Compliance Potential Mapping: A Tool to Assess Potential Contributions of Walking Towards Physical Activity Guidelines

Md Moniruzzaman (monirrm@mcmaster.ca)

PhD Candidate, School of Geography and Earth Sciences, McMaster University,

1280 Main Street West, Hamilton ON L8S 4K1, Canada.

ITE District 7

ABSTRACT

Walking for transport is considered an appropriate form of physical activity for seniors. In order to evaluate the potential contributions of walking to physical activity, in this paper the concept of Compliance Potential Mapping is introduced. 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 recommended physical activity guidelines for seniors. The approach is conceptually intuitive and based on relatively straightforward map algebra operations. The approach for Compliance Potential Mapping proposed is demonstrated using the city of Montreal in Canada as a case study. The results indicate that the central parts of Montreal Island display higher potential for compliance with physical activity guidelines, but with variations according to gender, income, possession of driver's license and vehicle. Compliance Potential Maps offer valuable information for public health and transportation planning and policy analysis.

1. INTRODUCTION

Population aging continues apace in most of the industrialized world. In Canada, the growth rate of the senior cohort will accelerate in the next 25 years as individuals of the baby boom generation reach their senior years. Depending on 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, up from 4.7 million seniors in 2009 (1). Marked demographic changes such as these have prompted an interest in the travel and activity behavior of seniors around the world (2). Multiple studies now document the mobility and activities of seniors in both the developing and developed world (3-7). Given urban development styles that tend to favor mass personal motorization, concerns have been raised about the mobility expectations of contemporary and future generations of older adults – in particular the risk that these individuals will be increasingly car dependent (8, 9).

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 (10). For a vast majority of members of this population cohort car is the main mode of transportation. As a consequence, use of other modes tends to be very low. Recent statistics (11) indicate that travel by car (either as driver or passenger) is the main form of transportation for over 90% of seniors aged 65 to 74. This reduces only slightly to 86.9% of seniors aged 75 to 84, and to 80.4% for seniors aged 85 and over, with the major shift being from driver to passenger. In contrast, walking and cycling is the main mode of transportation for less than 5% of all seniors aged 65 and over, although with geographical variations – from a high of 4.9% in Montreal to only 2.4% outside of Census Agglomerations (CA) and Census Metropolitan Areas (CMA). Besides the system implications of continued reliance on car mobility, including congestion, emissions, and dependence on others for mobility, the low adoption of active transportation also prompts concerns about health and quality of life. Previous research suggests that car use is associated with undesirable health outcomes (12), which may in fact contribute to reduce mobility in aging.

Regular physical activity among the older adults increases their life expectancies and decreases the risk of developing common chronic diseases (13, 14). Direct health benefits of physical activity include the reductions in risk factors associated with heart diseases and type-2 diabetes, colon cancer, and osteoporosis (15, 16). It also helps to extenuate the physiological changes an aged senior in a sedentary society might face as well as assist in prevention and treatment of disability (17). Past studies also reported many psychological benefits of physical activity for people of advanced aged– for instance, fewer depressive symptoms (18, 19), increased self-efficacy (20, 21), and improved psychological well-being (22, 23). In addition to these health and psychological benefits, economic benefits of physical activity are also evident. For example, in 2001, an economic burden of $5.3 billion dollars which is equivalent to 2.6% of total health care cost was attributed to Canadian for being physically inactive (24, 25). 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 (26, 27). However, according to the 2005 Canadian Community Health Survey (CCHS), only 52% of the respondents over 12 or older reported that they were at least moderately active in their leisure time and percentage is even lower (43%) when we look at the senior age cohort only i.e. 65 years and over. Nonetheless, leisure time is not a panoptical representation of overall physical activity and therefore the 2005 CCHS respondents were also asked to report their non-leisure time activities. Among those activities, time spent in active transportations accounts for a significant proportion. For instance, 24% of the respondents reported that they spent at least six hours a week on walking or bicycling as a means of transportation in their past three months.

Active travel, on the other hand, is an inexpensive mode of transportation that could help seniors to increase their levels of physical activity while meeting their daily mobility needs. Past studies also reported that vigorous intensity physical activity is not required for health benefits, instead, most of the necessary health benefits can be achieved through moderate intensity physical activity (28, 29). Walking for transport (for instance, to and from frequently visited activity locations including from public transit) in particular is considered as one of the most important forms of physical activity for seniors and does not require any additional time demand. It is also an appropriate activity for seniors who were sedentary in earlier life, as it tends to place the right amount of stress on joints (30).

