TRIVARIATE ORDERED PROBIT APPROACH TO ANALYZE THE TRIP GENERATION BEHAVIOR OF SENIORS

Md Moniruzzaman (monirrm@mcmaster.ca), School of Geography & Earth Sciences, McMaster University, Phone: 905-525-9140 ext.24082; Fax: (905)546-0463

Antonio Páez (paezha@mcmaster.ca), School of Geography & Earth Sciences, McMaster University, Phone: 905-525-9140 ext.26099; Fax: (905)546-0463

Darren Scott (scottdm@mcmaster.ca), School of Geography and Earth Sciences, McMaster University, Phone: 905-525-9140 ext.24953; Fax: (905)546-0463

Catherine Morency (cmorency@polymtl.ca), Department of Civil, Geological and Mining Engineering, École Polytechnique, Phone: 514-340-4711 ext.4502; Fax: (514)340-3981

ABSTRACT

The objective of this paper is to analyze the multi-modal trip generation behaviour of seniors with a focus on walking. Application of a trivariate ordered probit model allows us to jointly study trip-making frequency for three transportation modes, i.e., walking, car, and transit, among seniors in Montreal Island, using data drawn from the 2008 edition of Montreal's Household Travel Surveys. Personal, mobility tools, and neighborhood characteristics along with six accessibility parameters are considered to determine their association with trip generation. By virtue of applying a trivariate ordered probit model, this study implicitly deals with mode choice and trip generation simultaneously. The study finds that walking trip generation tends to decrease with age, but with important geographical variations. Walking trip frequency also tends to decrease with income. These effects are moderated by higher job density, proportion of built-up area, and number of activity locations.

Keywords: Elderly mobility, trip generation, walking, trivariate ordered probit model, spatial analysis, accessibility, neighborhood characteristics.

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 age 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 also 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 Schmoecker, 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, there is a concern that in this context 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, possession of driver license among seniors is very high, with three in four seniors in 2009 holding a driver's license in Canada. With car as the most popular mode of transportation, shares of other modes remain substantially low. Among seniors aged 75 to 84, the share of transit is only 7%, and 4% for walking and cycling combined (Turcotte, 2012). However, as seniors become older their ability to drive a car is reduced because of impaired health, inadequate visual, cognitive, and auditory functions (Raitanen et al., 2003; Schmocker et al., 2005; Turcotte, 2012). Previous research, for instance, indicates that seniors who use their car face dramatically reduced mobility, perhaps due to self-censoring (Mercado and Páez, 2009). 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; Transport Canada, 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; U.S. Department of Health and Human Service, 1999), and provides ample benefits, including increases in the cognitive function of seniors (Yanagimoto et al., 1999). 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 other mobility tools, 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).

The objective of this paper is to analyze the multi-modal trip generation of seniors, considering three modes: car, transit, and walking. Decisions regarding the frequencies with which these modes are used are very likely interdependent. The trip generation of older adults has been the subject of previous research, however disregarding the mode of travel (e.g. Pettersson and Schmoecker, 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. In order to address this gap in the literature, in this paper we use a trivariate ordered probit model which accounts for common unobserved factors which contribute the trip making frequency decisions by multiple modes, with a focus on walking. The study implicitly deals with mode choice and ordered trip generation simultaneously. Individual's socio-demographic, mobility and neighborhood characteristics along with six accessibility parameters are examined to assess their associations with trip frequencies by the three different modes considered. Furthermore, spatial analysis of model coefficients, implemented by means of trend surfaces (see Bailey and Gatrell, 1995), allows us to capture contextual variations across the study region. Visualization using maps of estimated values of trip generation produce geographically detailed insights of seniors' walking behavior in the region under study.

2 BACKGROUND

Early studies of trip generation behaviour 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 Schmoecker, 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.

