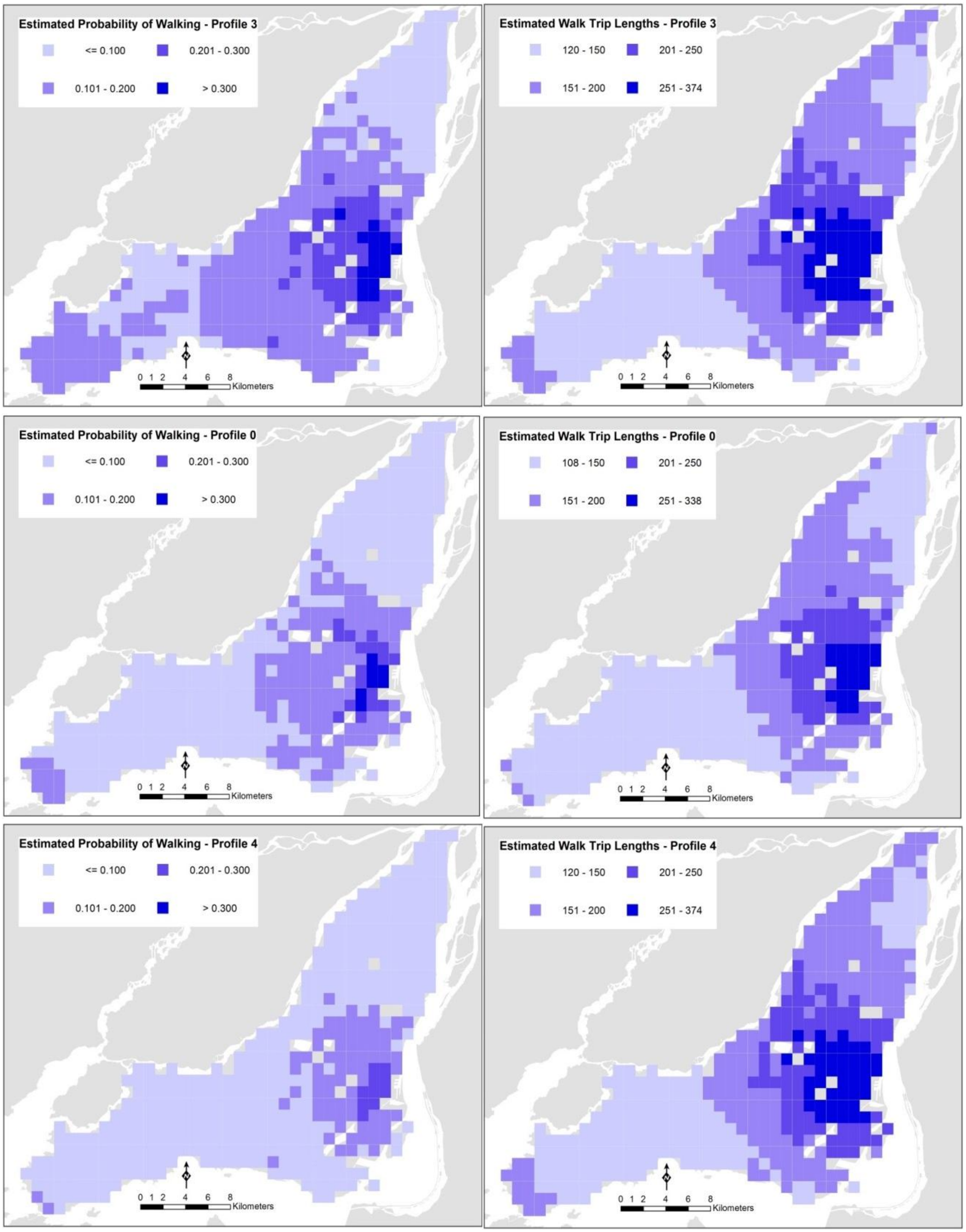
Walking trip lengths are estimated in a similar way. The general pattern of variation is similar to that observed for the probability of walking, decreasing from the central parts of Montreal Island. In other words, other things being equal, seniors are more likely to walk, and also to make longer walking trips, when their place of residence is in the central parts of the city, even after controlling for density and neighborhood built environment variables. As expected, trip length tends to decline with increasing age. Trip length tends to be relatively modest, at less than 150 m per trip, for most of Montreal Island for seniors aged 75 and older, with the exception of the downtown core. Similarly, trip lengths for individuals in the 55 to 64 cohort who walk, are estimated to surpass 150 m along a broad band across the center of the Island, and exceed 250 m in the downtown core. Geographical variations in the probability and extent of walking suggest that even for the oldest cohort analyzed, the prospect of compliance with physical activity guidelines is better in the downtown core than in the suburbs. Conversely, younger seniors living in the suburbs are unlikely to meet physical activity guidelines by walking.

Variations by Income

A second comparison of interest is with respect to the effect of income in walking behavior. The results appear in Figure 2.2. Profiles 3, and 4 are generated as counterparts of Profile 0 (base profile), to illustrate the effect of income. The difference among these profiles is in the income ranges, with Profile 0 representing a senior with an income 20-40 thousand dollars and Profile 3 with an income less than 20 thousand dollars, whereas Profiles 4 represents more affluent seniors, with incomes in the 40-60 thousand dollars range.

The comparison among income groups indicates that the lowest income seniors (Profile 3) are more likely to take walk trips (with probabilities in the range between 0.101 and 0.200). One step increase in income class reduces the propensity of taking walk trips (Profile 0) and this propensity is further reduced for Profile 4 with income level between 40-60 thousand dollars. In terms of estimated trip lengths, there is no difference in trip length between Profile 3 and 4 as income less than 20 thousand dollars (Profile 3) was taken as a reference category and income 40-60 thousand dollars is not significantly different from this class. On the other hand, walking trips of individuals corresponding to Profile 3 (income less than 20 thousand dollars) tend be longer relative to seniors corresponding to Profile 0 (income 20-40 thousand dollars). Geographic variability follows a similar pattern as it is as a function of age, i.e. residents in the central core of the Island are more likely to walk, and take longer walking trip as well.

Figure 2.3 Geographical variations in estimated probability of walking (left) and walking trip length (Right) as a function of income.



2.6. Summary and Conclusions

As is the case in most of the developed world, the number of seniors in Canada will rapidly increase and then stabilize within the next four decades. A topic of current interest, given its connections to well-being and health, is the mobility of seniors. In this study, we investigated the use of different modes of transportation and the associated trip lengths for seniors in Montreal Island. Using Montreal's Household Travel Survey of 2008, and a joint discrete-continuous modelling framework, we investigated the effect of several individual, household, and neighborhood design variables, on the propensity of using three modes of transportation, and the length of these trips. Trip length is a useful measure that relates to everyday competence and, in the case of walking, can be linked to estimates of physical activity.

The findings from this study offer valuable insights pertaining to the multi-modal travel behavior of seniors. First, the probability of using transit and walking decrease (with respect to traveling by car) as people age. Trip length also decreases with increasing age, albeit more substantially for the case of transit and walking than for car. The effect of urban form (population and employment density) and neighborhood design factors (built density, street density, and land use mix) is to increase the probability of walking, but not the length of walking trips.

Spatial modeling allowed us to detect significant and non-trivial intra-urban variations in the estimates of the probability of walking (and by inference, of other modes as well). Spatial variations in trip length – even after controlling for density and built environment variables – are also noteworthy. In particular, we found that seniors of all ages considered are more likely to walk and to undertake longer trips when their place of residence is in the central parts of the Island.

An interesting feature of our spatial modeling approach is that estimates of trip length can be readily converted to proportion of recommended weekly physical activity time. According to the Public Health Agency of Canada, seniors should participate in at least 2.5 hours or 150 minutes of moderate-to-vigorous physical activity per week, with a recommendation to break down activities into sessions of 10 min or more (Public Health Agency of Canada, 2011). Considering an average walking speed of 68.4 m/min (Montufar et al., 2007), each return walking trip of 300 m would provide approximately 5.85% of weekly recommended physical activity. This would decrease to 4.87%, 3.90%, and 2.92% for return walking trips of 250, 200, and 150 m respectively. Therefore, a single walking trip per day, with its corresponding return, could provide between 20% and 41% of weekly recommended physical activity if conducted regularly during the week. Maps displaying the variations in estimated trip length can be examined to assess the potential contribution to physical activity guidelines of typical walking trips in different parts of Montreal.

As a complement, probability maps for undertaking walking trips can also provide estimates of compliance with physical activity guidelines. The analysis, for instance, indicates that younger and/or more affluent seniors around the CBD area tend to undertake longer walk trips that could potentially provide in excess of 46% of recommended physical activity time if conducted regularly. At the same time, the probability of a given trip being conducted on foot is in the neighborhood of 0.30. In other words, approximately one out of every three trips undertaken by these individuals is a walking trip.

A direction for further research, to complement the results presented in this paper, is to investigate the frequency of trip making by different modes. If this frequency also displays geographical variations similar to those observed for trip length, the result would be a fuller, more complete picture of the walking behavior of seniors from a geographical perspective.

Chapter 3 Trip generation behavior of seniors

3.1. Introduction

The number and proportion of people in the senior age cohorts in post-industrial nations is increasing at a historically rapid rate. The growth rate of these cohorts will accelerate in the next 25 years as individuals of the baby boom generation reach their senior years. Canada, a case in point, had 4.7 million seniors in 2009, twice the number recorded for this age group in 1981. Depending on specific growth rate projections, it is estimated that there will be between 9.9 and 10.9 million seniors in Canada by 2036 and between 11.9 and 15.0 million by 2061 (Statistics Canada, 2010).

Along with changing demographics, there is increasing evidence that the travel and activity behavior of seniors in Canada is changing (Newbold et al., 2005; Scott et al., 2009), a phenomenon observed in other developed countries (e.g. Alsnih and Hensher, 2003; Burkhardt and McGavock, 1999; Collia et al., 2003; Schmocker et al., 2010) and some developing countries as well (Pettersson and Schmoeker, 2010). Seniors in Canada, as in other English-speaking countries, tend to grow old in their own homes in order to remain engaged in their usual social, recreational, and/or volunteer activities (Rosenberg and Everitt, 2001; Turcotte, 2012). Having come of age in an era of pervasive urban sprawl supported by mass personal motorization, concerns have been raised that contemporary and future generations of older adults will be increasingly car dependent (Alsnih and Hensher, 2003; Rosenbloom, 2001) and at risk of social exclusion (Páez et al., 2009).

To be sure, car remains the most popular mode of transportation, and use of other modes is substantially lower. In Canada, the share of transit among adults aged 75 to 84 is only 7%, and 4% for walking and cycling combined (Turcotte, 2012). Previous research, however, indicates that seniors who use their car become dramatically less mobile (Mercado and Paez, 2009), perhaps due to self-censoring, the onset of functional limitations, or even preference for a more sedated lifestyle (Raitanen et al., 2003; Schmocker et al., 2005; Turcotte, 2012; Ziems et al., 2010). Alternative transportation, in particular para-transit, is an attractive option that combines aspects of public transportation with a degree of flexibility not afforded by fixed route services. It is questionable, however, whether on-demand para-transit services can be sufficiently deployed to meet the needs of a growing elderly population because of high cost and an adverse fiscal environment (Hess and Lombardi, 2005; Mercado et al., 2010). Reliance on motorized modes, moreover, may in fact be part of a vicious circle, by contributing to declining health conditions that could further reduce mobility in aging (Frank et al., 2004).

In contrast to automobility and transit use (including para-transit), walking represents an inexpensive mode of transportation that, if feasible, could help seniors to simultaneously meet their daily mobility and physical activity needs. Walking is in fact considered a fine leading off physical activity for older adults who were sedentary in their early life (Alberta Center for Active Living, 2007; Cunningham and Michael, 2004; Owen et al., 2004). Furthermore, walking has been found to increase cognitive function (Yanagimoto et al., 1999), to a greater extent even than other forms of exercise (Nagamatsu et al., 2013). Despite the appeal of walking, this mode of transportation may not be for everyone, due to individual demographic and socio-economic circumstances, the availability of mobility tools such as driver licence and vehicle ownership (Scott and Axhausen, 2006), and the characteristics of the surrounding environment, among other factors. It is therefore of interest to understand the factors that promote or deter walking for seniors, both from a transportation/urban planning as well as from a public health perspective (Buehler et al., 2011).

In this paper we analyze the trip generation of seniors, with a focus on walking, while simultaneously considering two other common modes of transportation, car and transit. The trip generation of older adults has been the subject of previous research, however disregarding the mode of travel (e.g. Pettersson and Schmoeker, 2010; Roorda et al., 2010), or segmenting (and using separate models) by trip purpose only (e.g. Páez et al., 2007; Schmocker et al., 2005). As a consequence, relatively little is known about the walking behavior of seniors in the context of multi-modal trip generation. To examine this issue we use a trivariate ordered probit model which accounts for common unobserved factors that contribute to trip making frequency by multiple modes. Individual socio-demographic, mobility, neighborhood, and accessibility variables are examined to assess their associations with trip frequencies by the three modes. Spatial expansion of model coefficients, implemented by means of trend surfaces (see Bailey and Gatrell, 1995), allows us to assess variations in the geography of walking among seniors in Montreal.

3.2. Background

Early studies of trip generation were mostly aggregated in nature, with observations collected for areal units, for instance zip codes, census tracts, or traffic analysis zones. While some studies of the trip generation of seniors still rely on this approach, mainly for practical applications (e.g. Flynn and Boenau, 2007), progress in data collection and the availability of disaggregated data sets have made it possible to analyze trip generation processes at the individual level, primarily using limited dependent variable models (Greenwald and Boarnet, 2001; Guo et al., 2007; Pettersson and Schmoeker, 2010; Roorda et al., 2010; Schmocker et al., 2005; Sehatzadeh et al., 2011). These studies have found statistically significant associations between trip frequency and individual characteristics, including age, gender, household structure, income, mobility tools, and neighborhood built environments.

Past studies have found that contemporary seniors tend to be more mobile and make diversified trips relative to earlier generations of seniors (Schwanen and Páez, 2010). For instance, comparing the travel behavior of older Americans from 1983 to 1995, Rosenbloom (2001) found that seniors in 1995 made 77% more vehicle trips, spent nearly 40% more time driving, and drove 98% more miles than seniors in 1983. While senior's travel appears to have increased, it still lags behind the mobility of younger age cohorts. Indeed, the bulk of research on aging and mobility indicates that with increasing age mobility becomes generally more limited (Kim, 2003; Mercado and Paez, 2009; Schmocker et al., 2005; Tacken, 1998), although substantial between-place and between-person heterogeneities have been reported in some cases (e.g. Páez et al., 2007; Roorda et al., 2010). In terms of use of car, Alsnih and Hensher (2003) reported that seniors in the 65-75 year cohort are not significantly different from 18-59 age cohort.