It is thus of interest to understand the factors that influence walking behavior, and the potential contributions of walking to the physical activity of seniors. In this paper, Compliance Potential Mapping (CPM) is introduced as a method to assess the level of physical activity associated with walking as a form of transportation. CPM is based on the analysis of the travel behavior of seniors, with due consideration to individual demographic and socio-economic circumstances, the availability of other mobility tools, and the characteristics of the surrounding environment, among other factors. Geographical analysis of walking behavior produces maps of estimates of walking trip length and frequency. These maps are overlaid to generate estimates of expected total walking length, which are in turn related to physical activity guidelines for seniors. The approach is model-based and sensitive to variations in travel behavior by individual and locational attributes, and can thus be used to conduct very detailed analyses of walking as a source of physical activity for seniors. CPM is demonstrated using the city of Montreal, in Canada, as a case study. The method should be of interest to public health and transportation planners, and can become a valuable tool in efforts to study the potential health benefits of walkable neighborhoods, or to identify those where interventions may be required in order to promote walking for transport among seniors.

2. METHODS

2.1 Estimates of Travel Behavior

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

$$\hat{l}_{pi} = f\left(\boldsymbol{Z}_{pi}\hat{\boldsymbol{\theta}}\right) \tag{1}$$

$$P\left(\hat{t}_{pi} = k\right) = g\left(\boldsymbol{X}_{pi}\hat{\boldsymbol{\beta}}\right) \tag{2}$$

Where l_{pi} is the estimated length of a walking trip for senior p at location i, as a function of a set of variables $\boldsymbol{Z}$ and estimated parameters $\boldsymbol{\theta}$. The probability P that the number of estimated trips undertaken by senior p and location i is equal to k is estimated as a function of variables $\boldsymbol{X}$ and estimated parameters $\boldsymbol{\beta}$. It is desirable that the estimates of travel behavior reflect variations in the attributes of the senior, including age, employment status, household structure, and built environment, all factors known to influence mobility. An advantage of using model-based estimates is that the significance of relationships between trip length and frequency and each of these attributes can be tested in a conventional way.

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. Use of spatial models in the analysis of trip length is also popular and was frequently used in earlier studies, for instance – spatial expansion method (31), multi-level model (32). 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 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 decade (33). 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 (34). Moreover, multivariate ordered probit model 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 (35).

2.2.1 Trip length estimates: joint discrete-continuous model

The discrete part of the joint discrete-continuous model is the well-known Multinomial Logit (MNL) model and the continuous part is the continuous time hazard-based model. The MNL part assumes that an individual will choose an alternative with highest utility i.e. a transportation mode that gives the highest utility among the available transportation modes. On the other hand, the continuous time hazard model is used to estimate the trip length for a particular trip of the individual given a specific mode of transportation. However, the dependent variation, trip length, is log transformed and it thus provides a log-normal hazard model. In order to jointly estimate the discrete and continuous part of the models, the error terms of the two models are correlated. The probability that senior *p* at location *i* selects a transportation mode *m* and travel a positive distance of $\hat{l}$ by the transportation mode can be written as:

$$\Pr\left(\text{Distance}=\hat{l}_{mpi}\cap Mode=m\right)=\Pr\left(\text{Distance}=\hat{l}_{mpi}\cap\varepsilon\le J_1\left(\varepsilon_m\right)\right)$$
$$=\frac{1}{\sigma_{mt}\hat{l}_{mpi}}\phi\left(\frac{\ln\left(\hat{l}_{mpi}\right)-\theta_m Z_m}{\sigma_{mt}}\right)\Phi\left(\frac{J_1\left(\varepsilon_m\right)-\rho_{mt}J_2\left(\alpha_{mt}\right)}{\sqrt{1-\rho_{mt}^2}}\right) \quad (3)$$

Marginal distributions of the two transformed random variables are expressed as equivalent standard normal variables, namely $J_1\left(\varepsilon_m\right)$ and $J_2\left(\alpha_{mt}\right)$, assumed to follow a bivariate normal distribution and the parameters are estimated under the distribution accordingly (see for more details: 36).

2.2.2 Multivariate ordered probit

Assume that the same senior *p* at location *i* has *j* number of ordered interrelated decisions to be made simultaneously. Therefore, the model structure with the ordered responses can be written as:

$$y_{1pi}^*=\beta_1 x_{1pi}+\varepsilon_{1pi},\, y_{1pi}=m,\text{ if and only if }\mu_{m,1}<y_{1pi}^*\le\mu_{m+1,1},$$
$$y_{2pi}^*=\beta_2 x_{2pi}+\varepsilon_{2pi},\, y_{2pi}=n,\text{ if and only if }\mu_{n,2}<y_{2pi}^*\le\mu_{n+1,2},$$
$$\vdots \quad (4)$$
$$y_{jpi}^*=\beta_j x_{jpi}+\varepsilon_{jpi},\, y_{jpi}=o,\text{ if and only if }\mu_{o,j}<y_{jpi}^*\le\mu_{o+1,j}$$

where y_{1p}, y_{2p}, ……, y_{jp} are the observed number of ordered responses made by individual *p*. Depending on the *j* i.e. number of ordered responses, the model structure can take different forms – for instance, a bivariate ordered probit structure when there are two ordered responses, a trivariate ordered probit when there are three ordered responses, and so on and so forth. The set of error terms $\varepsilon_p=(\varepsilon_{1p}, \varepsilon_{2p},...., \varepsilon_{jp})$ are assumed to be distributed as multivariate normal with zero mean and R correlation matrix. Nonzero elements in the correlation matrix represent the correlations of common unobserved factors in the ordered decisions (37).