Studies concerning seniors typically take 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 (Statistics Canada, 2006). The bulk of research on aging and mobility indicates that with increasing age mobility becomes generally more limited (Kim, 2003; Mercado and Páez, 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) find that seniors in the 65-75 year cohort are not significantly different from 18-59 age cohort. These researchers point out that contemporary seniors tend to be more mobile and make diversified trips relative to earlier generations of seniors. 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. On the other hand, past studies also found that seniors require special attention to meet their transportation demand when they become 75 years or older (Alsnih and Hensher, 2003; Cao et al., 2010; Tacken, 1998), hence the need to distinguish between younger and older seniors in travel behavior studies (Alsnih and Hensher, 2003; Schmocker et al., 2005).

Previous research has found that elderly mobility behavior also varies as a function of gender. 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 and Winsten-Bartlett, 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). In another study, Hough et al. (2008) found that women with good social networks are more likely to travel frequently. Household structures also influence the mobility behavior of elderly people and show significant association with trip generation. Schmocker et al. (2005) 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 couples with children. Roorda et al. (2010) studied the trip generation behavior of vulnerable population 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. In a case study for the city of Montreal, Canada, Roorda et al. (2010) found that all income groups tend to make fewer trips than individuals in households with incomes over 100 thousand dollars. In contrast, Schmocker et al. (2005) in their study of the trip generation of elderly and disabled people in London found that individuals in households with lower (less that 10 thousand pounds) and higher (more than 50 thousand) incomes tend to make fewer work and personal business trips than middle income classes (10-25 and 25-50 thousand). On the other hand, all income classes tend to make fewer recreational trips when compared to the highest income class. Similar results were found for the income classes in the study of trip generation of older people in Metro Manila (Pettersson and Schmoecker, 2010). Nonetheless, van den Berg et al. (2010) did not find any significant relationship with income classes for the number of social trips. Trip generation is also associated to possession of, or access to, various mobility tools. Several studies report that vehicle ownership and use, and driver license 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).

In general terms, there is increasing evidence that neighborhood characteristics influence the trip generation behavior of individuals (Cao et al., 2010; Frank et al., 2007; Kim, 2003; Pettersson and Schmoecker, 2010; Sehatzadeh et al., 2011; van den Berg et al., 2010). Mixed findings, positive and negative associations, have been found about the impact of population density on elderly mobility in earlier studies. Population density was found to be positively correlated with the number of trips made by the elderly (Pettersson and Schmoecker, 2010; Roorda et al., 2010). However, others have found it to be negatively associated with the trip frequency among older adults (Guo et al., 2007; Kim, 2003). Kim (2003) also found that urban form factors developed from population and employment densities did not display significant relationships with the mobility status of the elderly.

Factors related to the neighborhood environment are more likely to impact choices relating to slower, non-motorized modes, in particular walking (Moniruzzaman and Paez, 2012). 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 (Nagell 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, activity locations close to an individual's residence and distances to those nearest activity locations can be used to study trip generation behavior (Naess, 2006). Better accessibility to activity locations is conducive to walking, and tends to discourage driving and vehicle possession (Krizek and Johnson, 2007; Sehatzadeh et al., 2011).

3 METHODS

The literature summarized in the preceding section focused on different aspects of the mobility behavior of older adults. In case of trip frequency analysis, which is the focus of this study, the univariate ordered probit model has been extensively used as a modeling technique (Hough et al., 2008; Páez et al., 2007; Pettersson and Schmoecker, 2010; Roorda et al., 2010; Schmocker et al., 2005). Other studies have used the negative binomial model to analyze trip generation (Cao et al., 2010; van den Berg et al., 2010). All these studies analyzed trip generation for a specific mode of transportation (e.g. walking or car or public transit) and/or for a specific trip purpose (working or shopping or recreational trips), or simply the overall number of trips. However, travel decisions by different modes are likely interdependent and the factors influencing them can be known or remain unobserved. For example, the decision to use transit due to the lack of a valid driver license can be accounted by incorporating a dummy variable. Other factors may not be available to the analyst. For example, a traveler may travel by 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. The decisions are thus correlated. A multivariate-outcome model is appropriate in such situations. For instance, using a bivariate ordered probit model Guo et al. (2007) jointly investigate the number of trips made by motorized (car, van, truck, motorcycle, carpool vehicle, and taxi) and non-motorized (bicycle and walk) modes. In what follows, a trivariate ordered probit allows us to examine three modes simultaneously: car, transit, and walking.