Gender is also a factor that has been found to influence travel behavior. Women live longer (Arber and Ginn, 1991), their health conditions deteriorate earlier (Arber and Cooper, 1999; Leveille et al., 1999), and they tend to live alone more frequently and be less affluent than older men (Rosenbloom et al., 2002). As a result, the mobility needs of older women tend to be different from those of older men (Kim, 2003). In general, women make fewer trips than men (Schmocker et al., 2005; Tacken, 1998), although this may be alleviated by having good social support (Hough et al., 2008).

Household structures also influence the mobility behavior of elderly people and show significant association with trip generation. Schmoeker et al. (2005) in the study of seniors 65 years or over and "younger disabled" who are less than 65 found that compared to couples with children, all other households make more shopping and recreational trips. They also found that, in the case of personal business trips, single households make more trips than people who live with a couple and children. Roorda et al. (2010) studied the trip generation behavior of vulnerable populations in three Canadian cities (Hamilton, Montreal and Toronto) and showed that compared to single households, couples and couples with children make fewer trips in all three cities. Trip generation is also influenced by the employment status of seniors. Compared to seniors who are not employed, seniors who work part or full time tend to travel more frequently (Páez et al., 2007; Roorda et al., 2010).

Household income also affects the trip generation of seniors. According to Roorda et al. (2010) higher income associates positively with trip making in Montreal. Schmoeker et al. (2005) found in their study of London that individuals in middle income households (between 10-50 thousand) tend to make fewer work and personal business trips, but those in higher income make more recreational trips. Similar income effects were reported for older people in Metro Manila (Pettersson and Schmoeker, 2010). Nonetheless, van den Berg et al. (2011) did not find any significant relationship with income classes for the number of social trips. Trip generation is also affected by various mobility tools. Several studies report that vehicle ownership and use, and driver licence possession, have a positive impact on trip frequency by car, and a negative impact on the use of transit and walking (Lachapelle and Noland, 2012; Páez et al., 2007; Roorda et al., 2010; Schmocker et al., 2005; Sehatzadeh et al., 2011).

As well, there is evidence that neighborhood characteristics influence the trip generation behavior of individuals, although the results remain mixed (Cao et al., 2010; Kim, 2003; Sehatzadeh et al., 2011; van den Berg et al., 2011). Factors related to the neighborhood environment are more likely to impact choices relating to slower, non-motorized modes, in particular walking (Moniruzzaman et al., 2013). For instance, in their study of walking frequency Sehatzadeh et al. (2011) report that, in addition to direct effects, built environment variables indirectly impact walking through their effect on vehicle ownership. Other built environment-related attributes such as street density, intersection density, land use mix, have also been found to influence the mobility decisions of aging individuals (Nagel et al., 2008; Saelens and Handy, 2008; Sallis et al., 2004; Sehatzadeh et al., 2011). Many of the studies regarding mobility and built environments, particularly when the focus is walkability, often deploy a composite walkability index that combines several related neighborhood attributes (Cervero and Kockelman, 1997; Frank et al., 2005; Leslie et al., 2007; Saelens et al., 2003). As an alternative, the number of activity locations close to an individual's residence, and distances to those nearest activity locations can be used to study trip generation (Naess, 2006). Better accessibility to activity locations is conducive to walking, and tends to discourage driving and vehicle possession (Krizek and Johnson, 2006; Sehatzadeh et al., 2011).

3.3. Methods

Conventional tools to analyze trip generation include the ordered probit model (Hough et al., 2008; Páez et al., 2007; Pettersson and Schmoeker, 2010; Roorda et al., 2010; Schmocker et al., 2005) and the negative binomial model (Cao et al., 2010; van den Berg et al., 2011). These models can be used for analysis of overall trips, or by segmenting the sample to consider a specific mode of transportation (e.g. walking or car or public transit) and/or a specific trip purpose (working or shopping or recreational trips). It is possible, however, for travel decisions, made by seniors, by different modes to be correlated due to unobserved common factors. For example, a traveler may use car more frequently because of the need to reach places not serviced by transit. An unobserved factor can have a positive impact in the decision to use certain modes, and a negative one in the decision to use others. A multivariate-outcome model is appropriate in such situations (Guo et al., 2007).

To study the multi-modal trip generation of seniors, we use a trivariate ordered probit. This is a model for three ordinal outcomes, which are analyzed jointly with due consideration to their potential correlations (Scott and Kanaroglou, 2002). In this paper, the three ordered responses are the trips made by seniors on three modes of transportation. For illustration, let *m*, *n*, and *o* represent the number of trips made by a senior, *i*, by walking, car, and public transit, respectively. Therefore, the structure of the model with the ordered choices can be written as:

$$\begin{aligned}
y_{1i}^{*} &= \beta_1 x_{1i} + \varepsilon_{1i}, y_{1i} = m, \text{ if and only if } \mu_{m,1} < y_{1i}^{*} \le \mu_{m+1,1}, \\
y_{2i}^{*} &= \beta_2 x_{2i} + \varepsilon_{2i}, y_{2i} = n, \text{ if and only if } \mu_{n,2} < y_{2i}^{*} \le \mu_{n+1,2}, \\
y_{3i}^{*} &= \beta_3 x_{3i} + \varepsilon_{3i}, y_{3i} = o, \text{ if and only if } \mu_{o,3} < y_{3i}^{*} \le \mu_{o+1,3}
\end{aligned} \tag{11}$$

where y^*_{1i}, y^*_{2i}, and y^*_{3i} are latent variables that reflect the propensity to undertake *m*, *n*, and *o* trips by each mode. The *x's* and *β's* are the vectors of explanatory variables and their respective coefficients, whereas the *μ's* are estimable threshold parameters. The random components ε_{1i}, ε_{2i}, and ε_{3i} are assumed to follow a joint trivariate normal distribution with zero mean and the following variance-covariance matrix:

$$R = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix} \tag{12}$$

where the *ρ's* are the correlations among the unexplained part of the models, i.e., the *ε's* in equation (1). Nonzero elements in the correlation matrix **R** indicate that there are common unexplained factors present in the model. The probability that a senior *i* will take *m*, *n*, and *o* trips respectively by each of three modes can be written as:

$$P_{mnoi} = \int_{-\infty}^{-\beta_1 x_{1i}} \int_{-\infty}^{-\beta_2 x_{2i}} \int_{-\infty}^{-\beta_3 x_{3i}} \phi_3(\varepsilon_1, \varepsilon_2, \varepsilon_3, \rho_{12}, \rho_{13}, \rho_{23}) d\varepsilon_3 d\varepsilon_2 d\varepsilon_1 \qquad (13)$$

where ϕ_3 (●) is the trivariate normal cumulative density function.

The parameters to be estimated within the trivariate ordered probit modeling framework include the β parameter vectors, *m+n+o-3* thresholds, and *ρ's*. The parameters are estimated by forming a likelihood function which requires the computation of trivariate normal integrals.

3.4. Data sources

3.4.1. Montreal's Household Travel Surveys

The same database used for this study i.e. Montreal's Household Travel Survey conducted in 2008. The transportation modes considered are the most prevalent in the region and frequently used by seniors, including traveling by car (both as driver and passenger), transit, and walking, to the exclusion of modes infrequently used by seniors, such as cycling. There are some studies where trip frequencies are analyzed by their purposes – for instance, walking for transport versus recreation (Spinney et al., 2012), work trips by walking (Craig et al., 2002), non-work trips by car (Boarnet and Sarmiento, 1998), non-work trips by all modes (Cervero and Kockelman, 1997). In this study instead we concentrate on the use of different modes, while aggregating by all trip purposes. Based on these criteria, we retrieved a total of 31,631 home-based trips in 2008 undertaken by 13,127 seniors, for all purposes and three modes of transportation.

3.4.2. Selection of Variables

Time-geography (Hagerstrand, 1970) provides a useful conceptual framework for variable selection. The way different time-geographic constraints and facilitators affect the mobility of seniors is discussed by Mercado and Páez (2009). Of interest are individual level variables that relate to personal capabilities and constraints, such as age, gender, household structure, occupation, and income. Mobility tools, such as driver licence and vehicle ownership, influence the trade-offs between space and time, and are known to influence behavior. In addition, land use and built environment attributes provide information about the context for mobility. Density variables are consistent with theories of urban development (Alonso, 1964), whereas empirically there is increasing evidence of the importance of the built environment in influencing travel behavior (Handy et al., 2005). In addition to the list of variables appeared in Table 2.1, the following variables were added to the list for this study.

Table 3.1 Additional list of explanatory variables with description

Variable name	**Description**
Vehicle ownership	Number of household vehicle
Built environment: Network density	Principal component computed from street density and intersection density
Accessibility: Activity locations	Number of activity locations within a quarter-mile (400m)

	distance from the home location*10^{-3}
Accessibility: Nearest pharmacy	Distance from home to the nearest pharmacy (km)
Accessibility: Nearest health facility	Distance from home to the nearest health facility (km)
Accessibility: Nearest bank	Distance from home to the nearest bank (km)
Accessibility: Nearest grocery	Distance from home to the nearest grocery store (km)
Accessibility: Nearest library	Distance from home to the nearest library (km)

Among the built environment related variables considered in Chapter 2, street density (based on centerline length) and intersection density (based on number of four or more way intersections) are highly correlated which the author failed to test in Chapter 2. In order to reduce the risk of collinearity, street density and intersection density (correlation coefficient=0.75) were preprocessed using principal component analysis (PCA). As a result, the first principal component (which accounted for 87% of total variability) was used as a more general network density variable.

Accessibility variables considered are number of activity locations available locally and distance to five nearest essential facilities, namely pharmacy, health facility, bank, grocery, and library. In the case of local activity locations, it encompasses including wide variety of establishments, such as churches, restaurants, museums & art galleries, amusement parks, etc. These variables were obtained from a business location database and distance calculations. To calculate the number of local activity locations, a 400 m buffer around the place of residence was used, a value selected to provide a behavioral basis for accessibility (see Paez et al., 2012) based on previous results regarding the trip length of seniors in Montreal (Chapter 2).

3.5. Results and discussion

The dependent variables for the model were number of trips seniors undertook by mode, classified into trip generation categories as shown in Table 3.2. After categorization, the ordered dependent variables were regressed against a broad array of explanatory variables, as listed in Table 2.1 and 3.1. The starting point for a specification search was with a fully specified model, with variables selected based on theoretical and empirical reasons as discussed above. Then, a general-to-specific search was conducted to generate the most parsimonious model possible. This was accomplished by gradually removing the least significant variable until all remaining variables were significant at $p<0.05$. This type of specification search is preferred to reduce the risk of omitted variable bias (Greene, 2003). For comparison purposes, a null model was also estimated using the threshold parameters only. The log-likelihood of the null model is -23,024.505. The log-likelihood for the full model with only significant variables is -19,932.3. The likelihood ratio for the models is 6184.41 which is greater than the critical value of chi-squared (95.751) with 57 degrees of freedom (the number of significant variables in the final models except the thresholds) at the $p<0.001$ level of significance.

Table 3.2 Frequency distributions of all home-based trips of seniors made by modes

	Frequency after reclassification		
Number of trips	Walking	Car	Public transit
0	10594	4573	10006
1-2	2206	7077	2945
3 or more	327	1477	176

The goodness of fit of the models was evaluated using an overall goodness of fit statistic, namely McFadden's adjusted-ρ^2 (Train, 2003) which is calculated by following equation:

$$\bar{\rho}^2 = 1 - \frac{LL(\beta) - K}{LL(c)} \tag{14}$$

where $LL(\beta)$ is the value log-likelihood for the full model, $LL(c)$ is the log-likelihood for the null model, and K is the number of explanatory variables. The likelihood ratio index is bounded between 0 and 1. The adjusted value of the likelihood ratio index computed for the models in this paper is 0.1318 which is considered a good fit in the family of discrete choice models.

The results of the trivariate ordered probit model appear in Table 3.3, which depicts the relationship of the explanatory variables with the latent probability of generating ordered trips by walking, car, and transit among seniors in the study area. The first two parameters in the table are the thresholds that separate the underlying probability of making the ordered choices shown in Table 3.2.

Table 3.3 Trivariate ordered probit model. Outcome variables: home-based trip classes by mode

	Walking		**Car**		**Transit**	
	Coefficient	***p*-value**	**Coefficient**	***p*-value**	**Coefficient**	***p*-value**
Threshold parameters						
Threshold 1 (trip=1to2)	-4.55107	0.000	2.11222	0.000	0.66927	0.000
Threshold 2 (trip=3+)	-3.27084	0.000	4.16240	0.000	2.58410	0.000
Personal characteristics						

Age: Younger senior	Reference		Reference		Reference	
Age: Senior	-0.09593	0.004	0.10561	0.000	-0.10825	0.001
Age: Elder senior	-0.13704	0.000	0.15988	0.000	-0.27965	0.000
Gender	-	-	-	-	0.06647	0.007
Household: Single	Reference		Reference		Reference	
Household: Couple	-0.17138	0.000	0.17743	0.000	-0.16471	0.000
Household: Other	-0.21186	0.000	-	-	-	-
Occupation: Full-time	-0.34254	0.000	-0.06160	0.026	0.28727	0.000
Occupation: Part-time	-0.12986	0.012	-	-	0.22927	0.000
Occupation: Retired	Reference		Reference		Reference	
Occupation: At-home	-	-	-	-	-	-
Income: <20k	Reference		Reference		Reference	
Income: 20-40k	-	-	0.17878	0.000	-	-
Income: 40-60k	-0.11245	0.005	0.37244	0.000	-0.12502	0.003
Income: 60k or more	-	-	0.43104	0.000	-0.20710	0.000
Income: RF/DK	-	-	0.20683	0.000	-0.16778	0.000
Mobility tools						
Driver licence	-0.35083	0.000	0.940072	0.000	-0.73564	0.000
Vehicle ownership	-0.11725	0.000	0.27377	0.000	-0.29382	0.000
Land Use						
Population density: Low	Reference		Reference		Reference	
Population density: Medium	-	-	-	-	-	-
Population density: High	-	-	-0.08562	0.000	0.07149	0.012
Job density: Low	Reference		Reference		Reference	
Job density: Medium	-0.11543	0.000	-0.07555	0.002	0.29177	0.000
Job density: High	-0.29964	0.000	-0.56463	0.000	0.92636	0.000
Neighborhood characteristics						
Built environment: Network density	-	-	-	-	-	-
Built environment: BSF to DA	-	-	-0.26745	0.016	-	-
Built environment: Land use mix	-	-	-	-	-	-
Accessibility: Activity locations	1.19290	0.000	-0.84600	0.000	-0.74140	0.000
Accessibility: Nearest pharmacy	-	-	-	-	-	-
Accessibility: Nearest health facility	-	-	-	-	-0.23381	0.000
Accessibility: Nearest bank	-0.16496	0.000	0.06127	0.001	-	-
Accessibility: Nearest grocery	-	-	-	-	-	-
Accessibility: Nearest library	-	-	-	-	-	-
Summary statistics						

Number of observations = 13,127;	McFadden's adjusted-ρ^2 = 0.1318	
ρ (walking and car) = -0.50963;	ρ (walking and transit) = -0.16158;	ρ (car and transit) = -0.68684
LL (Null model) = -23,024.5;	LL (Full model) = -19932.3;	Likelihood ratio = 6184.4

3.5.1. Socio-demographic characteristics

The results suggest that compared to younger seniors, seniors and elder seniors are less likely to make more walking trips. Similar results are found for transit. However, in the case of car trips increasing age increases the propensity of seniors to make more car trips, either as a driver or as a passenger. Gender is the second explanatory variable in this study. Here, we find that the trip generation of females is not different from that of males in terms of walking and car trips. However, a difference is detected in the generation of transit trips, with females having a greater propensity of traveling by transit. The effects of different household structures are also examined in this study. From a descriptive analysis, it was found that seniors often live in one of the three types of household, namely single, couple, and other multi-family household. Seniors living in couples or in other multi-family type households have a lower probability of more walking than single seniors. In the case of car, however, seniors in couples tend to have a greater propensity towards more trips, while the propensity for transit use decreases for seniors living as a couple.