2.3 Compliance Potential Maps

Once these estimates are obtained as per the preceding discussion, Compliance Potential Maps can be generated by means of relatively straightforward map algebra operations, such as additive or multiplicative overlays. Consider the situation illustrated in Figure 1. The top map layer on the left consists of the estimates of walking trip length. Additional layers are estimates of the probability that the estimated number of walking trips is k (1, 2, and 3+ in the example). The expected distance associated with one walking trip is the product of estimated trip length times one (trip), times the probability that the frequency of walking trips is one. Further, the expected distance associated with two walking trips is the product of the estimated trip length times two (trips), times the probability that the frequency of walking trips is two. These map algebra operations are repeated for each of K trip frequency classes (three in this example) as shown on the right side of Figure 1.

The operations above result in a set of K layers with estimates of trip length for each trip frequency class. Estimates of total daily walking distance (TDWD) are obtained by means of the additive overlay of all trip length estimate layers. More formally, the estimate for each geographical sub-unit in a map is calculated using the following equation:

$$TDWD_{pi} = \sum_{k=1}^{K} \hat{l}_{pi} * k * P\left(\hat{t}_{pi} = k\right) \quad (5)$$

The potential for compliance with physical activity guidelines is evaluated in the following fashion. 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. Montufar et al. (38) 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 thus:

$$WWM_{pi} = (TDWD_{pi} * w) / s \quad (6)$$

Finally, weekly walking minutes are converted into the percentage of physical activity recommended in relevant guidelines, such as the New Canadian Physical Activity Guidelines (26).

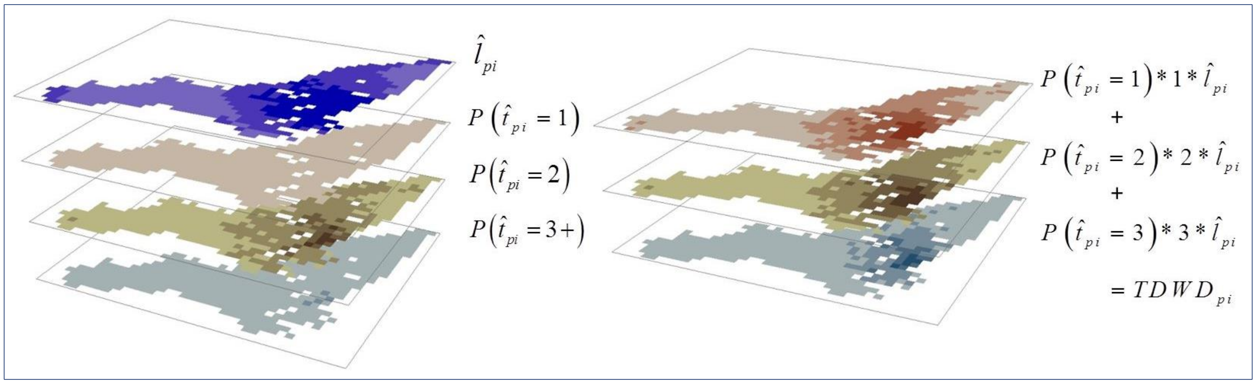

Figure 1: Overlay of map layers and calculation of trip distance for trip frequencies

3. EMPIRICAL DEMONSTRATION

3.1 Context and Data

Montreal is the most populous city in the province of Quebec and second most populous city across Canada after Toronto. Montreal Island which is the focus of this study is the most developed part of the Montreal Census Metropolitan Area. Montreal Island, like many North American cities, has been facing a tremendous population growth as well as a rapid growth in the senior age cohorts and this will continue to increase until 2061. According to the statistics of the *Institut de la Statistique du Québec* (ISQ), some census subdivisions in the Island exceed over 60% of its population in the seniors age cohorts i.e. 65 years or older (more details about the context can be found in: 36).