A multivariate ordered probit is an appropriate technique in a situation where several potentially correlated ordered responses are to be modeled against the same or different sets of covariates. Due to high computational cost involved in the estimation process, trivariate model was rarely used in the past. Scott and Kanaroglou (2002) developed a trivariate ordered probit model to determine the interaction between household heads (male head, female head, and both together) and activity settings (number of non-work, out-of-home activity episodes). Ongoing computational advances make it possible to implement models of this kind with increasing ease.

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:

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

where y_{1i}, y_{2i}, and y_{3i} are the observed number of trips made by individual i by mode *j*=1, 2, 3. The variables 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:

$$R = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix} \quad (2)$$

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:

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

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.

4 DATA SOURCES

4.1 Montreal's Household Travel Surveys

The database used for this study is Montreal's Household Travel Survey conducted in 2008. This is the ninth edition of the origin-destination (OD) survey conducted for the entire metropolitan area. In addition, this database is the largest survey of mobility in Quebec and one of the largest in the world. The primary objective of this travel survey is to provide data to support transportation planning and operations in the region, applied and basic travel behaviour research. For the purpose of the analysis conducted in this paper, a subset of trips was extracted to include only home-based trips, i.e., all trips where one end of the trip was the place of residence, made by the senior cohorts, including the transitional cohort of individuals aged 55-64 years, and in Montreal Island only. After extracting the subset, a few observations 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 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 were 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 trip purpose. 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.

4.2 Measuring neighborhood characteristics

Neighborhood characteristics considered in this study includes population density, employment density, street density, intersection density, building square footage to area ratio, and land use mix. Among these characteristics population and employment densities are categorical and measured at the individual level. On the other hand street density, intersection density, building square footage to area ratio, and land use mix are continuous variables and were extracted at the dissemination area (DA) level which is the smallest geographic unit of analysis publicly available in Canada. Street density was calculated as total street length in km in a DA divided by the corresponding DA area in square kilometers. Similarly, intersection density was calculated as the number of 3 or more way intersections in a DA divided by the corresponding DA area in sq.km. Street density and intersection density are highly correlated to each other (correlation coefficient 0.75). As a result, principal component analysis (PCA) was applied between the two transportation network related attributes. The first principal component in this study accounts for 87% of total variability between the two correlated attributes. Considering the characteristics of the two attributes used in the PCA, the principal component here was renamed as network density.
Building square footage to area ratio was calculated as total built-up area in sq.km in a DA divided by the total area of the DA in the same unit. This ratio represents the share of built-up area in DA. Value closer to 0 indicates sparse development and value closer to 1 indicates compact development within the DA. Land use mix however was calculated using the following normalized entropy formula:

$$-\frac{1}{ln(N)}\sum_{i=1}^{N} P_i \ln(P_i) \qquad (4)$$

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

Table 1 – List of explanatory variables with description

Variable name	Description
Age: Younger senior	If age is 55 to 64 years =1, 0 otherwise
Age: Senior	If age is 65 to 74 years =1, 0 otherwise
Age: Elder senior	If age is 75 or above =1, 0 otherwise
Gender	If female = 1, 0 otherwise