The occupational status of seniors is also important in determining the trip generation behavior of seniors and their impact varies across different transportation modes. Being retired is the most common occupational type among the seniors found in the Montreal’s Travel Diary database and taken as the reference category for occupational status of seniors. Working full- or part-time reduces the probability of making more walking trips but increases the probability of transit trips. Working seniors face more rigid time constraints which may account for the reduction in walking trips. In terms of car trips, the only statistically significant coefficient is for full-time workers, a status that reduces the propensity for trip making. At-home workers are not significant for any of the modes which imply that at-home workers are not different in their trip generation behavior than retired seniors.

Like other personal characteristics, income was recorded as a categorical variable. The reference variable is the lowest income class (<$20,000). Income categories are found to be significant for all modes of travel. In the case of walking, the only significant category is income 40-60 thousand dollars and it negatively influence towards higher numbers of walking trips. The effect of income is found completely monotonic for the car trips i.e. with increasing income seniors are prone to use car more frequently, whereas the opposite is observed for transit.

3.5.2. Mobility tools

Two mobility characteristics of the seniors were examined in this study – namely possession of driver licence (binary variable), and number of household vehicle ownership (continuous measure). Both mobility tools are significant across the transportation modes. As expected, possession of driver licence decreases the propensity of walking and transit trips while increasing the trip generation of cars. In addition, this mobility tool has the highest magnitude of those related to travel by car (see also Páez et al., 2007). The relationship between number of household vehicle ownership and trip frequencies are in the same direction as the possession of driver licence. Number of vehicle in the household decreases the propensity of making higher walking, and transit trips and increases the propensity of making car trips.

3.5.3. Land use and built environment

Five land use and built environment related variables were examined to find their association with the trip frequencies of seniors, as per Table 2.1 and 3.1. Of the variables examined, two were not significant for any mode: network density and land use mix. Population density was categorized as low, medium, and high. Low population density was taken as the reference category. We find that high population density decreases the likelihood of making more car trips and increases the likelihood of transit trips. It does not however show a significant relationship with walking trip frequency. Medium population density is not statistically significant across the travel modes. This finding indicates that there is no such difference in trip frequencies between low and medium density neighborhoods. Similar to population density, job density was categorized as low, medium, and high. The frequency of walking and car trips tends to decrease with increasing job density. On the other hand, the propensity of transit trips tends to increase with job density. It is noteworthy that high job density has the largest coefficient for transit trip frequency. The findings make sense that the central business district where job density is higher and parking is expensive. Building square footage to DA area is a continuous variable in the models. It indicates the percentage of the built-up area in the neighborhoods. As hypothesized, it has negative association with the propensity of car trips. Since suburban neighborhoods have a lower ratio of building square footage to actual land area, the effect is to encourage seniors to use car more often than their counterparts in the downtown neighborhoods. Nonetheless, the variable has no statistical significance with the walking and transit trip generation models.

3.5.4. Accessibility

Six accessibility variables were considered. The first of these variables was defined as the number of activity locations within a 400 m radius of the place of residence. Activity locations around the place of residence encourage people to walk in the destinations instead of using motorized vehicles. Prior expectation was that this accessibility related variable would positively influence the propensity of walking trips and negatively for the car and transit trips. The results support the expectation. The findings say that walking is more prevalent in areas with a high number of activity destinations, and motorized mode (car and transit) use less prevalent (see Cerin et al., 2007). Five destination related accessibility variables were considered in the models of trip frequencies by different modes. These are the obvious destinations seniors have to visit in their daily life. Among the five types of destinations examined, nearest distances to the pharmacy, grocery and library are not significant. Increasing distances to nearest bank tend to increase the propensity of traveling by car. This variable however was not significant for the transit trip frequency model. In contrast, increasing distance to health care facilities reduces the probability of traveling more frequently by transit. The finding is sensible in so far as distance to the health facility decreases the probability of a senior using transit or walking to the facility.

They would instead prefer to use their car. In the case of walking, as the distances to the nearest bank increases, it becomes less probable that seniors will walk. This result confirms the importance for seniors of having access to destinations that matter (q.v. Cerin et al., 2007).

3.5.5. Spatial Analysis of Walking Frequency

To investigate the geography of walking behavior, in addition to the variables discussed above, we introduced as covariates six geographical attributes, namely distance to the CBD and a quadratic trend surface derived from the coordinates of the home location (Morency et al., 2011; Páez et al., 2010b; Roorda et al., 2010). The parameters in Table 3.4 were estimated along with the parameters presented in Table 3.3. The most effective way to assess the effect of the trend surface is to map the impact on the behavior of interest. To generate such map we superimposed a regular grid-cell of size 1 sq.km across the study area. The centroid of each grid-cell is then used to estimate the probability of different trip frequencies for the senior profiles in Table 2.4 and 3.5.

Table 3.4 Estimated geographic parameters for walking, car and transit frequencies

	Walking		**Car**		**Transit**	
	Coefficient	***p*-value**	**Coefficient**	***p*-value**	**Coefficient**	***p*-value**
Trend surface						
Latitude	-2.07359	0.000	0.64656	0.000	0.53641	0.000
Longitude	-0.85325	0.000	0.27462	0.010	-	-
Latitude*Longitude	-	-	-	-	-	-
Latitude squared	0.30044	0.000	-0.08565	0.002	-0.10498	0.000
Longitude squared	0.47191	0.000	-0.16294	0.001	-	-
Distance to CBD (km)	-1.40873	0.000	0.43436	0.000	-	-

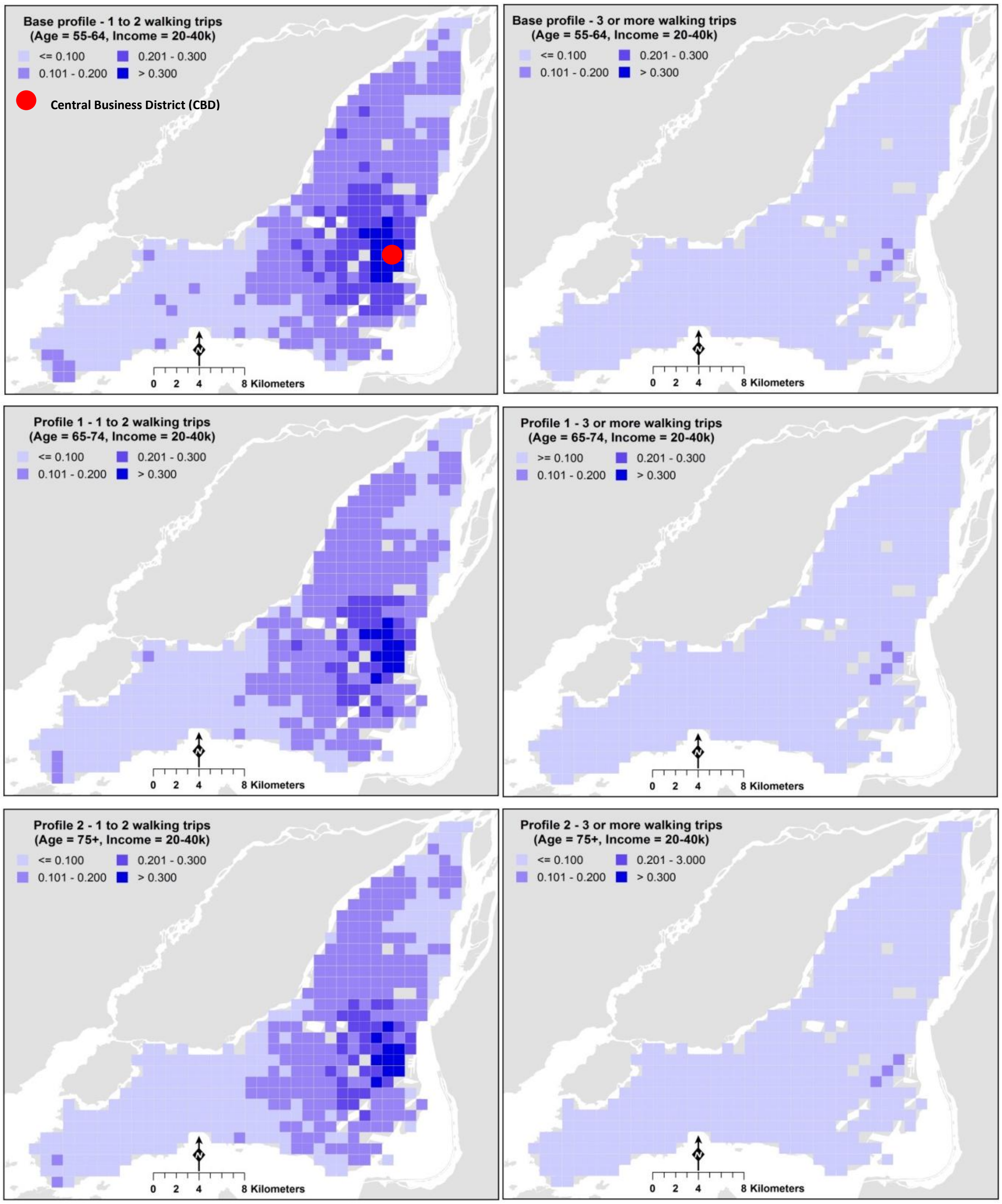
Table 3.5 Individual profiles for estimating the probability of walking trip frequency

Variables	Base Profile	Age Profiles		Income Profiles	
	0	1	2	3	4
Vehicle owned	1	1	1	1	1
Activity locations	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior
Nearest pharmacy	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior
Nearest health facility	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior
Nearest bank	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior
Nearest grocery	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior
Nearest library	Nearest senior	Nearest senior	Nearest senior	Nearest senior	Nearest senior

Geographical Effects: Age

Profiles 1 and 2 are identical to Profile 0, but for the age variable. Profile 0 represents a transitional adult (age 55-64 years), while Profile 1 is for a younger senior, and Profile 2 for an older senior. These profiles are compared in order to explore the effect of age in walking trip frequency. Figure 3.1 shows the spatial variation in the estimated propensity of making 1 to 2, and 3 or more walking trips as a function of age.

Figure 3.1 Geographical variations in estimated probability of making 1 to 2 (left), and 3 or more (right) walking trips as a function of age.



There is only a little geographic variation in the estimated probabilities of making 3 or more walking trips for Profile 0 through 2. Most of the grid-cells have probabilities from 0 to 0.1. However, more variation is found for Profile 0 through 2 in case of making one to two walking trips. Probabilities between 0.1 and 0.2 dominate but scattered grid-cells are also found with higher values (0.20-0.30). Substantially more variation in the probabilities is found as age increases. Estimates for Profile 1 show that grid-cells within probability range 0.2-0.3 tend to be reduced to the lower range 0.1-0.2 and grid-cells with probabilities >0.3 reduced to the lower range 0.2-0.3 for both one to two, and three or more walking trips. An intriguing finding from this trend surface analysis is that limited differences in the probabilities were found when comparing Profiles 1 and 2 i.e. increasing the age from 65-74 years to 75 or above. Previous studies concluded that with increasing age among seniors, especially after 75 years or above, seniors have a tendency to shift from driving automobile towards walking and/or using public transit (Rosenbloom, 2003; Tacken, 1998). Nonetheless, our findings suggest that this shift is likely caused by a combination of factors in addition to age.

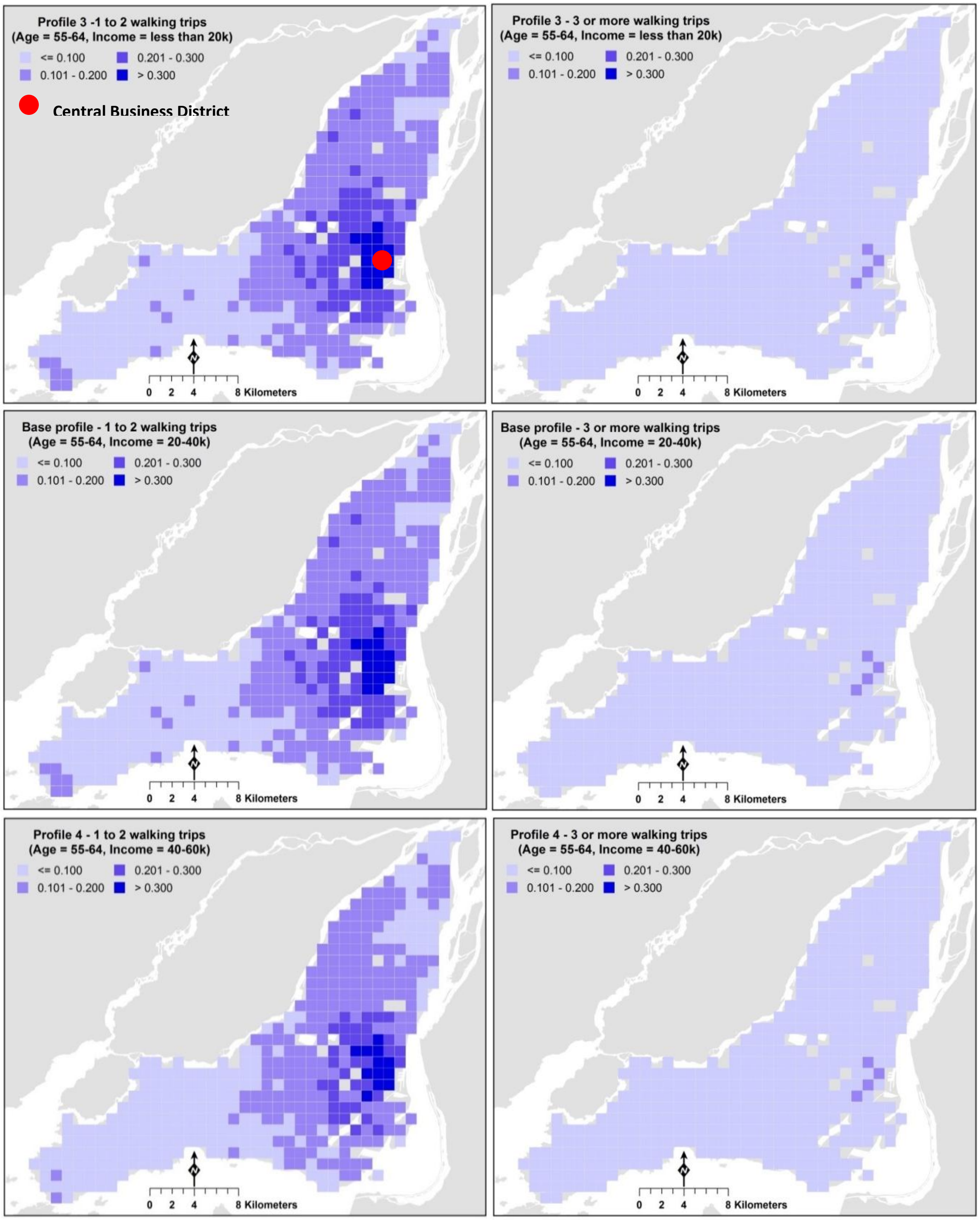
Geographical Effects: Income

Profiles 3 and 4 are designed to illustrate the effect of income on walking propensity. Profiles 0, 3 and 4 correspond to seniors who are identical in all respect but income. Figure 3.2 shows the spatial variation in the estimated propensity of making 1 to 2 and 3 or more walking trips as a function of income, i.e., the only difference among those profiles is income range, with Profile 0 representing a senior with an income 20-40 thousand dollars and Profile 3 with an income less than 20 thousand dollars, whereas

Profiles 4 represents more affluent seniors, with incomes in the 40-60 thousand dollars range.