The 2008 Montreal Household Travel Survey database was used to estimate the models of trip length and trip frequency. A subset of senior respondent i.e. 65 years and older including their transitional age cohort, 55-64 years, was taken for this particular analysis. Before actually estimating the models, the dataset was cleaned in several ways. For instance, there were only a few student seniors or seniors who are lone parents of young children. These records were removed because of their extremely low variability. Moreover, only home-based trips were included to allow spatial analysis based on senior's home location. In terms of the transportation mode concerned, three most popular transportation modes (car, transit, and walk) among the seniors were included in the final dataset. Trips with zero distance were excluded as well from the dataset. Finally a total of 31,631 trips made by 13,127 individual seniors aged 55 or over was considered for the model estimations. Average trip length for all three modes is 5.33 km whereas average walking trip length is only 0.74 km with a standard deviation of 1.06 km. On the other hand, average trip frequency for all modes and walking only is 2.41 and 2.16 per senior, respectively.

The 2009 DMTI spatial (39) data were used for extracting the built environmental variables in the study, namely – street density, intersection density, land use mix etc. Unit of aggregation for these variables is Dissemination Area (DA) which is the smallest geographic scale available from Statistics Canada at free of cost. In addition to the built environmental variables, six accessibility related variables were also calculated to include in this study. They are namely – number of activity locations within 400m buffer of senior's residence and network distance to the five nearest facilities (pharmacy, health facility, bank, grocery, and library).

3.2 Selection of Variables for Analysis

List of variables to be considered in the analysis of trip length and frequency of the senior age cohorts was prepared from an in-depth search of literatures in the field of travel behavior. Broad categories of these variables include senior's socio-demographic characteristics, mobility tools in possession, urban form and neighborhood characteristics, and accessibility. Exactly same set of variables was used for both trip length and trip frequency models because they influence both of the travel behavior parameters in a relatively same fashion. For instance, seniors make shorter and fewer trips than younger people and however contemporary seniors are more mobile and make diversified trips than seniors of earlier generations (8, 40, 41). In case of recreational (41) and social trips (33) however seniors tend to travel longer distances than the younger generation. Male seniors are more likely to make longer as well as frequent trips than females (33, 40). Mercado and Páez (32) on the other hand found that female as a car drivers travel longer but as car passengers and bus riders they make shorter trips. Household income positively influences the trip length and trip generation behavior across senior age cohorts (32, 42, 43). However, no significant relation was found with income classes in the analysis of social trip frequencies by van den Berg et al. (33). Mobility tools i.e. possession of driver's license and/or automobile in the senior's household significantly affect the trip length and frequencies of all age groups. Schmocker et al. (41) elaborately studied the effect of mobility tools on trip frequency by transportation modes and found that vehicle ownership and possession of driver's license have positive association with car trip frequency and negative association with transit and walking frequencies.

Accessibility and neighborhood characteristics are also important determinants of travel distance and frequency nonetheless the results found in past studies are mixed. These attributes are more important for walking related trips. For instance, Sehatzadeh et al. (44) found that walking trip frequencies are directly and indirectly influenced by the built environmental variables where indirect influence on the vehicle ownership. Nagell et al. (45) in another study found that street density, intersection density, land use mix etc. affect the mobility decisions of elderly people. A composite walkability index was found to be associated neighborhood walking where the index was calculated based on the several neighborhood related attributes (46). Activity locations close to someone's place of residence encourage them to walk more and drive less and thus important determinant of mobility decisions among the elderly and all other age cohorts (47, 48). Table 1 shows the complete list of variables considered in this analysis.

Table 1 List of variables with definitions

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

4. RESULTS AND DISCUSSION

4.1 Trip length

In this section we describe the results of the walking trip length part of the joint discrete-continuous models. Variables statistically significant at *p*-value less than 0.05 are highlighted in the discussion. Firstly, age was introduced as three categories in the model. It is found that as senior becomes older they are more likely to make shorter walking trips compared to the younger seniors (i.e. age 55 to 64). In terms of walking trip length, there is no significant difference between male and female seniors. Possession of driver’s license tends to decrease the walking trip lengths among seniors. Compared to full-time working seniors, retired and at-home working seniors tend to make longer walking trips. Findings make sense as senior is engaged in full-time work, they have limited time budget to make longer walking trips and therefore prefer to take transit or drive personal vehicle which is evident from the car and transit trip length models in this study. Higher income seniors (>80k) make longer walking trips when compared to the lower income seniors (<20k). It is more surprising that none of the built environment related variables is statistically significant in affecting walking trip lengths. The correlation parameter between the mode choice and trip length models is found to be negative indicating a positive correlation i.e. the common unobserved factors of the two mobility decisions tend to co-vary in same direction.