Household type: Single, Couple, Other multi-person household	If household is of indicated type =1, 0 otherwise
Occupation: Full-time, Part-time, Retired, At-home	If occupation is of indicated type =1, 0 otherwise
Income: <20k	If income is less than $20,000 =1, 0 otherwise
Income: 20-40k	If income is $20,000 to 39,999 =1, 0 otherwise
Income: 40-60k	If income is $40,000 to 59,999 =1, 0 otherwise
Income: 60k or more	If income is $60,000 or above =1, 0 otherwise
Income: RF/DK	If income is do not know or refused =1, 0 otherwise
Driver's licence	If status of driver's licence is yes =1, 0 otherwise
Vehicle ownership	Number of household vehicle ownership
Population density: Low, Medium, High	If population density is of indicated type=1, 0 otherwise
Job density: Low, Medium, High	If employment density is of indicated type=1, 0 otherwise
Neighbourhood: Street density	Total street lengths (km)/DA area (square km)
Neighbourhood: Intersection density	Total number of intersections /DA area (square km)
Neighbourhood: Network density	Principal component computed from street density and intersection density
Neighbourhood: BSF to DA	Total area of building square footage (BSF)/DA area (values between 0 to 1)
Neighbourhood: Land use mix	Normalized values between 0 to 1
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)
Trend surface: CBD distance	Euclidian distance from Central Business District (CBD) to home location (km)
Trend surface: X, Y	Coordinates of home location

5 RESULTS AND DISCUSSION

Results of the analysis are discussed in this section. Dependent variables for the models were number of trips seniors undertook on the survey day by walking, car, and/or public transit. Number of trips was recorded as a continuous variable in the database. Trips were reclassified into trip generation categories as shown in Table 2.

Table 2 – Frequency distributions of all home-based trips of seniors made by modes

	Frequency before reclassification				Frequency after reclassification		
Number of trips	Walking	Car	Public transit	Number of trips	Walking	Car	Public transit
0	10594	4573	10006	0	10594	4573	10006
1	278	404	433	1	278	404	433
2	1928	6673	2512	2 or more	2255	8150	2688
3	38	58	35	Total	13127	13127	13127
4	254	1243	128				

5	4	3	3				
6	26	152	10				
7	1	19	-				
8	2	2	-				
10	1	-	-				
14	1	-	-				
Total	13127	13127	13127				

After categorization, the ordered dependent variables were regressed against a broad array of explanatory variables, as listed in Table 1. At first, the models were run with the threshold parameters only to generate a null model. The log-likelihood of the null model is -20,491.66. The null model was followed by a backward stepwise specification search staring with a fully specified model that included all explanatory variables, and progressing by gradually removing the least significant variable until all remaining variables were significant at p<0.05. The log-likelihood for the full model with only significant variables is -17,185.15. The likelihood ratio for the models is 6613.03 which is greater than the critical value of chi-squared (102.15) with 62 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 – 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=1)	-4.27404	0.0000	2.37921	0.0000	0.66942	0.0000
Threshold 2 (trip≥2)	-4.16984	0.0000	2.52905	0.0000	0.84641	0.0000
Personal characteristics						
Age: Younger senior	Reference		Reference		Reference	
Age: Senior	-0.10066	0.0030	0.13106	0.0000	-0.07742	0.0260
Age: Elder senior	-0.14624	0.0000	0.25257	0.0000	-0.29760	0.0000
Gender	-	-	-	-	0.07864	0.0020
Household: Single	Reference		Reference		Reference	
Household: Couple	-0.14410	0.0000	0.19962	0.0000	-0.19376	0.0000
Household: Other	-0.19247	0.0000	-	-	-	-
Occupation: Full-time	-0.38864	0.0000	-0.07974	0.0170	0.31726	0.0000
Occupation: Part-time	-0.17199	0.0010	-	-	0.22434	0.0000
Occupation: Retired	Reference		Reference		Reference	
Income: <20k	Reference		Reference		Reference	
Income: 20-40k	-0.08307	0.0140	0.16109	0.0000	-	-
Income: 40-60k	-0.15098	0.0000	0.31739	0.0000	-0.12700	0.0040
Income: 60k or more	-	-	0.39296	0.0000	-0.21627	0.0000
Income: RF/DK	-	-	0.17137	0.0000	-0.13266	0.0000
Mobility tools						
Driver licence	-0.39556	0.0000	0.97168	0.0000	-0.78261	0.0000
Vehicle ownership	-0.14299	0.0000	0.34426	0.0000	-0.28567	0.0000