Income 20-40 thousand of dollars (Profile 0) was the reference category in the trivariate model and, on the other hand, the effect of income less than 20 thousand (Profile 3) towards the probability of making more walking trips is not significant indicating that these two income classes are not different from one another. For this reason, there is no change in between Profile 0 and 3 in Figure 2. However, we can see from Profile 3 that the highest probability range (>0.3) dominates the grid-cells around the CBD of Montreal Island for one to two walking trips. However, when comparing between Profile 4 and the base profile, it was found that probability of making more walking trips decreased drastically as income range among seniors increased. Prevailing probability range for Profile 4 across the area is <=0.1 which was 0.1-0.2 for Profile 0 or Profile 3.

Figure 3.2 Geographical variations in estimated probability of making 1 to 2 (left), and 3 or more (right) walking trips as a function of income.



3.5.6. Correlation coefficients

A diagnostic of the model is the significance of the correlation coefficients. If not significant, a parsimonious implementation would be to estimate separate equations. In the present case, the correlation coefficients (walking and car, walking and transit, and car and transit) in the model are highly significant (p<0.0001), and support the use of the trivariate approach. In addition, the coefficients are negative (-0.51, -0.16, and -0.69 for walking and car, walking and transit, and car and transit, respectively) which indicate that the error term of the trip generation model for one mode is negatively correlated with the error term for another mode i.e. unobserved senior's attributes for one mode, walking for instance, are negatively correlated with the unobserved senior's attributes for another mode, say car or public transit, and vice versa. The largest coefficient was found between car and public transit, indicating all the unobserved attributes which facilitate the propensity of car trip frequency are hindering the trip frequency by public transit and vice versa. The finding makes sense as availability of free transit pass from the employer; an unobserved variable for instance, increases the propensity of making higher number of transit trips and, hence, reduces the propensity of making higher number of trips by car. The correlation coefficient between walking and car is -0.51 which also indicates that all the unobserved attributes promoting the likelihood of walking trips are impeding the likelihood of car trips. Interestingly, the coefficient between walking and transit is also negative (-0.16) but substantially smaller in magnitude.

3.6. Summary and conclusions

Population ageing in many countries has attracted increased attention towards the transportation situation of seniors (Schwanen and Páez, 2010). Numerous previous studies have noted that seniors are a heterogeneous group but one that tends to display lower levels of mobility. This presents an analytical and policy challenge. In some cases, it is thought that low mobility may be a question of unmet demand, and possible evidence of social exclusion (Engels and Liu, 2011). If such is the case, encouraging and facilitating mobility may be desirable. However, low mobility may reflect instead a preference for more sedated lifestyles. The question of unmet demand versus preferences has been explored in recent papers. Ziems et al. (2010) find that utility lost due to reduced out-of-home activities is compensated in seniors by increased utility derived from discretionary activities at home. Páez and Farber (2012), on the other hand, find that the probability of expressing a desire for more activities during leisure time declines with increasing age among people with disabilities. In this case, policies that encourage mobility may be inefficacious or even counterproductive.

In the case of walking, which has been the focus of this paper, the implications are relatively straightforward. Walking is inexpensive and environmentally friendly. It is an activity that does not require any specific knowledge, and is suitable for people of all ages. Regular walking is thus recommended to maintain good health and prevent diseases. The challenge is how to encourage walking among seniors.

Our analysis of trip frequency of seniors indicates that the propensity to walk among seniors declines with age, access to a vehicle, and possession of a driver licence. While policies to curb vehicle ownership are onerous and difficult to implement, increasingly there is a push to adapt licensing rules in response to the growing population of senior drivers. Licence ownership is a key mobility tool for driving, however, by discouraging walking it may have subtle, but nonetheless negative effects. It would be important, then, to balance the potential benefits in terms of walking versus the loss of motorized mobility of various licensing rules. More frequent testing after a certain age and licensing based on function are unlikely to produce a smooth transition from motorized to active travel, whereas gradual withdrawal of privileges, such as driving at night or the use of highways, might encourage walking and particularly the use of transit for some trips without abruptly curtailing mobility (Mercado et al., 2010, pp. 652-653).

Of the set of land use variables considered, it was found that population density does not significantly affect walking frequency, however higher employment densities decrease the probability of making walking trips. The number of activities available locally, including churches, restaurant, and galleries and museums, significantly increases the probability of walking more frequently. Above and beyond the effect of land uses and built environment, a trend surface indicates that the probability of walking tends to decrease with distance from the CBD. Together, these findings suggest that walking may be easier for seniors where numerous commercial activities can be found, in relatively central locations but that are not dense employment centers.

An important aspect of our analysis is the use of a trivariate ordered probit model. The correlation coefficients between the unobserved parts of the equations for walking and car, and walking and transit are significant and high. These coefficients capture the interactions in trip making between these modes. More concretely, if missing variables in the walking equation influence the propensity to travel by this mode positively, their impact on trip making by car is negative, and vice versa. On the other hand, a smaller negative correlation between the unobserved components of walking and transit (-0.16) suggests that these modes are substitutes but to a more limited degree.

Chapter 4 Compliance Potential Mapping

4.1. Introduction

Regular physical activity is beneficial across the lifespan. For children and youth it provides numerous health benefits and moreover has long-lasting effects (Janz et al., 2000). At the other extreme of the life course, physical activity increases the life expectancies of older adults and decreases their risk of developing common chronic diseases (Kruk, 2007; Paterson et al., 2007). Active travel is increasingly seen as an important source of physical activity, to the extent that it has been identified as one of the big issues in preventive medicine (Sallis, 2012), and even called the perfect preventive medicine (Tudor-Locke, 2012). It is an inexpensive form of transportation that can introduce physical activity while meeting daily mobility needs (Morabia and Costanza, 2010). Moreover walking, because of its low risk of injury, is the top recommended physical activity for seniors and is available in different settings throughout the year (U.S. Department of Health and Human Services, 2008; US Department of Health and Human Services, 1999). It is thus of interest to understand the factors that influence walking behavior (which we did in chapter 2 and 3), and its potential contributions to physical activity.

In this paper, Compliance Potential Mapping (CPM) is introduced to assess the level of physical activity associated with walking for transportation. CPM is based on the analysis of travel behavior, with due consideration to individual demographic and socio-economic attributes, the availability of mobility tools (e.g. possession of driver’s licence and household vehicle), and the characteristics of the built environment. Geographical analysis of walking behavior produces maps of estimates of walking trip distance and frequency. These maps are overlaid to generate estimates of expected total walking distance, which are in turn related to physical activity.

The approach proposed is sensitive to variations in travel behavior by individual and locational attributes, and can be used to conduct very detailed analyses of walking as a source of physical activity. CPM is demonstrated for older adults using the Montreal Island as a case study.

4.2. Methods

4.2.1. Estimates of Travel Behavior

Generation of Compliance Potential Maps is a straightforward procedure that depends on the estimation of two elements of travel behavior, namely walking trip distance and frequency. In general terms, suppose that these estimates can be obtained by means of statistical models, as follows:

$$\hat{d}_{pi} = f\left(\boldsymbol{Z}_{pi}\hat{\boldsymbol{\theta}}\right) \tag{15}$$

$$P\left(\hat{t}_{pi} = k\right) = g\left(\boldsymbol{X}_{pi}\hat{\boldsymbol{\beta}}\right) \tag{16}$$

where d_{pi} is the estimated distance of a walking trip for individual p at location i, as a function of a set of variables Z and estimated parameters θ. The probability P that the number k of estimated trips $\hat{t}_{pi}$ undertaken by individual p at location i is estimated as a function of variables X and estimated parameters β. It is desirable that the estimates of travel behavior reflect variations in the attributes of the individual, including age, employment status, household structure, and built environment.

There are numerous specific modeling approaches that could be adopted, some of which are briefly discussed next.

4.2.2. Modeling Approach

Trip lengths in the travel behavior literatures are usually estimated in a linear or log-linear form. The estimation methods also vary from a simple ordinary least squared regression to more complicated utility-based hazard duration model. However, use of different transportation modes is important in determining the trip lengths of individuals and ignoring this issue brings the possible endogeneity effects into the model. A joint discrete-continuous modeling framework (Habib, 2011) is therefore used to account for such endogeneity in these two decision processes. On the other hand, probabilistic approaches – for instance, a truncated normal, Poisson, or negative binomial model to estimate trip frequencies has gained popularity over the past decades (van den Berg et al., 2011). These models were preferred over the linear models because of the unrealistic output from the linear model i.e. negative trip count. Nonetheless, these alternative probabilistic approaches have some drawbacks as they do not link to the behavioral theory. Discrete ordered choice models can address some of the shortcomings of the past approaches and is based on the theory of random utility (Train, 2003). Moreover, multivariate ordered probit model (Bhat and Srinivasan, 2005; Scott and Kanaroglou, 2002) to analyze the multimodal trip frequencies is preferred over the two or more separately estimated univariate ordered probit models as the multivariate models account for the common unobserved factors in the behavior of interest and estimates the probabilities under one formulation (Bhat and Srinivasan, 2005).

4.2.3. Compliance Potential Maps

Given estimates of travel behavior, Compliance Potential Maps can be generated by means of map algebra operations, as shown in Figure 4.1. However, as we focus on walking because of its contribution towards physical activity among the elderly age cohorts whereas other two modes do not and therefore estimation of those modes were not used in the subsequent analysis in this study. The top layer on the left consists of estimates of walking trip distance. Additional layers are estimates of the probability that walking trip frequency is *k* (e.g. 1, 2, and 3+). The expected walking distance corresponding to each trip class is obtained by multiplying the estimated trip distance times *k*, times the probability that the frequency of walking trips is *k*. These map algebras result in a set of *K* layers as shown on the right side of Figure 4.1. Estimates of total daily walking distance (*TDWD*) are obtained overlaying all expected trip distance layers, so that for each geographical sub-unit *i* (e.g. Dissemination Area, Census Tract, Traffic Analysis Zone, Zip Code etc.) in a map *TDWD* is:

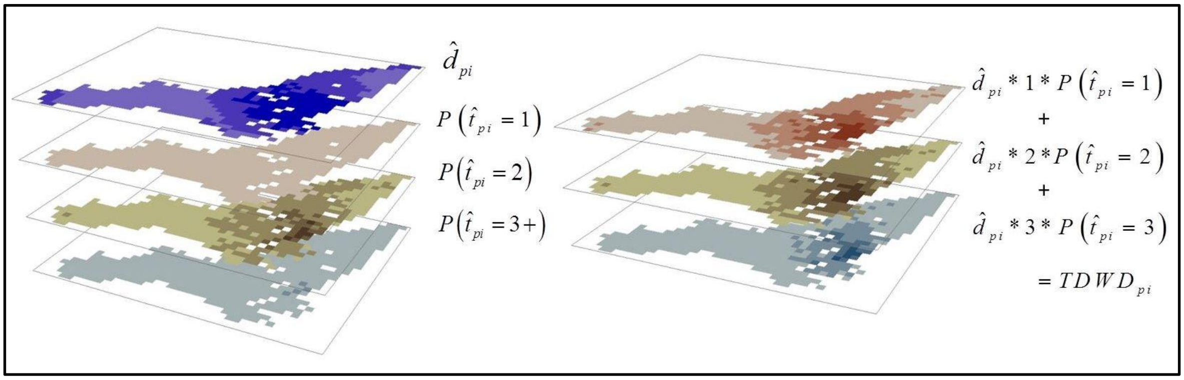
$$TDWD_{pi} = \sum_{k=1}^{K} \hat{d}_{pi} * k * P\left(\hat{t}_{pi} = k\right) \tag{17}$$

The potential for compliance with physical activity guidelines is evaluated as follows. First, it is assumed that the daily behavior is repeated over *w* days every week (e.g. five days a week). Total weekly distance is estimated multiplying *TDWD* by *w*. Then, using a suitable value for walking speed *s*, the weekly distance is converted to total weekly walking minutes. For instance, Montufar et al. (2007) proposed an average walking speed of 68.4m/min for seniors. Using the selected value for speed, the weekly walking distance is then converted into weekly walking minutes:

$$WWM_{pi} = (TDWD_{pi} * w) / s \tag{18}$$

According to the New Canadian Physical Activity Guidelines, weekly recommended minimum physical activity requirements for the seniors are 2.5 hours or 150 minutes (Tremblay et al., 2011). Considering an average walking speed of 68.4 m/min for seniors (Montufar et al., 2007), 150 min of physical activity is equivalent to 10.26 km of walking per week. Finally in compliance with the guidelines, weekly walking minutes are converted into the percentage of physical activity recommended in relevant guidelines, such as the New Canadian Physical Activity Guidelines (CSEP, 2011; Tremblay et al., 2011).

Figure 4.1 Overlay of map layers and calculation of trip distance for trip frequencies.