4.2 Trip frequency

The results of the walking trip frequencies from the multivariate ordered probit is presented in this section. Similar to the trip length, age was introduced as three categories in the multivariate models with age 55-64 years as reference category. With increasing age (65-74 and 75+), seniors become less likely to make higher number of walking trips. Compared to single seniors, couple household seniors are less likely to make more trips. Full-time and part-time seniors make less walking trips due to their time budget compared to the retired seniors. Higher income seniors tend to make less walking trips than lower income seniors. Possession of driver's license makes the seniors less likely towards higher number of walking trips. Seniors in the medium and high job density areas are also less likely to make more walking trips and more likely to make trips by transit. However, effect of population density on the propensity of undertaking more walking trips is not significant. Square footage to building ratio is the only significant built environment variable in determining the propensity of walking trips. This variable positively affects the propensity. Number of activity locations within the quarter-mile buffer around the senior's residence is positively associated with the walking trip making propensity. Similar findings were found in her elderly walkability studies (49). All three correlation parameters in the multivariate ordered probit models are found to be negative. Unlike the interpretation of the correlation parameter in joint discrete-continuous models, negative correlation in the multivariate ordered probit models indicates negative association i.e. the common unobserved factors of three trip frequency models tend to vary in opposite direction.

4.3 Geographic variations in trip length and frequency

The effect of individual variables was discussed in the preceding sections. A key feature of our analysis is to make it evident that these changes may not be uniform, instead 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 of home location. Therefore, in addition to the traditional covariates discussed in the preceding sections, six geographic attributes were included into the models, namely – distance from CBD and quadratic trend surface of latitude and longitude i.e. latitude, longitude, latitude squared, longitude squared, and latitude times longitude. One of the advantages of including this trend surface is that it captures the geographic variations of the behavior of interest assuming that the components of the trend surface are statistically significant. In other words, use the geographic attributes as independent variables into the models might capture the geographic variations in the dependent variable when their effects are statistically significant.

Another advantage of this approach is that it allows complete visualization of the variations, if any, in the dependent variable. For instance, it is possible to show the geographic variations of the trip length and frequency in particular for this analysis. To do that adequate number of square grids are superimposed on the study area of interest and then the coordinates of the grid centroid are used to estimate the variations of the behaviors. This grid is used for visualization purposes only, and the size of the cells has no impact whatsoever on the preceding analysis. Two completely different senior profiles were also created to contrast the variations in the behaviors. For example, Profile 1 – a male senior of age between 65 and 74 years, income less than 20 thousand dollar, retired, living in a couple type household structure, and possesses no driver's license nor an automobile; on the other hand, Profile 2 – a female senior age between 65 and 74 years, income 80-100 thousand dollar, retired, living in a couple type household structure, and possesses driver’s license and an automobile. Using the walking trip length model from joint discrete-continuous models, the variation in the lengths of the senior Profile 1 and 2 are estimated and showed in Figure 2. More detailed about the variation of walking trip length can be found elsewhere (36).

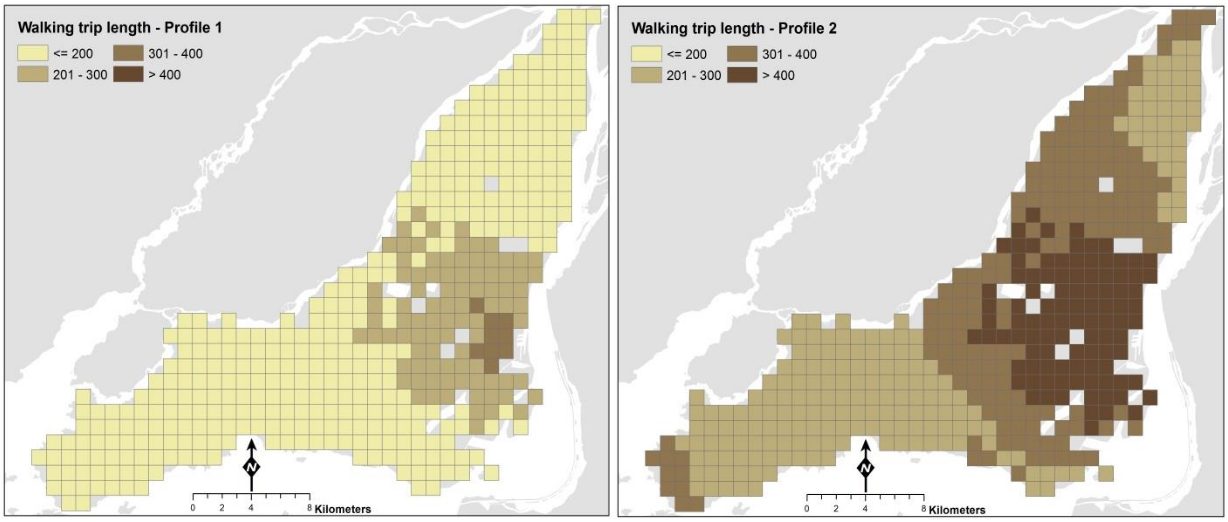

Figure 2: Geographic variations in walking trip lengths

On the other hand, using the using the walking trip frequency model from multivariate ordered probit models, probabilities of undertaking 1, 2, and 3+ walking trips are estimated for the same senior profiles and showed in Figure 3.