Neighborhood characteristics						
Population density: Low	Reference		Reference		Reference	
Population density: High	-	-	-0.07398	0.0090	0.09886	0.0010
Job density: Low	Reference		Reference		Reference	
Job density: Medium	-0.11477	0.0000	-0.13319	0.0000	0.33212	0.0000
Job density: High	-0.29330	0.0000	-0.72572	0.0000	1.08065	0.0000
BSF to DA	0.30964	0.0430	-0.47386	0.0000	-	-
Accessibility						
Activity locations (400m)	0.95950	0.0000	-	-	-1.2656	0.0000
Nearest health facility	-	-	0. 15030	0.0150	-0.28080	0.0000
Nearest bank	-0.17130	0.0000	0.07710	0.0020	-	-
Nearest grocery	-0.14670	0.0250	0.19920	0.0010	-0.15130	0.0250
Summary statistics						
Number of observations = 13,127			McFadden's adjusted-ρ^2 = 0.1583			
ρ (walking and car) = -0.52		ρ (walking and transit) = -0.13			ρ (car and transit) = -0.72	
LL (Null model) = -20,491.66		LL (Full model) = -17,185.15			Likelihood ratio = 6,613.03	

5.1 Socio-demographic characteristics

Seniors were categorized by their age as transitional adults (55<=age<=64), younger seniors (65<=age<=74), and older seniors (age>=75). 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 higher probability of 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 is found to be significant for all modes of travel. In the case of walking, the effect is non-monotonic, indicating that low-income and higher-income seniors are more likely to walk more compared to middle-income seniors. Frequency of car use tends to increase with income, whereas the opposite is observed for transit.

5.2 Mobility tools

Two mobility characteristics of the seniors were examined in this study – namely possession of driver's license, and number of household vehicle ownership. Both of the mobility tools are consistently significant, positively or negatively, across the transportation modes. As expected, possession of driver's license 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. The relationship between number of household vehicle ownership and trip frequencies are in the same direction as the possession of driver's license. Number of vehicle in the household decreases the propensity of making higher walking, and transit trips and increases the propensity of making car trips.

5.3 Neighborhood characteristics

Five neighborhood related variables were examined to find their association with the trip frequencies of seniors, as per Table 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. 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 is the largest coefficient for transit trip frequency. Building square footage to DA area is a continuous variable in the models. As hypothesized, it has positive association with the propensity of higher number of walking trips and negative association with the propensity of car trips. Nonetheless, it has no statistical significance with the transit trip generation model.

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. The results indicate that walking is more prevalent in areas with a high number of activity destinations, and transit use less prevalent. In contrast, the coefficient has no statically significant impact on the propensity of trip generation by car. Among the five types of destinations examined, nearest distances to the pharmacy and library are not significant. Increasing distances to nearest health care facility, bank, and grocery store, tend to increase the frequency of traveling by car. In contrast, increasing distance to health care facilities and grocery stores reduce the probability of traveling more frequently by transit. In the case of walking, as the distances to the nearest bank and nearest grocery store increase, 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)

5.5 Spatial Analysis of Walking Frequency

In this study we conduct spatial analysis by incorporating six geographical attributes within the models, namely distance to the CBD and a quadratic trend surface derived from the coordinates of the home location (Table 4). These attributes are incorporated to capture geographic variability in the average behavior across the study area (see for example: Morency et al., 2011; Páez et al., 2010; Roorda et al., 2010). An appropriate technique to assess the impact of the trend surface is to map the impact of the coefficients on the behavior of interest. In order to generate such map of the estimated propensity of senior's trip generation behavior we superimposed a regular grid of size 1 sq.km across the study area. The centroid of each grid is then used to estimate the behavior. The grid is used for visualization purposes only, and the size of the grid cells has no impact whatsoever on model estimation. In order to focus on walking behavior we extended this geographic analysis for this mode only.