4.3. Materials

To illustrate the concept of Compliance Potential Mapping, the case of older adults in Montreal Island, Canada, is considered. Data for the analysis are drawn from the 2008 Montreal Household Travel Survey database. The database is an outcome of Origin-Destination (OD) survey which was firstly started in 1970 and the 2008 database is ninth in the series. September 3rd to December 19th of 2008 was the time frame when the 2008 OD survey was conducted. A total of 31,631 trips made by 13,127 individual seniors aged 55 or over were available for analysis. The distribution of the total trips is walking 17.35%, transit 19.44%, and car 63.21%. Average trip distance for seniors across the three modes included in this study is 5.33 km, whereas average walking trip distance is 0.74 km, with a standard deviation of 8.44 and 1.06 km, respectively. Average trip frequency for all modes is 2.41 per senior and for walking 0.45. In addition to mobility information, built environment variables (including street density, intersection density, and land use mix) were created from the 2009 DMTI spatial (DMTI Spatial Inc., 2009) database.

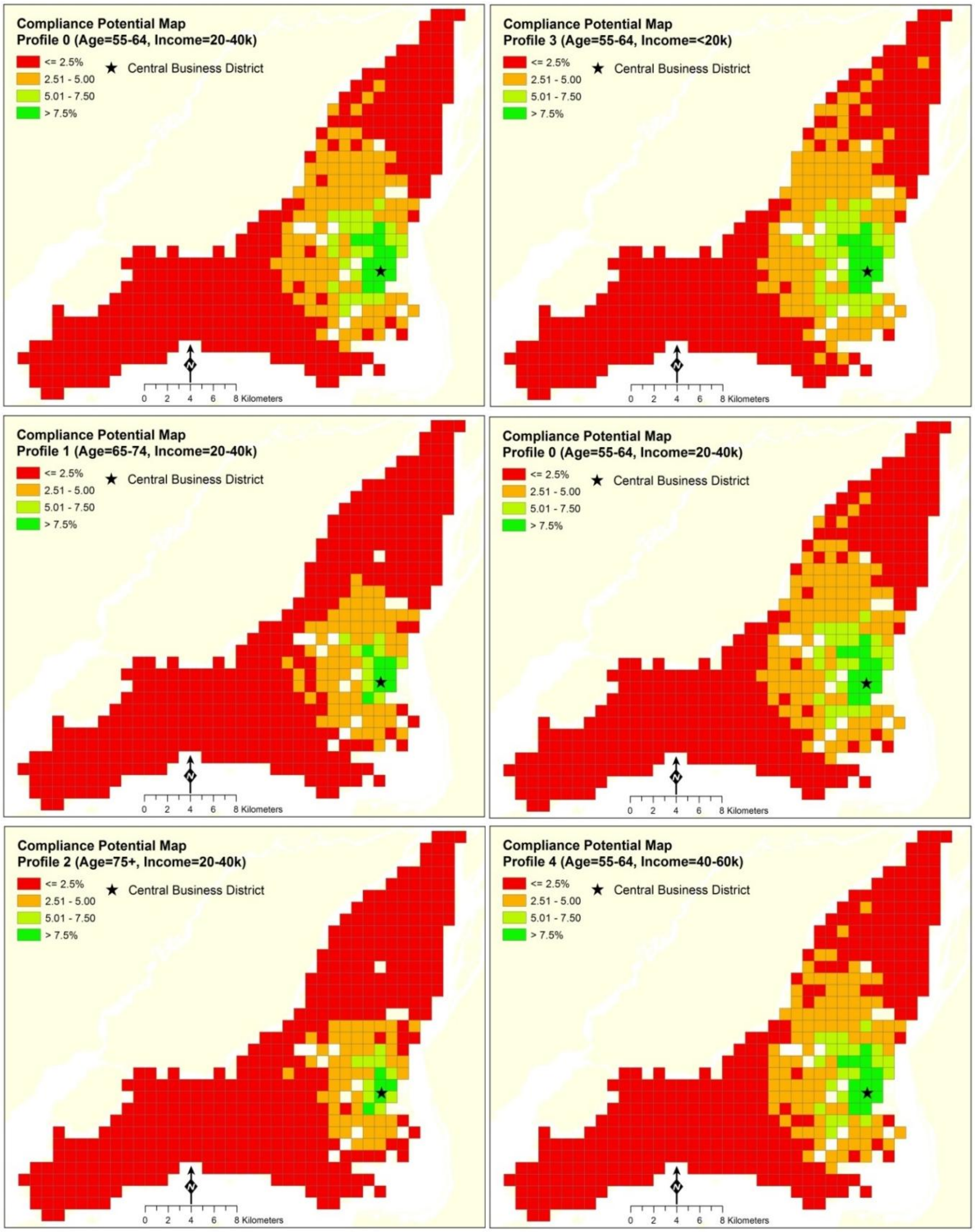
4.4. Compliance Potential Maps for senior profiles

Maps of trip length (Figure 2.1 and 2.2) and trip frequency probability (Figure 3.1 and 3.2) are used to calculate *TDWD* as per equation (5) and *WWM* is estimated using equation (6). Finally the estimated *WWM* is converted into the percentage of minimum physical activity compliance prescribed in New Canadian Physical Activity Guidelines (CSEP, 2011; Tremblay et al., 2011).

Compliance Potential Maps are shown in Figure 4.2 for the five individual profiles in Table 2.4 and Table 3.5. The variable underlying each grid-cell indicates the estimated contribution towards physical activity guidelines (in percentage) that seniors characterized by Profiles 0 through 4 can derive from walking for transportation. The maps are produced assuming that mobility behavior is repeated for five days a week.

Maps on the left side of Figure 4.2 depict the geographic variations of the physical activity compliance as a function of age and maps on the right depict the same but as a function of income. The location of the central business district (CBD) is labelled in each of the maps to link the spatial variations of the percentage contribution with the central part of the Island. It is observed in all of the maps in Figure 4.2 that seniors living closer to CBD obtain higher percentage and it starts to decrease as distance from the CBD increases.

Figure 4.2 Compliance Potential Maps for selected senior profiles as a function of age (left) and income (right)



In the CBD area, many activity locations can be found within short walking distances. There are also higher mixture of land uses, higher employment densities, and better public transit facilities. All these attributes make its user conducive to higher level of walking. Moreover, availability of short distant activity locations engages people in trip chaining but under-reported as single trip and this turns out in longer walking trips in the CBD area (Dumont et al., 2014). Although the models used to estimate the *TDWD* were controlled for a wide list of covariates including individual's socio-economic characteristics, land use, built environment and accessibility characteristics, and a quadratic trend surface where one of the parameters was distance between senior's home and CBD, the potential compliance still varies as a function of age and income as shown in Figure 4.2. In other words, if all other attributes are kept constant, seniors walk longer and more frequent in the central part of the city and hence obtain higher level of physical activity from walking for transport compared to their counterparts living in the suburban areas. However, as they age the percentage decreases. For example, number of grid-cells where seniors are obtaining over 7.5% of the physical activity guideline is decreasing from Profile 0 to Profile 2 and, on the other hand, number of grid-cells where seniors are obtaining less than 2.5% of compliance is increasing. The results make sense as seniors age their ability to walk also decreases and therefore they make shorter as well as less frequent walking trips. In case of income profiles (Profile 0, 3 and 4), the potential contribution of walking decreases as income of the senior increases and follow the same pattern as of age i.e. seniors in the central part of Montreal Island obtain higher percentage and the percentage decreases as distance from CBD increases. For example, there are more grid-cells in profile 3 (income: less than 20 thousand dollars) where seniors obtain over 7.5% of the physical activity compliance compared to the income profile 0 where a senior has income in between 20 and 40 thousand dollars. Similarly, profile 0 has more grid-cells with over 7.5% compliance compared to number of grid-cells in profile 4 where income is higher (income: 40-60 thousand dollars).

4.5. Summary and conclusions

In this paper the concept of Compliance Potential Mapping was introduced and the approach was demonstrated by means of case study of seniors in Montreal. Models of walking behavior show that the walking trip distance and frequency of seniors are determined by individual attributes, mobility tools, as well as the built environment and accessibility. Spatial analysis reveals significant geographical variations on walking behavior. Mapping these variations has potentially useful policy applications. For instance, lower income seniors are at high risk of not obtaining adequate physical activity because of their limited access to recreational facilities (Gordon-Larsen et al., 2006) and therefore walking for transport is the best way to meet physical activity compliance. Compliance Potential Maps for five individual profiles help to identify the potential contributions of walking for transport to physical activity at various locations within Montreal.

It is important to note that maps displayed in this chapter are illustrative of the applicability of the approach, and the models allow a great degree of flexibility in defining the individual profile for detailed analysis. Travel surveys are collected in many major urban regions, and provide a rich source of information that can be used to generate

Compliance Potential Maps. On the other hand, given the characteristics of the data (1 day travel diary), some assumptions are required. For instance, it was assumed that the daily behavior is repeated over five days a week. This gives a conservative estimate by excluding weekend days. Additional study with week-long travel diary data is suggested as a matter for future research. In addition, availability of GPS-based travel database may relax the assumption of the constant walking speed by replacing it with actual walking speed.

The concept of Compliance Potential Mapping is very general, and provides a systematic way to assess health and transportation policies. However, it should be noted that the potential contribution of walking towards physical activity accounts for only home-based transportation related walking. Actual contribution will probably be higher when non-home-based walking trips are incorporated into the calculation. Moreover, the contribution would even be higher when leisure-time walking is incorporated. With the availability of non-home-based and leisure-time walking data the proposed method can be used to estimate the total contribution of walking towards physical activity. The CPMs can be used in a number of ways. First, the maps help to identify areas where compliance with physical activity guidelines is potentially low. Secondly, the models could be used to assess changes in any of the variables to assess the anticipated impact of changes in population or built density, street and intersection densities, or the availability of activity locations and services. Urban features that contribute towards physical activity guidelines can be investigated in detail, and their differential impact on various individual profiles and locations evaluated. Thirdly, the tool could be used to target neighborhoods for policy interventions in order to help to use resources efficiently. Alternatively, these maps could be used to guide purposive data collection for qualitative research. The flexibility and potential of the suggested applications should make Compliance Potential Mapping an interesting tool for public health professionals, urban and transport planners, and policy makers.

Chapter 5 An investigation of walkable environments

5.1. Introduction

Healthy aging among the Canadian seniors can enormously reduce the economic burden faced by Canada by decreasing the need for health care and long–term care needs (Laditka, 2001; Sasseville et al., 2012). Rowe and Kahn (1987) proposed a model to define healthy or "successful aging". The model consists of three components, namely low probability of disease and disease–related disability, high cognitive and physical functional capacity, and active engagement in life. Regular physical activity can improve the prospects for successful aging. Routine physical activity, for instance, reduces the risk of developing chronic diseases and contributes to prevent premature death (Blair et al., 2001; Blair et al., 1989; Myers et al., 2004). According to the new Canadian Physical Activity Guidelines, seniors 65 years and older should engage in at least 150 minutes of moderate–to–vigorous physical activity per week, in bouts of 10 minutes or more (Tremblay et al., 2011). Although the available activity guidelines have been demonstrated to be adequate to reduce health risks, inactivity among Canadian seniors is on the rise (Public Health Agency of Canada, 2010).

Physical activity behavior is influenced by numerous factors. Dishman and Sallis (1994) classify these factors into seven domains: demographic and biological, psychological, cognitive and emotional, behavioral attributes and skills, social and cultural, physical environment, and physical activity characteristics (perceived effort and intensity). Encouraging more active lifestyles requires interventions along these domains. An area of current and growing interest concerns the effect of physical environments on physical activity. Past studies have identified relationship between physical environment and physical activity among older adults (Brownson et al., 2009; Gebel et al., 2007; Heath et al., 2006; Saelens et al., 2003; Sallis, 2009). Different approaches, from complex ecological to behavior–specific models, have been used to explore the physical environment-physical activity link (Handy et al., 2002; Humpel et al., 2002; King et al., 1995; Sallis et al., 1998; Stokols, 1996).

Two elements stand out in the literature on physical environments and physical activity in the case of seniors. On the one hand, in terms of public health policy, walking is perceived as a suitable activity, whereas on the other, the built environment is perceived as a tractable policy variable (Owen et al., 2007; Owen et al., 2004; Sallis, 2009; Sallis and Owen, 1999; Siegel et al., 1995). Both perceived and objective measures of the built environments have been studied in earlier researches that aimed at identifying varying degrees of walkability (Gebel et al., 2009; Gebel et al., 2011; McGinn et al., 2007; Owen et al., 2007; Owen et al., 2004). In case of perceived measures of local built environments, perceptions of residents regarding their neighborhoods have been linked to health conditions (e.g. residents that report low walkability are more likely to report poor health status) (Echeverría et al., 2008; Macleod et al., 2002). Objective measures of the built environment, on the other hand, are usually extracted from available geographic databases using Geographic Information Systems(GIS), and include factors such as residential density, street connectivity, and land use mix (McGinn et al., 2007). A composite score is sometimes calculated based on a set of built environment features to produce a so-called walkability index (Frank et al., 2009; Leslie et al., 2007), although it has been noted that this approach is too aggregate to suggest specific policy actions (Saelens et al., 2003).

Until recently, the focus of research has been on neighborhood–scale or meso-scale attributes of built environments (Lee and Moudon, 2006; Taylor et al., 2012). Partly, this is explained by the fact that street-scale or micro-scale attributes are not typically systematically collected (Parmenter et al., 2008; Purciel et al., 2009). However, along with neighborhood–scale built environments, street–scale features are also important in determining the walkability of a neighborhood. This has led researchers to purposeful collection of data by means of walkability audits, an approach that yields relevant information about street-scale built environments, although at a relatively high cost (Araya et al., 2006; Brownson et al., 2009; Clarke et al., 2010; Griew et al., 2013; McMillan et al., 2010; Rundle et al., 2011).

In this paper, we investigate the attributes of walkable environments, from the perspective of seniors. The study is inspired by recent research useful to select case studies for walkability audits (see Moniruzzaman and Páez, 2012). The basic idea is to use a model of a behavior of interest, in this case the decision to walk for transportation by seniors (Moniruzzaman et al., 2013). The results of the model are used, in combination with cluster analysis, to identify sites where walking is systematically under-predicted by the model (i.e. locations where walking is more prevalent than what the model predicts) and sites where it is over-predicted (i.e. locations where walking is more prevalent than what the model predicts). By conducting walkability audits on a set of suitably selected sites where walking is more/less prevalent, information can be obtained regarding the attributes of the built environment that are systematically present or absent in places where walking is more common or uncommon than other factors would predict.