4.4 Compliance Potential Maps

Figure 4 shows the variations in physical activity compliance a senior might receive from his/her regular walking for transport. Maps shown in the figure are produced using the same senior profiles described in Section 5.3. Square grids of 1 km are superimposed over the study area, Montreal Island, and the coordinates of the centroid of each grid are used to estimate the *TDWD* for the grid location using the Equation (5). After estimating the *TDWD*, *WWM* is estimated by using the Equation (6). Finally the estimated *WWM* is converted into the percentage of minimum physical activity compliance prescribed in New Canadian Physical Activity Guidelines (27).

In figure 4, the value underneath each grid cell indicates how much the minimum physical activity compliance seniors of profile 1 and 2 can achieve assuming that he/she is making three walking trips in a day and repeating the behavior over five days a week i.e. fifteen walking trips a week. Three walking trips a day is used for this demonstration only and can be changed according to the discretion of the researcher. Map on the left side of Figure 4 depicts the geographical variation of the compliance as a function of the attributes in Profile 1 and map on the right depicts the same but as a function of the attributes in Profile 2. Primary difference between the Profile 1 and 2 is that Profile 1 senior is relatively poor with no access to personal automobile whereas Profile 2 senior is more affluent with access to personal automobile. Because of this profiling difference, the compliance potential varies a lot from Profile 1 to 2. For example, in the CBD area, three of the square grids have compliance of 11.57, 10.77, and

10.47% for Profile 1 whereas those exactly same grids have compliance of 36.30, 34.69, and 33.53% respectively.