Table 4 – Estimated geographic parameters for walking, car and transit frequencies

	Walking		**Car**		**Transit**	
	Coefficient	**p-value**	**Coefficient**	**p-value**	**Coefficient**	**p-value**
Latitude	-1.82670	0.0000	0.41105	0.0000	0.54488	0.0000
Longitude	-0.88076	0.0000	0.69776	0.0000	-	-
Latitude*Longitude	-	-	-0.12834	0.0040	-	-
Latitude squared	0.25504	0.0000	-	-	-0.10330	0.0000
Longitude squared	0.47399	0.0000	-0.19396	0.0000	-	-
Distance to CBD (km)	-1.30135	0.0000	0.55160	0.0000	-	-

Five senior's profiles including a base profile were created to estimate the probability of being in a certain ordered trip frequency class. The base profile was created based on a frequency analysis of the significant variables in the database. For instance, the base profile has characteristics which were found most frequently in the database (note that 52.44% of the seniors own one vehicle in their household). However, the values of the continuous neighborhood attributes and accessibility parameters are variable across the grid cells, and obtained, in case of neighborhood attributes, from the nearest DA and, in case of accessibility parameters, from the nearest senior (see Table 4). In this respect, base profile (Profile 0) is compared with age and income profiles to visualize the variations in the propensity of the behavior. We describe the results of this analysis in the following subsections.

Table 5 – Individual profiles for estimating the probability of walking trip frequency

Variables	**Base Profile**	**Age Profiles**		**Income Profiles**	
	0	**1**	**2**	**3**	**4**
Age	55-64	65-74	75+	55-64	55-64
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
Vehicle owned	1	1	1	1	1
Population density	High	High	High	High	High
Job density	Low	Low	Low	Low	Low
BSF to DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA	Nearest DA
Activity locations	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

5.5.1 Trend surface: 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 generation. Figure 1 shows the spatial variation in the estimated propensity of making 1 and 2 or more walking trips as a function of age.

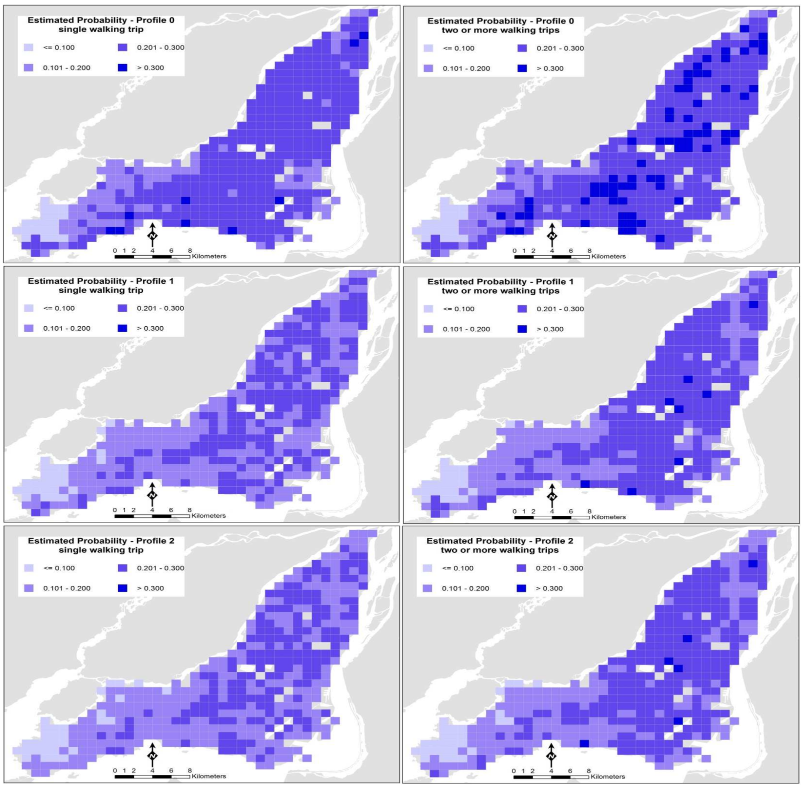

Figure 1 – Geographical variations in estimated probability of making 1, and 2 or more walking trips as a function of age