In–person walkability audits were conducted on a selection of street segments across Montreal Island. The street–scale environmental features were collected by a combination of two walkability audit instruments, namely the Pedestrian Environment Data Scan (PEDS) (Clifton et al., 2007) and Seniors Walking Environment Assessment Tool – Revised (SWEAT–R) (Michael et al., 2009). The total cost of the in–person audits was less than CAD 3,000. The information so collected was analyzed by means of a chi–squared test of independence. The results of the analysis report that under–predicted segments are linked with more marked cross–walks, horizontal and vertical mixtures in land uses, flat and highly connected street segments, four–way intersections, and low traffic volume whereas over–predicted segments are related to more unmarked cross–walks, residential and/or vacant land use, less connected and slight or steep hilled sidewalks, dead-ends or three–way intersections, and high traffic volume. Findings from this study can be used by the Ville de Montréal (City of Montreal) in designing walking friendly neighborhoods for elderly in Montreal Island.

5.2. Background

With growing interest in street–scale built environmental features, researchers have developed numerous audit instruments to collect street–scale information for different purposes. This includes school environment audit tools (Lee et al., 2013), active neighborhood audit tools (Hoehner et al., 2007), park walkability audit tools (Dills et al., 2012), neighborhood walking and cycling among children (Timperio et al., 2004), senior walkability audit tools (Michael et al., 2009), worksite walkability audit tools (Dannenberg et al., 2005), recreation facility audit tools (Cavnar et al., 2004), and rural community walkability audit tools (Brownson et al., 2004). In regards to neighborhood walkability, there are over 50 different tools available (Gray et al., 2012). Some of them are very comprehensive and hence are time consuming. For instance the Walking Suitability Assessment Form (Emery et al., 2003) takes on average 30 min to audit a street segment. Other tools contain only specific walkability information and require only few minutes per segment. For instance the Pedestrian Environment Data Scan (Clifton et al., 2007) takes only 3–5 min on average per segment.

With recent developments in technology, a new approach to conduct neighborhood walkability audits has been used, based on Google Street View to virtually audit street segments. This has been a viable alternative to replace in–person walkability audits (Badland et al., 2010b; Clarke et al., 2010; Griew et al., 2013; Kelly et al., 2013; Rundle et al., 2011). Google Street View is freely available for most urban areas in developed countries and has the potential to reduce the high cost of in–person audits (Ben-Joseph et al., 2013; Griew et al., 2013). This approach, however, has some limitations. Although it provides reliable information for traffic calming devices, street furniture, sidewalk condition and lighting on the street, reliability has been found to be lower for items such as sidewalk width, curb cuts, litter, and material contrast with ground surface due to obstructed view created by parked cars (Kelly et al., 2013; Rundle et al., 2011). Moreover, Street View is not available for all street segments and it would still be time consuming to audit street segments across large regions without appropriate selection or sampling of segments. In other words, regardless of the approach (i.e., in–person or virtual), a systematic technique can also be used to reduce the time and cost of a walkability study.

Past studies used either random or systematic selection methods to select sites for walkability audits. Kelly et al.(2013) used a geographically stratified sampling to select segments in two US cities. They stratified the neighborhood blocks into eight strata by two poverty classes, two race classes, and two commercial land use classes and then randomly selected 50 segments from each stratum. Griew et al.(2013) on the other hand used a weighted method to identify areas to study walkability. In their approach, a large UK town in the North West of England was firstly chosen and then a buffer of 800 m from the population weighted centroid of the town was created to identify neighborhoods for the audit. Finally, 25% of the 216 eligible street segments within the buffer were randomly audited both in–person and using Google Street View to test reliability of their audit tool. Ben–Joseph et al. (2013) in a comparison study between on–site and three different virtual audits in Boston, MA, used participant’s nearest intersection from home location to select street segments. A total of 84 segments were audited within 1,000 m of 21 participants’ addresses. However, it is not reported whether selection of segments was random or systematic. In another study in the US, Millstein and colleagues (2013) collected micro–scale environmental data based on the macro–scale walkability index that defined neighborhoods as having low or high walkability. Using the Network Analyst extension (ArcView 9.3, ESRI, Redlands, CA, USA), they mapped the shortest route from the participant's home to the nearest pre–defined destination within a quarter–mile. Segments along the shortest routes were selected to conduct walkability audits. Witten and colleagues (2012) used a similar method to categorize neighborhoods as having low or high walkability, and then selected 48 neighborhoods for four New Zealand cities (six high and six low walkable neighborhoods for each city). Rundle and colleagues (2011), for their virtual walkability audit in New Work City, chose 38 high–walkable face blocks, equally divided between poor (>= 20% of population in poverty classified as poor) and non-poor (<20% in poverty classified as poor) census tracts where high–walkable face blocks were identified in another study using GIS measures (Neckerman et al., 2009). Clarke and colleagues (2010) used a secondary source, the Chicago Community Adult Health Study (Sampson et al., 2002), to identify 343 stratified neighborhood blocks. From these blocks they selected 60 that yielded a total of 244 street segments for virtual audits, and ensured full coverage of blocks across the city of Chicago.

It is evident from the above literature review a number of approaches have been implemented to select samples of street segments for walkability research. Most approaches are descriptive and are often based on only one or two confounding factors, such as income, race, concentration of population, or walkability indices estimated from macro–scale built environmental factors. However, it is not unreasonable to anticipate that other confounding factors might be important as well. For instance, age, gender, occupation, and job density are all factors known to influence travel behavior (Cervero et al., 2009; Kitamura et al., 1997; Moniruzzaman et al., 2013; Páez et al., 2013). Selection approaches that omit these factors are likely to be biased. Nonetheless, it becomes cumbersome to draw conclusions when a large number of confounding factors are incorporated into the descriptive selection approaches. This study therefore adopts and adapts the model–based approach proposed by Moniruzzaman and Páez (2012) to select street segments. Use of a modeling approach allows the incorporation of a large number of confounding factors believed to influence walking behavior.

5.3. Methods

A model–based approach to select segments for walkability audit was firstly introduced by Moniruzzaman and Páez (2012). The basis of the approach is to use a model of travel behavior, namely a modal split model to predict the proportion of commuters traveling by foot. Analysis of residual pattern of the model was conjectured to represent systematic factors that could influence walkability – including elements of the micro-scale environment. Residual pattern was retrieved by means of a filtering technique (Griffith, 2004). The resulting filter in turn, was examined to identify areas where walking was under– or over– predicted, or in other words, where walking was more or less prevalent than the model predicted. Further, it was conjectured that areas where walking was more prevalent than predicted by the model would have attributes more conducive to walking than areas where the model over-predicted walking. This model–based approach was successfully implemented in a study of walkability in Hamilton, Ontario (Canada). The implementation, however, was based on aggregated census data. In this study, in contrast, we propose a similar model–based approach, but use individual-level data and discrete choice modeling techniques for higher resolution and detailed results. Below we describe the approach in detail.

5.3.1. Modeling

This study used the joint discrete–continuous model estimated in chapter 2 where the discrete part dealt with mode choice behavior and the continuous part dealt with trip distance associated with each mode. Three modes were considered, namely car, transit, and walking. The mode choice behavior was estimated by means of a multinomial logit (MNL) model formulation, whereas a hazard model formulation was used for the trip distance part of the model. The Montreal Household Travel Survey for 2008 was used to estimate the joint models. The data included a total of 31,612 trips made by 13,127 adults aged 55 or older (that is, a transitional cohort, and seniors 65 or older). Only the MNL model results however are used in this study, and therefore the remainder of the chapter concentrates only on the estimates of mode choice behavior (Table 2.2).

5.3.2. Estimating walking behavior

Using the estimated coefficients from the mode choice model (Table 2.2), we firstly predicted the probability that a senior chooses to use the three modes studied. Secondly, using the estimated probabilities, we simulated for each senior 100 possible outcomes regarding the choice of a particular mode of transportation. The results were then analyzed in the following way. The simulated outcomes were compared to the actual travel behavior. This resulted in three possible combinations of actual-predicted behavior: 1) walking was both observed and predicted (the model correctly forecasts the behavior); 2) walking was observed but not predicted (the model under-estimates the behavior); and 3) walking was not observed but the model predicted walking (the model over-estimates the behavior). Hereafter we refer to these as the predictive categories.

5.3.3. Cluster analysis

Following the analysis of outcomes, we ran one hundred cluster analyses over the Island of Montreal to detect any possible clusters of street segments where the predicted outcomes of walking behavior are matched, under-, or over-estimated by the model. The spatial scan statistic for multinomial data proposed by Jung et al. (2010) is appropriate technique for this cluster analysis as the target variable is in multinomial form (available in SaTScan[1]). This scan statistic uses circular or elliptical window around the location of cases or user defined points and ensures that it has certain percent (e.g. 50%) of total population within the window. Then it statistically tests whether distribution of cases within the windows is different from the cases outside the window (Jung et al., 2010; Ozdenerol et al., 2005). It uses a likelihood ratio test to compare the potential windows (clusters) and detects the most likely cluster by the highest likelihood ratio. Statistical

1http://www.satscan.org/

significance of the likelihood test is evaluated by simulation. A cluster is significant at *p*–value 0.05 if the likelihood ratio of the real dataset is among the top 5% of all likelihood ratios including the generated datasets. Secondary clusters are also detected and statistically tested using the same approach (Jung et al., 2010).

To implement the spatial scan statistic a case file and a coordinate file are needed. The case file includes the list of all seniors with their predictive categories i.e. whether a senior had a matched, under, and over prediction in their behavior. The coordinate file contains the geographic coordinates of the senior's home location. A grid file with coordinates of the centroids of Dissemination Areas (DAs) was optionally added into the analysis to specify the centers of search windows. For the analysis of clusters, we chose the following parameters: circular windows with a limiting radius of 500 m. The reason to limit the window size to 500 m is that it is an appropriate average distance for a senior to walk for a one way trip (see Moniruzzaman et al., 2013). We also removed all restrictions (e.g. no geographical overlap) for reporting secondary clusters. After running the analysis for each of the hundred simulated outcomes with the above criteria, we examined the results. After each run, SaTScan usually provides a cluster information file that identifies all significant and non–significant clusters along with their latitudes, longitudes, window size, and Loglikelihood ratios. In addition, a stratified cluster information file provides observed and expected number of cases, and relative risk (RR) for all categories in each cluster. The RR is calculated as ratio of observed and expected number of cases within a cluster divided by ratio of observed and expected number of cases outside the cluster. Mathematical notation for the RR (Jung et al., 2010) is shown as below:

$$RR = \frac{c/E[c]}{(C-c)/(E[C]-E[c])} \tag{19}$$

where c is the observed number of cases within a cluster, $E[c]$ is the expected number of cases within the same cluster, C is total number of cases, and $E[C]$ is the expected number of total cases which is equal to C i.e. $E[C] = C$. The two output files were firstly merged, and secondly significant clusters (p–value<=0.05) from all hundred runs were compiled into a single spreadsheet. After doing so we found 34,630 significant clusters over the Montreal Island. Four exclusion criteria were added to further reduce the number of clusters of interest. 1) There must have at least ten seniors within each cluster window, to avoid large variability; 2) the number of observed cases within the window must be greater than zero for all three categories (matched, under, and over); 3) the RR of observed-predicted matches must not be the highest for clusters; and (4) the RR ratio between under – and over–prediction must be greater than or equal to three where:

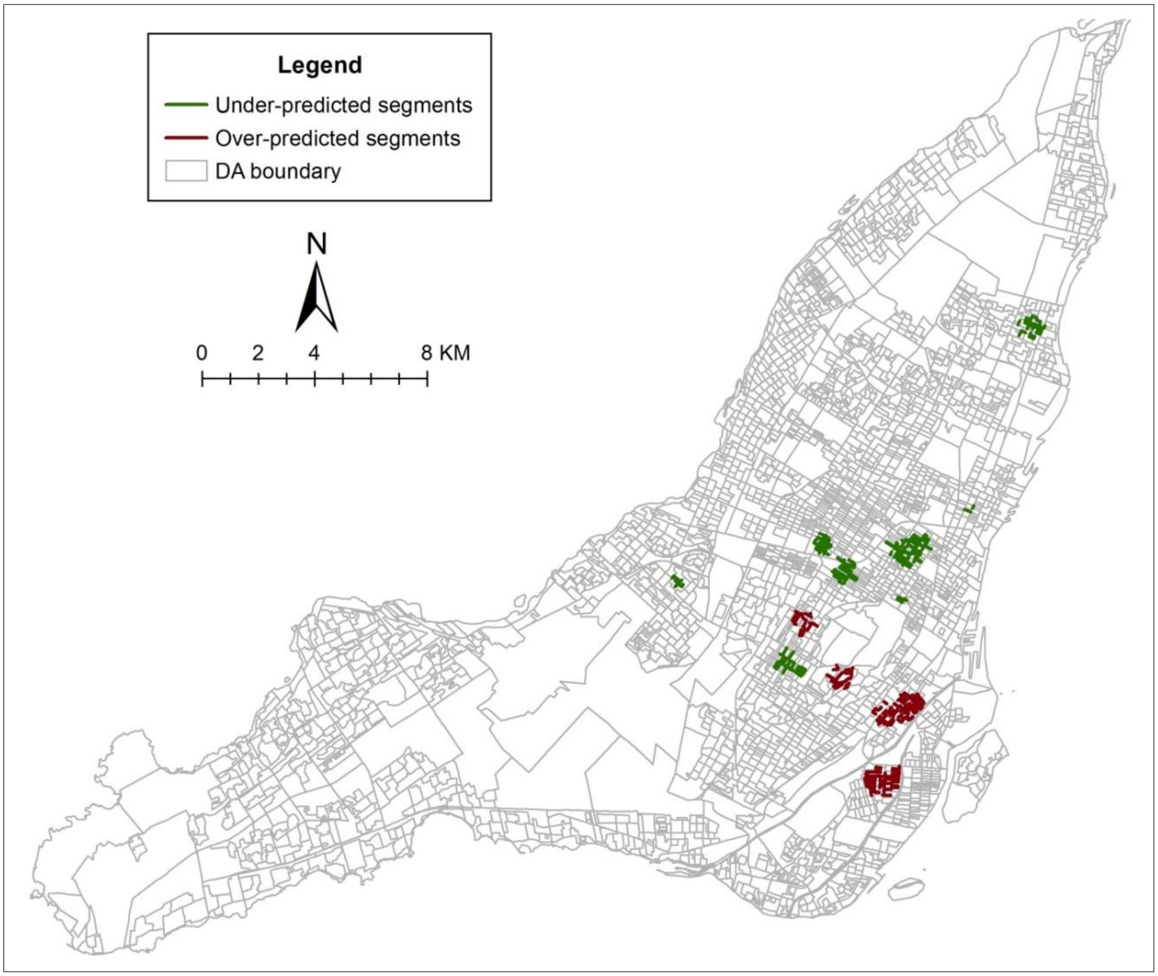
$$RR\ ratio = \begin{cases} \dfrac{RR_{under-prediction}}{RR_{over-prediction}}, if\ case\ of\ under-prediction \\ \\ \dfrac{RR_{over-prediction}}{RR_{under-prediction}}, if\ case\ of\ over-prediction \end{cases} \tag{20}$$

We suggest that use of exclusion criteria must be dependent on the number of significant clusters. If there are few significant clusters, no exclusion criteria might be necessary.