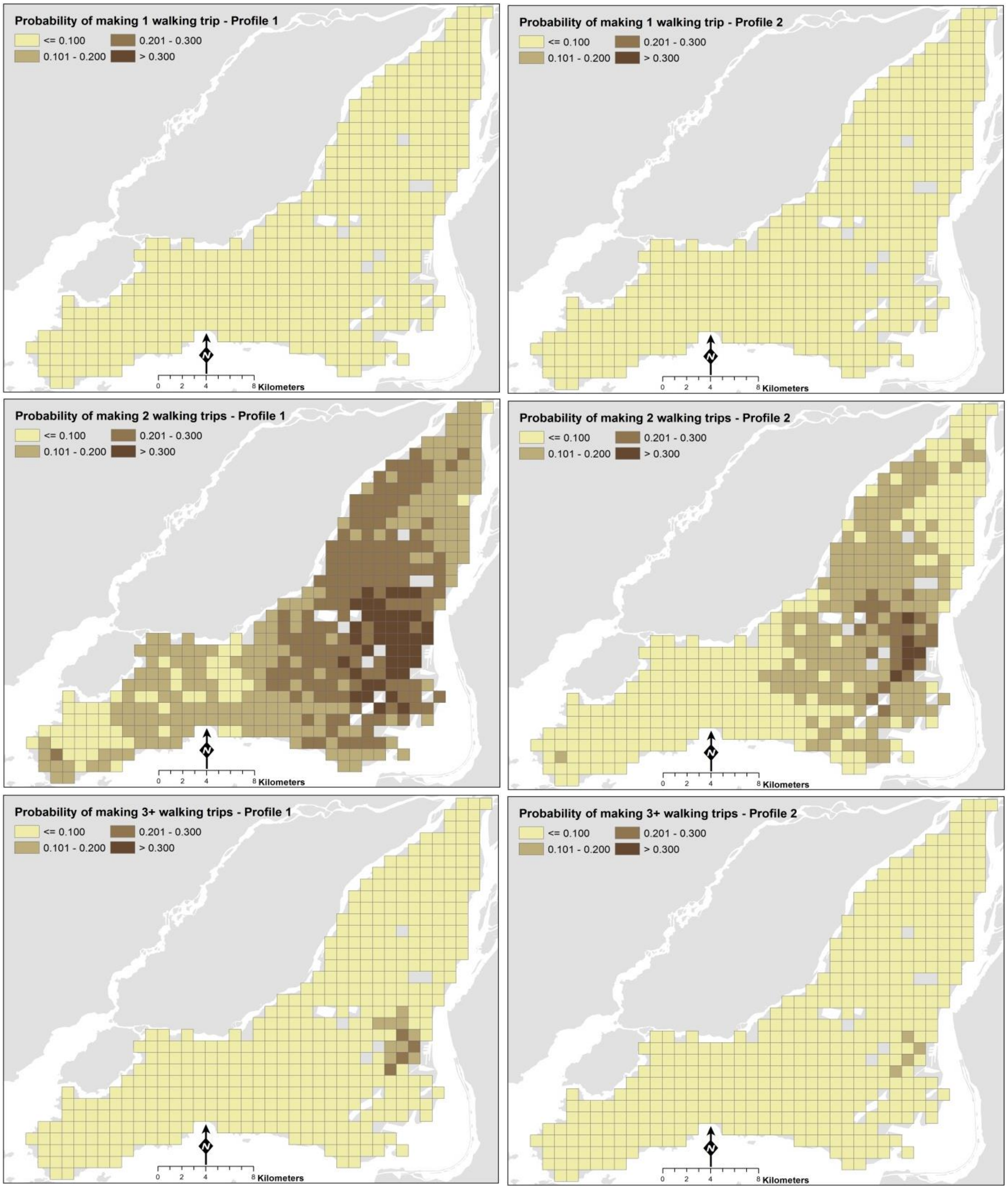

Figure 3: Geographic variations in probabilities of walking trip frequency

It is very intriguing that affluent seniors with access to personal automobile achieve more benefits from regular walking than relatively poor seniors without access to a personal automobile. It can be seen from Figure 2 that Profile 2 seniors are making longer walking trips than seniors in Profile 1. On the other hand, Figure 3 shows that seniors in Profile 1 are more likely to undertake higher number of walking trips than Profile 2 seniors. Therefore, it can be concluded that longer but fewer walking trips are required to achieve higher compliance.

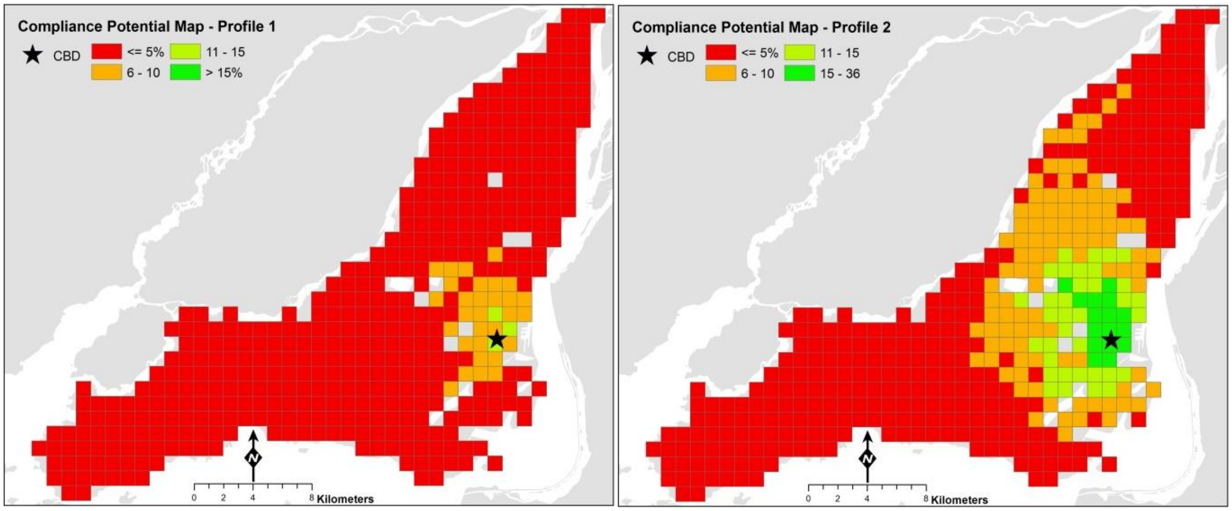

Figure 4: Compliance Potential Maps for two selected senior profiles

The location of the central business district (CBD) is labelled in the each of the maps to link the spatial variations of the compliance potential in relation with the central part of the city. It is observed in both of the maps in Figure 4 that seniors around the central part of the Montreal Island are achieving higher compliance and it starts to decrease as distance from the CBD increases. In the CBD area, many activity locations can be found within short walking distance. There are also more mixed land uses, higher employment densities, and better public transit facilities. All these attributes make its user conducive to walking. Moreover, availability of short distant activity locations engages people in trip chaining and this turns out in longer walking trips in the CBD area. Although the models used to estimate the *TDWD* were controlled for a wide list of covariates including individual's socio-economic characteristics, urban form and neighborhood characteristics, and a quadratic trend surface where one of the parameters was the distance between senior's home and CBD, the potential compliance for the same profile still varies across space as shown in Figure 4. 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 receive more of physical activity compliance compared to their counterparts living in the suburban areas. It has an important policy perspective. Seniors in the suburban areas are achieving only a little benefit from their regular walking for transport and if they are not active in leisure time physical activity as well, they are at the risk of having poor health status and eventually at the risk of being socially excluded. Therefore, health policy makers should pay particular attention to those seniors living in the suburban areas. Urban planners and designers, and transportation planners should introduce new design features that would encourage suburban seniors to walk more and drive less.