There is only a little geographic variation in the estimated probabilities of making one walking trip for Profile 0. Most of the grids have probabilities from 0.2 to 0.3. However, more variation is found for Profile 0 in case of making two or more walking trips. The probability range 0.2 to 0.3 still dominates across the study area but scattered grids are also found with higher probability rage (>0.30). Substantially more variation in the probabilities is found as age increases. Estimates for Profile 1 show that grids within probability range 0.2-0.3 tend to be reduced to the lower range 0.1-0.2 and grids with probabilities >0.3 reduced to the lower range 0.2-0.3 for both one and two 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 finding showed that this shifting is not only for a single factor age rather some other confounding factors e.g. impaired driving skills, deteriorated health conditions may also be responsible.

5.5.2 Trend surface: income

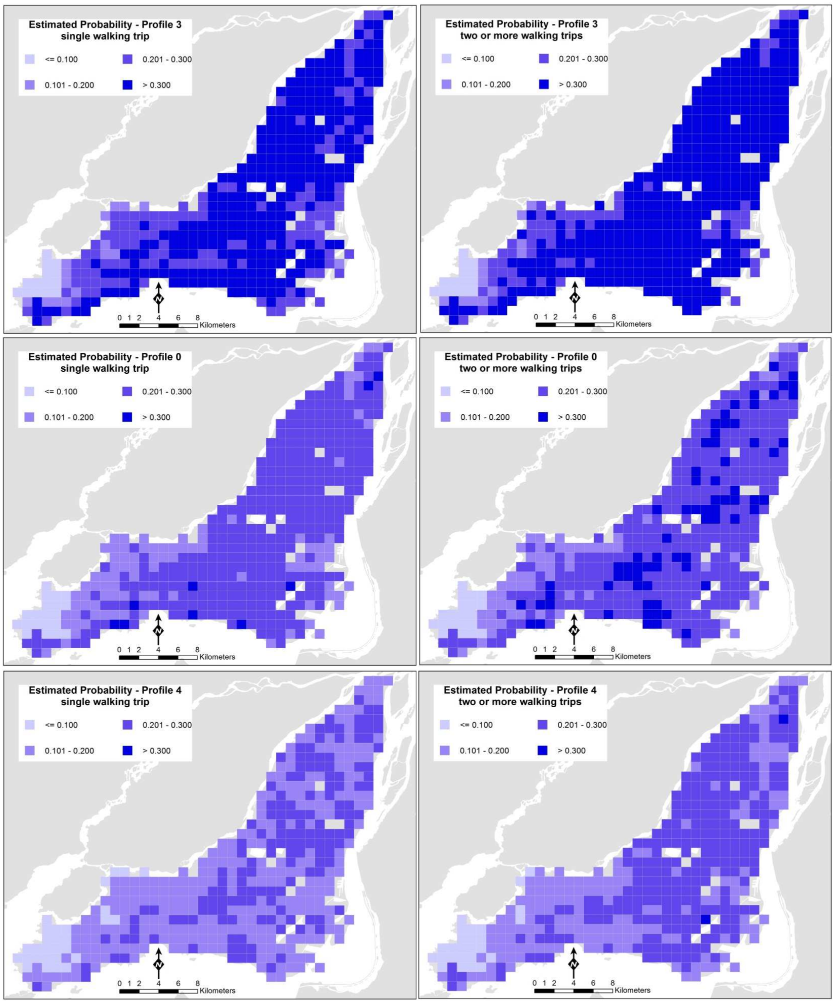

Figure 2 – Geographical variations in estimated probability of making 1, and 2 or more walking trips as a function of income

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 2 shows the spatial variation in the estimated propensity of making 1 and 2 or more walking trip 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.