5.3.4. Selection of street segments

The post–cluster analysis with the exclusion criteria resulted in 4,816 clusters for both under– and –over prediction. These clusters were then overlaid with the street segment layer of Montreal Island. All highways were excluded from the layer since they are not meant for pedestrian use. In total 8,623 out of 36,177 street segments were selected from the overlay, with 5,998 segments belonging to the under–prediction class and 2,625 to over–prediction. Then we considered the number of times each segment was part of a cluster and used that number (i.e. highest numbers) to target approximately 1,000 segments, equally divided between under- and over-predicted segments. Finally, keeping the available budget in mind, 403 segments were randomly chosen for field work. The selected segments were more or less evenly divided between clusters where the behavior is under– (199 segments) and over– (204 segments) predicted (Figure 5.1).

Figure 5.1 Location of audited street segments in Montreal Island



5.3.5. Walkability audits

Two instruments were used for the walkability audits. Most of the items however were collected using PEDS. The SWEAT–R was used to collect items that are particularly related to seniors (e.g. are there any senior–oriented buildings) or items that are not available in PEDS (e.g. do the buildings contain vertical–mixed use, type of public spaces present, signal time at intersection) or items present in both instruments but more suitable for our study if taken from SWEAT–R (e.g. predominant building height). All these items were scripted in ArcPad Application Builder for auditing with handheld devices. The advantage of using handheld devices is that data are directly stored in a database and hence no additional time is required for transferring paper data to digital format (Araya et al., 2006; Brownson et al., 2009; Moniruzzaman and Páez, 2012; Weiss et al., 2010). Six research assistants were hired. The assistants participated in a one-day training session, both in class and in field, conducted by the author. After training, the assistants were divided into three groups for field work. The author acted as a back–up assistant in case one of assistants was unavailable on specific dates. The in–person audit was conducted in the first week of October 2013 and took five continuous business days for the three groups to complete the audit on 403 street segments across the Montreal Island. In addition to auditing, the assistants were instructed to photograph key elements of the environment.

5.4. Results and discussions

The analysis of the audit data was started arranging all items in contingency tables. These tables were statistically tested by means of the chi–squared test of independence where the test compares between observed and expected (theoretical) distribution of the items in the tables. Table 5.1 shows the results of significance for the audit items. There are some items in PEDS that were not collected by the auditors due to their irrelevance with this study (e.g. powerlines along segment, presence of med–hi volume driveways, degree of enclosure, articulation in building designs) or if the item is typically present in all segments (e.g. are there wayfinding aids, sidewalk width, sidewalk distance from building setbacks). The audited items were broadly classified into four groups, namely intersection, sidewalk and amenities, land uses, and miscellaneous. The purpose of this classification is to facilitate presentation, since items from two audit instruments were consolidated and presented as a single entity.

Twenty-nine items were tabulated in total and evaluated by the test of independence. Thirteen items passed the test with significance *p*–value <0.05. Non–significant items are primarily an outcome of city's design standards and, therefore, were found with similar probability among the under– and over-predicted segments. With the exception of sidewalk completeness, all other significant items are in agreement with general expectations about walkable environments. Table 5.2 summarizes the findings of all significant items from the test of independence including their disposition towards under– and –over prediction.

Table 5.1 Statistical significance of chi–squared test of independence for audit items

Variable	**Chi–squared test of independence (*p*–value)**
Items at segment's intersection:	
Is the crossing area at the ends marked? *	Significant (0.001)
Ramp/Curb cut at the ends*	N.S. (0.466)
Intersection type at the ends**	Significant (0.000)
Signal time at the ends*	N.S. (0.566)
Traffic control devices**	N.S. (0.346)
Sidewalk and amenities:	
Sidewalk completeness**	Significant (0.000)
Sidewalk connectivity**	Significant (0.002)
Slope of the segment**	Significant (0.026)
Amenities**	N.S. (0.794)
Trees shedding the sidewalk**	N.S. (0.296)
Lighting along the segment**	Significant (0.000)

Number of benches*	N.S. (0.350)
Presence of bus stop**	N.S. (0.255)
Sidewalk obstructions**	N.S. (0.195)
Overall cleanliness of the sidewalk**	N.S. (0.479)
Land uses:	
Land use along the segment**	Significant (0.021)
Vertical mix in the buildings*	Significant (0.000)
Type of public space: plaza*	Significant (0.000)
Type of public space: garden*	N.S. (0.423)
Type of public space: park/playground*	Significant (0.004)
Type of public space: recreational area*	N.S. (0.120)
Quality of public space*	Significant (0.030)
Gathering place: restaurant*	N.S. (0.692)
Gathering place: coffee*	Significant (0.024)
Gathering place: bar*	N.S. (0.373)
Gathering place: corner store*	N.S. (0.692)
Miscellaneous items:	
Building height*	N.S. (0.186)
Signs of senior activity*	N.S. (0.454)
Number of lanes in road **	Significant (0.033)

*Item from SWEAT–R, ** Item from PEDS; N.S. = Non–significant

Table 5.2 Summary of all significant items from the chi–squared test of independence and their dispositions towards over– and –under prediction

Variable	Summary of contingency tables and their dispositions
Items at segment's intersection:	
Is the crossing area at the ends marked?	(U) More segments with marked cross–walks on both ends and fewer segments with no marked cross–walks on any ends; (O) fewer segments with marked cross–walks on both ends and more segments with no marked cross–walks on both ends
Intersection type at the ends	(U) More segments with four–way intersections on both ends and fewer segments with other combination of intersections; (O) fewer segments with four–way intersections at both ends and more segments with other combination of intersections

Sidewalk and amenities:	
Sidewalk completeness	*(U) Fewer segments with complete sidewalks and more segments with incomplete sidewalks; (O) More segments with complete sidewalks and fewer segments with or incomplete sidewalks*
Sidewalk connectivity	(U) More segments with highly connected sidewalks and fewer segments with less connected sidewalks; (O) fewer segments with highly connected sidewalks and more segments with less connected sidewalks
Slope of the segment	(U) More segments with flat sidewalks and fewer segments with slight or steep hilled sidewalks; (O) fewer segments with flat sidewalks and more segments with slight or steep hilled sidewalks
Lighting along the segment	(U) More segments with pedestrian–oriented lighting and fewer segments with road–oriented lighting; (O) fewer segments with pedestrian–oriented lighting and more segments with road–oriented lighting
Land uses:	
Land use along the segment	(U) More segments with mixed land uses and fewer segments with residential and/or vacant land use; (O) fewer segments with mixed land uses and more segments with residential and/or vacant land use
Vertical mix in the buildings	(U) More segments with vertical mix of buildings and fewer segments with no mixture or no building; (O) fewer segments with vertical mix of buildings and more segments with no mixture or no building
Type of public space: plaza	(U) More segments with absence of plaza as public space and fewer segments with presence of plaza as public space; (O) fewer segments with absence of plaza as public space and more segments with presence of plaza as public space
Type of public space: park/playground	(U) More segments with absence of park/playground as public space and fewer segments with presence of park/playground as public space; (O) fewer segments with absence of park/playground as public space and more segments with presence of park/playground as public space
Quality of public space	(U) More segments with absence of any public space and fewer segments with high quality public space; (O) fewer segments with absence of any public space and more segments with high quality public space
Gathering place: coffee	(U) More segments with coffee shops as gathering place and fewer

	segments with no coffee shop as gathering space; (O) fewer segments with coffee shops as gathering place and more segments with no coffee shop as gathering space
Miscellaneous items:	
Number of lanes on street	(U) More segments with single lane street and fewer segments with multiple lane street; (O) fewer segments with single lane street and more segments with multiple lane street

Note: U: under–prediction (conjecture: more walkable), O: over–prediction (conjecture: less walkable)

Two items in Table 5.2 belong to the intersection class of features. The first item relates to availability of marked crossing areas at two ends of the audited segments. It was expected that more walkable segments would be associated with more marked cross–walks and vice–versa. There are more segments in the under–predicted areas whose both crossing areas are marked when observed count is compared with expected count. For instance, the observed number of segments whose both ends have marked cross–walks is 52 whereas expected count is 40. In contrast, number of observed segments (83) where none of the crossing areas is marked is prevalent in over–predicted segments when it is compared with its expected counts (Table 5.3). The type of intersections at the ends of the street segments is also significant. Four–way intersection typically facilitates direct and shorter routes to destinations compared to cul–de–sac and loop type intersections. It is therefore considered as an important feature of walking friendly neighborhoods (Randall and Baetz, 2001; Schlossberg et al., 2006). Table 5.4 shows that the number of four–way intersections on both ends of the segments exceeds the expectation (104 vs. 77) in segments where walking is more prevalent than predicted. On the other hand, combinations of dead-ends, three/four-way intersections are more dominant among the segments (152 vs. 125) where walking is less prevalent than predicted. Similar findings were reported by Moniruzzaman and Páez (2012) for Hamilton, Ontario.

Table 5.3 Marked cross–walks at the ends of the segments: contingency table

Segments where behavior is	Crossing area				Total
	Count	Marked on both ends	Not marked on any ends	Other combinations	
Under–predicted	Observed	52	52	95	199
	Expected	40	66.7	92.3	
Over–predicted	Observed	29	83	92	204
	Expected	41	68.3	94.7	
Total		81	135	187	403

Table 5.4 Type of intersection at the ends of the segments: contingency table

Segments where behavior is	Intersection			Total
	Count	Four–way on both ends	Other combinations	
Under–predicted	Observed	104	95	199
	Expected	77	122	
Over–predicted	Observed	52	152	204
	Expected	79	125	
Total		156	247	403

Sidewalk and amenities include the conditions of sidewalks (e.g. completeness, connectivity, and slope) and amenities on sidewalks that facilitate walking (e.g. lighting).

Sidewalk connectivity was audited as a continuous measure (i.e. number of total connections on both ends of the audited segments) and then categorized as no connection, 1–4 connections, 5 or more connections. It has been argued that a well–connected street network increases pedestrian safety and attracts more pedestrians (Kavage et al., 2005). More walkable segments are often characterized by highly connected sidewalks. For instance, five or more connections are observed in 81 segments where walking was more prevalent than predicted, compared to the expected count of 67.2. On the other hand, less connectivity is commonly seen in the over–predicted segments, 109 observed vs. 92.1 expected (Table 5.5).

The slope of the sidewalk was audited in three classes as it appears in PEDS, namely – flat, slight hill, and steep hill, and then reclassified into two for the contingency table. Flat terrain is more often found in high walkable segments (176 segments, versus 167.9 expected). In contrast, flat terrain is less common in segments where walking is less prevalent than predicted (Table 5.6). Contrariwise, there are more slight or steep hilled segments in less walkable streets, as seen in Table 5.6.

Another significant item in the sidewalk and amenities class is lighting along the segments. Three different lighting classes were considered: road–oriented, pedestrian–oriented, and no lighting. Pedestrian–oriented lighting is usually white in nature and therefore more attractive compared to standard road–oriented yellow light. It is also brighter as lamps are closely spaced and give users a feeling of safety (Evenson et al., 2009). We can see from Table 5.6 that pedestrian–oriented lighting predominates over road–oriented lighting in the more walkable segments. Accordingly, there are 93 segments with pedestrian–oriented lighting in more walkable segments (versus an expected count of 59.7), whereas road–oriented lighting is less common (102 observed versus 133.6). Less walkable segments, on the other hand, have fewer observed pedestrian–oriented lighting (25) than expected (58.3) and more road–oriented lighting (162) than expected (130.4).

Interestingly, sidewalk completeness is the only item with a counterintuitive result. In other words, whereas more complete sidewalks were expected to result in more walkable segments, we find that complete sidewalks are more often observed in segments where walking is less prevalent than predicted (Table 5.5). One possible explanation for this counter–intuitive results could be the presence of narrow street segments in Montreal Island that are particularly used for walking and sidewalks along the segments are not very well–defined rather street's right of way is also used for pedestrian walking (Figure 5.2).

Table 5.5 Sidewalk completeness and connectivity in the segments: contingency table

Segments where behavior is	Count	Sidewalk completeness		Sidewalk connectivity			Total
		Complete	N/A or incomplete	5 or more connections	1–4 connections	None	
Under–predicted	Observed	167	32	81	73	45	199*2
	Expected	178.8	20.2	67.2	89.9	42.0	
Over–predicted	Observed	195	9	55	109	40	204*2
	Expected	183.2	20.8	68.8	92.1	43.0	
Total		362	41	136	182	85	403*2

Table 5.6 Condition of slope and lighting along the segments: contingency table

Segments where behavior is	Count	Slope condition		Lighting			Total
		Flat	Slight or Steep hill	Pedestrian–oriented	Road–oriented	No lighting	
Under–predicted	Observed	176	23	93	102	12	199*2
	Expected	167.9	31.1	59.7	133.6	10.4	
Over–predicted	Observed	164	40	25	162	9	204*2
	Expected	172.1	31.9	58.3	130.4	10.6	
Total		340	63	118	264	21	403*2

Figure 5.2 Street with incomplete sidewalk but its right of way is meant for pedestrian use

The third part concerns land uses. With six significant items, this class of features appears to be the most important. The first of the items here is land use along both sides of a segment. Land uses were audited as residential, office/institutional, restaurant/café/commercial, industrial, recreational, and vacant/undeveloped as per PEDS. For analysis, land uses were reclassified as mixed use (i.e. more than one type of land use present except mixture of residential and vacant type land uses), residential and/or vacant, and others (e.g. commercial only). Mixed land uses bring the trip origins and destinations closer, thereby promoting trips by active modes (walking and cycling), whereas purely residential areas have the opposite effect (Cervero and Duncan, 2003; Cervero and

Kockelman, 1997; Ewing and Cervero, 2001; Khattak and Rodriguez, 2005; Krizek, 2003; Song et al., 2013). This study is in agreement with past research. Segments where walking were more common than predicted feature mixed land uses more frequently than not (134 as opposed to 124.9). These segments also had fewer residential and/or vacant land uses (51 as opposed to 63.2). In contrast, segments where walking was less prevalent have fewer mixed (119 as opposed to 128.1) and more residential and/or vacant land use (77 as opposed to 64.8). Similarly, higher vertical mix in land uses is frequently seen in more walkable segments and seldom in less walkable segments (Table 5.7).

Table 5.7 Land uses and vertical mix of buildings: contingency table

Segments where behavior is		Land use			Vertical mix of buildings		Total
	Count	Mixed use	Residential and/or vacant	others	Vertical mixed	None or N/A	
Under–predicted	Observed	134	51	14	90	109	199*2
	Expected	124.9	63.2	10.9	70.1	128.9	
Over–predicted	Observed	119	77	8	52	152	204*2
	Expected	128.1	64.8	11.1	71.9	132.1	
Total		253	128	22	142	261	403*2

Table 5.8 Public space: Plaza and Park/playground: contingency table

Segments where behavior is		Public space: Plaza		Public space: Park/playground		Total
	Count	No	Yes	No	Yes	
Under–predicted	Observed	193	6	186	13	199*2
	Expected	182.2	16.8	176.8	22.2	
Over–predicted	Observed	176	28	172	32	204*2
	Expected	186.8	17.2	181.2	22.8	
Total		369	34	358	45	403*2

Next the presence of two different types of public space (plaza and park/playground) was considered. Although public open spaces are usually found to be positively associated with walkable neighborhoods (Badland et al., 2010a), this finding is not consistent, and less walking has been reported when public open spaces are too close to someone's place of residence (Koohsari et al., 2013). Plazas, parks and playgrounds were less commonly found in segments where walking was prevalent. A possible reason for this contradictory finding may be that seniors may wish to avoid busy public spaces and prefer more quiet areas for walking (Garvin et al., 2012). Moreover, the Montreal Household Travel Survey data used to model the mode choice behavior used in this study were collected in between September and December in 2008. Winter in Montreal, Canada usually starts in early October and snowfall begins end of the month. Influence of open public space during the data collection period therefore seems counter–intuitive. Quality of public spaces in the street segments follows the same direction as the presence of public spaces. Compared to the expected counts absence of public spaces is persistent (108 observed whereas 94.3 expected) and presence of high quality public spaces is sporadic (24 observed whereas 28.1 expected) in more walkable segments whereas less walkable segments have more than expected high quality public spaces and fewer than expected segments where no public space is present (Table 5.9). The findings support the argument of Koohsari et al. (2013) that public spaces too proximal to one's residence may be small, have unpleasant features, and/or poor quality which hinders its attractiveness as destination. The last significant item is coffee as a gathering place. While seniors are likely to avoid public open spaces, they are more likely to walk to indoor gathering places, for instance coffee shops. A greater than expected number of coffee shops are found in more walkable segments whereas the observed count is below the expectation in less walkable segments (Table 5.10). Similar findings were found by Garvin et al. (2012) that indoor gathering places (e.g. coffee shops, shopping centers, and public libraries) are very important for seniors during winter months in Canada.

Table 5.9 Quality of public spaces in the segments: contingency table

Segments where behavior is	Quality of public space					Total
	Count	N/A	Neutral	Low quality	High quality	
Under–predicted	Observed	108	59	8	24	199*2
	Expected	94.3	64.2	12.3	28.1	
Over–predicted	Observed	83	71	17	33	204*2
	Expected	96.7	65.8	12.7	28.9	
Total		191	130	25	57	403*2

Table 5.10 Coffee as a gathering place along the segments: contingency table

Segments where behavior is	Gathering place: coffee			Total
	Count	Yes	No	
Under–predicted	Observed	19	180	199
	Expected	13.3	185.7	
Over–predicted	Observed	8	196	204
	Expected	13.7	190.3	
Total		27	376	403

Finally, some miscellaneous factors were considered. There is only one significant item in this class of features, namely the number of lanes in the segments. The number of street lanes is a simple indicator volume of traffic in the segment. A single lane street is typically low volume whereas streets with two or more lanes are more likely to be high volume. The item was audited as a continuous variable and then recoded as single lane (low volume) and two or more lanes (high volume). From this walkability audit, we find that observed number of segments with single lane in under–predicted segments is 99 which are greater than its expected count (88.4). On the other hand, the expected count (90.6) of single lane in over–predicted segments outnumbers the observed count (80). Similarly, observed number of segments (100) in under–predicted segments with two or more lanes is fewer than the expected count (110.6) (Table 5.11). Previously, high volume streets were found to be negatively associated with neighborhood walkability as the pedestrians feel unsafe while walking along a high volume streets (Giles-Corti et al., 2011; Larsen et al., 2012; Michael et al., 2006; Zhu and Lee, 2008). On the contrary, seniors seem to feel comfortable walking along low volume street segments as they are easier to cross than multi–lane streets and are typically associated with a stop sign where they can take as much time as they require compared to a signalized intersection where crossing time is given.

Table 5.11 Number of street lanes in the segments: contingency table

Segments where behavior is	Number of street lanes			
	Count	Single lane	Two or more lanes	Total
Under–predicted	Observed	99	100	199
	Expected	88.4	110.6	
Over–predicted	Observed	80	124	204
	Expected	90.6	113.4	
Total		179	224	403

5.5. Summary and conclusions

With the increasing number of seniors understanding what makes a neighborhood walkable is essential to improve their quality of life and well–being. Increased use of active transport (e.g. walking and cycling) is one of the prerequisites to achieve these objectives (WHO, 2007). A better understanding of walking and walkability calls for the study of street–scale built environmental features that facilitate walking.

In this paper we applied an approach that can expedite and reduce the cost of walkability audits, by selecting a reasonable sample of street segments in a broader region. The approach is based on the use of model for walking behavior. The idea was initially proposed by Moniruzzaman and Páez (2012) but has been adapted in this paper for the case of individual-level data and the use of discrete choice models.

For the case study, the mode choice model was estimated with a broad array of possible confounding factors, including seniors' socio-economic and demographic attributes, as well as meso-scale urban form and neighborhood characteristics around the place of residence. Using the walking part of the mode choice model, we predicted the choice of walking as a mode of transportation and identified whether the model predicted walking accurately or whether it under– or –over predicted walking. Our conjecture was that systematic under– or over-prediction could be caused by street–scale built environmental features that were not part of the mode choice models. Further analysis was conducted to locate areas where under– or over-prediction of walking clustered in space. This then formed the basis for field work conducting walkability audits.

Figure 5.3 Under-predicted (walking is more prevalent) street segments

In general, we found that segments where the model under–estimated walking (i.e. walking was more common than predicted by the covariates in the model) are associated with more marked cross–walks, more four–way intersections, and fewer dead-ends or three–way intersections. These segments also had more highly connected sidewalks, the terrain tended to be flat, and had more pedestrian–oriented lights. Also, for the case of seniors, the segments were more commonly single lane, and therefore lower volume (see Figure 5.2). On the other hand, less walkable segments were found to be associated with fewer marked cross–walks, more dead-ends and three–way intersections. The segments were also less connected, slight/steep slopes were more common, and had more road–oriented lighting. Furthermore, the segments tended to be high volume (Figure 5.3). In term of land uses, more walkable segments displayed more mixed land uses, more diversity in the rise of buildings, had fewer public spaces, but more coffee shops. Less walkable segments, in contrast, are more commonly single use (residential and/or vacant), building height tends to be more uniform, there are public spaces, but fewer coffee shops.

Figure 5.4 Over-predicted (walking is less prevalent) street segments

The approach presented in this paper was inspired by that of Moniruzzaman and Páez (2012). We warn, however, against a direct comparison of the case studies, since variations in the results might be the result of different foci in terms of demographics, namely working age cohort in Moniruzzaman and Páez (2012) versus seniors in the present paper.

Methodologically, the proposed approach has several merits to recommend. As the case study demonstrates, the approach can save time and money by systematically selecting a sample of segments from a relatively large city while capturing valuable information from street segments. Furthermore, this can be accomplished while accounting for a large number of confounders, as compared to previous research that only considered at most two confounding factors in the selection of segments. Also, the proposed method has broad applicability. For instance, the method can be used in different contexts and for different purposes (e.g. selecting segments for bikeability or other audits). Finally, it provides a list of street-scale built environmental features that encourage seniors to choose walk. This information can provide valuable insights for transportation planners, city designers, and health policy makers interested in active travel and seniors' health.

Chapter 6 Conclusions and Future Research

The number and percentage of seniors in Canada is projected to rapidly increase and then stabilize within the next four decades. This dramatic increase in Canada has drawn the attention of many disciplines, including health policy makers, towards interventions that support a healthy aging society. Increasing the use of active transportation modes, in particular walking, is one way to keep the senior age cohorts healthier and is very easy to achieve without many changes in the current development trend of cities. Walking is the most inexpensive transportation mode and does not require any specific skill and is suitable for people of all ages. Regular walking is thus recommended by physicians to maintain good health and prevent diseases (Elsawy and Higgins, 2010). The topic of this dissertation, given its connections to well-being and health, was the mobility of seniors.

6.1. Mode use and trip length

Chapter 2 investigated the use of three transportation modes (walking, transit, and car) and the associated trip length using data obtained from Montreal's Household Travel Survey. A joint-discrete continuous model was used to investigate their relationship with seniors' socio-economic, urban form, and built environment related variables. The findings of this study provide valuable insight in the field of travel behavior research. The study found that with increasing age, seniors become less likely to use transit and walking travel modes and favored the use of a car. Similar findings were found for trip length.

Interestingly, higher income seniors undertook longer walking trips; however choice of walking consistently decreased as income increased. As expected, possession of driver's licence was negatively associated with walking and transit and positively associated with car for both use and length of walking trips. Seniors in medium to high job density areas were less likely to use a car and were more likely to use transit and walking. High job density also decreased the length of car trips and increased the length of transit trips.

Moreover, mapping the spatial variations in mode use and trip length was made possible using the trend surface as a function of geographic coordinates of senior's place of residence. The maps showed evidence of spatial variations in mode use and trip length. However, results of this analysis do not provide a complete picture of seniors' travel behavior as they do not show how frequently seniors are undertaking the trips. To obtain a complete picture, it was therefore necessary to analyze trip generation behavior of seniors.

6.2. Trip generation

Chapter 3 investigated the trip generation behavior of seniors using the same dataset and the same list of variables. A trivariate ordered probit model was used to analyze the multi-modal trip frequencies. Results of the trivariate ordered probit model reported that propensity of undertaking frequent walking and transit trips decreased as seniors became older whereas it increased for car trip frequencies. Increasing income was positively associated with propensity of higher car frequencies and negatively associated with trip frequencies by transit. Access to mobility tools decreases the propensity of walking and transit trips and increases that for a car. Among the neighborhood characteristics, job density was consistently found to significantly impact trip frequencies across all modes in the study. Medium to high job density decreases the propensity of walking and car trip frequencies and increases for transit trips. Network density and land use mix were not found to be significant for any of the modes. Building square footage to DA area ratio negatively influenced the propensity of making a higher number car trips, and was not significant for the other two modes. Number of activity locations around seniors' place of residence is also an important determinant of higher number of walking trips. Spatial analysis of the behavior reveals that probabilities of walking trip frequency vary across the area as trip length in Chapter 2.

6.3. Compliance Potential Mapping

Chapter 4 introduced the concept of Compliance Potential Mapping (CPM) in order to estimate contribution of walking towards the recommended physical activity guidelines that seniors can obtain from regular walking trips to destinations. The proposed concept is based on the results of the models estimated in Chapter 2 and Chapter 3, more specifically, estimates of walking trip length from the joint discrete-continuous model and walking trip frequency from the trivariate ordered probit model were used to calculate the contribution. Firstly, maps of spatial variations in walking trip length and frequencies were produced from the model results. Secondly, the maps were overlaid using simple map algebra operations to obtain the potential physical activity compliance maps. Five senior profiles were created to demonstrate the concept of CPM in Chapter 4. It was found from the profiles that seniors at the central parts of Montreal Island had a relatively higher potential for compliance with physical activity guidelines compared to seniors in the suburban part of the Island. Moreover, the percentage of physical activity guideline met varied according to age, income, occupation, possession of driver's licence and vehicle, and neighborhood and accessibility parameters.

6.4. Street segment sampling approach

Chapter 5 adopted and adapted the model–based approach proposed by Moniruzzaman and Páez (2012) to select street segments and and then explored the attributes of walkable environments from the perspective of seniors. This study used the discrete mode use model estimated in Chapter 2. The walking part of the discrete choice model in Chapter 2 was used to predict seniors' choice to walk and found that the model under and over-predicts the walking behavior in different parts of Montreal Island. A multinomial spatial scan statistic was used to find clusters of under and over-predicted segments. Approximately 400 street segments with equal distribution between under and over-predicted segments were selected as a proof of principal. It was hypothesized that systematic over or under-estimation is caused by the missing street-scale built environment into the model of walking. More specifically, we hypothesized that under–predicted areas would be associated with better street-scale features whereas over-predicted areas would be associated with limited street-scale features. An in-person walkability audit was conducted in different part of Montreal Island using Pedestrian Environment Data Scan (PEDS) and Seniors Walking Environment Assessment Tool-Revised (SWEAT-R). Significant results of the street-scale built environmental features proved the proposed model-based street segment sampling approach in the chapter. This study also reported that more walkable segments were linked with more marked cross–walks, horizontal and vertical mixtures in land uses, and low traffic volume whereas less walkable segments were related to more unmarked cross–walks, residential and/or vacant land use, and high traffic volume.

6.5. Contributions and future research

Chapter 2 and 3 of this dissertation focused on three different travel behaviors for seniors in Montreal Island. Model results for the three behaviors of interest provide important policy implications. Significant factors in the models can be used to increase walking and transit ridership and hence decrease the use of car. Previous studies also focused on elderly travel behaviors and provided their estimates on the behaviors. However, this study provides robust estimates on the behaviors by estimating them from a multi-modal perspective. Moreover, spatial analysis of the behaviors shows substantial intra-urban variability in walking behavior, and the role of neighborhood design attributes and accessibility in influencing the mobility of seniors.

Compliance Potential Maps also offer valuable information for public health and transportation planning and policy analysis. Areas where seniors are obtaining only a little benefit from regular walking from transport can be identified and prioritized for alternative measures in order to meet physical activity requirements. Finally the implemented segment sampling approach can be used to sample street segments for walkability audits. The proposed approach saves both time and money in collecting features of street-scale built environment by providing a representative sample of street segments. In addition, this study provides a list of street-scale built environmental features that encourage seniors to choose walk which will provide valuable insights to transportation planners, city designers, and health policy makers interested in active travel and seniors' health.

This study opens avenue for future research. Analyses of trip length and trip frequency were conducted using a single day travel diary and, later on, the concept of CPM was introduced assuming that the same behavior is repeated over five days of the week. However, it would be more realistic to use a weeklong travel diary database to analyze trip length and frequency with the week-long database. In doing that the assumption of repeated behavior in estimating potential contributions of walking towards physical activity can be released. Should weeklong databases be available, the analysis can easily be done in future. Moreover, the concept of CPM can be implemented for overall walking (walking for transport and leisure) to obtain total contributions of walking in fulfilling physical activity guidelines.

The maps of potential physical activity compliance produced in Chapter 4 can be further analyzed along with a health database to find possible correlation between seniors' health status and percentage of potential physical activity compliance they are obtaining from regular walking for transport. In other words, are seniors that reside in neighborhoods with a higher percentage of features that support physical activity compliance healthier than seniors from low percentage areas? Finally, the model-based street segment sampling approach can be used for different population cohorts and in different context. For instance, a search for street-scale built environment factors that influence the bikability of a city can be conducted using a model of bike choice in the city.

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