We can see from Profile 3 (lower income) that the highest probability range (>0.3) dominates the grids across the Montreal Island for both one and two or more walking trips. However, when comparing between Profile 3 and the base profile (Profile 0: income 20 to 40 thousand dollars), it was found that probability of making o and two or more walking trips decreased drastically as income range among seniors increased. Prevailing probability range for Profile 0 across the area is 0.2-0.3 which was >0.3 for Profile 3. The probability range decreased more with one stage increase in the income range (Profile 0: 20-40 to Profile 4: 40-60 thousand dollars) which again confirms that increasing income reduces the propensity to make more walking trips ceteris paribus.

5.6 Correlation coefficients

All three possible correlation coefficients (walking and car, walking and transit, and car and transit) in the trivariate ordered probit models are highly significant at p-value<0.0001. In addition, the coefficients are negative (-0.52, -0.13, and -0.72 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 -0.52 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 (-0.13) but substantially smaller in magnitude.

6 SUMMARY AND CONCLUSIONS

Rapid increase in the percentage of seniors in Canada has prompted attention towards healthy aging. One way to achieve this broad goal is by encouraging increased use of active modes of transportation among seniors, in particular walking, a suitable mode for older adults. In his study, we examined the multimodal trip generation behavior of seniors with a focus on walking trips.

By applying a trivariate ordered probit model, we found that trip frequencies of seniors by walking, car, and transit are determined by personal, mobility tools, neighborhood, and accessibility factors. As seniors age they are more likely to increase the propensity of making higher number of trips by car and, hence, reduce the propensity of making trips by walking, and public transit. The income of seniors was also found to influence their trip making behavior, with walking being more prevalent among lower and higher income individuals, other things being equal. Access to or ownership of mobility tools tends to decrease the number of walking and transit trips, but to increase mobility by car. As licensing rules are adjusted to the reality of an aging population, the effect may reduce overall mobility for seniors. Among the neighborhood characteristics examined in this paper, job density consistently influences the trip generation behavior across all modes. It has positive impact on the probability of making higher number of transit trips and negative impact on the propensity of walking and car trips. The number of activity locations around the residence positively influences the propensity of walking trips and negatively influences the propensity of transit trips. This finding has broad policy implications. Increasing the accessibility to the nearest activity locations would tend to favor walking as a mode of transportation, and hence reduce the number of car trips on the roads. High negative correlations of the unobserved part of the models between car, and transit (-0.72) and walking, and car (-0.52) indicate the competing nature between these modes. A smaller negative correlation between the unobserved components of walking and transit trip suggests that these modes are substitutes but to a more limited degree.
Spatial analysis of walking frequency reveals greater heterogeneity in this behavior as people age. Mapping the probability of walking trips has potentially intriguing policy applications. According to the Public Health Agency of Canada, weekly recommended minimum physical activity requirements for the seniors are 2.5 hours or 150 minutes which must be moderate-to-vigorous and in bouts of 10 min or more (Public Health Agency Canada, 2011). Considering an average walking speed of 1.14 m/s (Montufar et al., 2007), 150 min of physical activity is equivalent to 10.26 km of walking per week. In an earlier study, Moniruzzaman et al. (2012) showed that walking trip lengths among seniors vary across Montreal Island. By combining trip making frequency with estimates of walking trip length it could be possible to investigate the potential contributions of walking towards physical activity guidelines. For example, a senior who makes 2 walking trips in a day with an average trip length of 500 m, would complete 1 km of walking on a single day. If the senior repeats the behavior over five working days on a typical week, this would accumulate 5 km of walking on the week. Considering the average walking speed (1.14 m/s), 5 km would be equivalent to 73 minutes of walking which would contribute approximately 49% of weekly recommended physical activity for seniors. Compliance maps could be produced by overlapping the two maps i.e. trip length and trip frequency and be used for policy prescriptions in future, more specifically identifying the areas of interest from the compliance map where seniors are receiving less benefits from regular walking and hence require some policy measures (e.g. increasing accessibility to local activity locations) to encourage them in walking. This is a matter of ongoing research.

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