5. SUMMARY AND CONCLUSIONS

Dramatic increase in both number and percentage of seniors in Canada has drawn the attention of health policy makers towards the development of 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 very easy to achieve without much changes in the current development trend. In his study, we examined the multimodal trip length and trip generation behavior of seniors with a focus on walking trips.

By applying a joint discrete-continuous and a multivariate ordered probit model, we found that both trip lengths and frequencies of seniors by walking, car, and transit are determined by personal, mobility tools, neighborhood, and accessibility factors. Spatial analysis of walking length and frequency reveals greater heterogeneity in this behavior as people age. Mapping the variations of trip length and probability of walking trips has potentially intriguing policy applications. According to the New Canadian Physical Activity Guidelines, weekly recommended minimum physical activity requirements for the seniors are 2.5 hours or 150 minutes (27). Considering an average walking speed of 1.14 m/s (38), 150 min of physical activity is equivalent to 10.26 km of walking per week. Using the compliance estimate equation presented in this paper, the regular walking for transport can easily be related with the recommended physical activity compliance.

It is also important to note that maps displayed in this paper are meant to be an exemplar only and are completely based on the statistical models estimated in this study. Some assumptions made, for instance – the daily behavior is repeated over five days a week. However, we are not sure whether seniors are actually repeating the behavior more or less than five days over a week. Therefore, it requires additional study with week-long travel diary data which remains matter of future research. Nonetheless, the study is very systematic and has policy prescription, for example – the maps could be used in targeting neighborhoods where more effort is required to make the seniors conducive to walking.

REFERENCES:

1. Statistics Canada. Population projections for Canada, Provinces and Territories. ; 2010.
2. Schwanen T, Páez A. The mobility of older people - an introduction. Journal of Transport Geography 2010;18(5):591-595.
3. Pettersson P, Schmoeker JD. Active ageing in developing countries? - trip generation and tour complexity of older people in Metro Manila. Journal of Transport Geography 2010;18(5):613-623.
4. Ipingbemi O. Travel characteristics and mobility constraints of the elderly in Ibadan, Nigeria. Journal of Transport Geography 2010;18(2):285-291.
5. Burkhardt JE, McGavock AT. Tomorrow's Older Drivers: Who? How Many? What Impacts? Transportation Research Record 1999;1693:62-70.
6. Schmoeker JD, Su FM, Noland RB. An analysis of trip chaining among older London residents. Transportation 2010;37(1):105-123.
7. Hjorthol R. Winter weather - an obstacle to older people's activities? Journal of Transport Geography 2013;28:186-191.
8. Rosenbloom S. Sustainability and automobility among the elderly: An international assessment. Transportation 2001;28(4):375-408.
9. Alsnih R, Hensher DA. The mobility and accessibility expectations of seniors in an aging population. Transportation Research Part A-Policy and Practice 2003;37(10):903-916.
10. Rosenberg M, Everitt J. Planning for aging populations: inside or outside the walls. Progress in Planning 2001;56:119-168.
11. Turcotte M. Profile of seniors’ transportation habits; 2012.

12. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. American Journal of Preventive Medicine 2004;27(2):87-96.
13. Paterson DH, Jones GR, Rice CL. Ageing and physical activity: evidence to develop exercise recommendations for older adults. Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme 2007;32:S69-S108.
14. Kruk J. Physical Activity in the Prevention of the Most Frequent Chronic Diseases: an Analysis of the Recent Evidence. Asian Pacific Journal of Cancer Prevention 2007;8:325-338.
15. Bauman A. Updating the evidence that physical activity is good for health: an epidemiological review 2000-2003. Journal of Sciences and Medicine in Sport 2004;7(1 suppl):6-19.
16. Bricker S, Powell K, Parashar U, Rowe A, Troy K, Seim K, et al. Physical Activity Report, Georgia, 2001. Georgia: Georgia Department of Human Resources, Division of Public Health and the American Heart Association, Southeast Affiliate; 2001.
17. Singh MAF. Exercise Comes of Age: Rationale and Recommendations for a Geriatric Exercise Prescription. Journal of Gerontology: Medical Sciences 2002;57A(5):M262-M282.
18. Ruuskanen JM, Ruoppila I. Physical activity and psychological well-being among people aged 65 to 84 years. Age and Ageing 1995;24:292-296.
19. Mather A, Rodriguez C, Guthrie M, McHarg A, Reid I, McMurdo M. Effects of exercise on depressive symptoms in older adults with poorly responsive depressive disorder: randomised controlled trial. The British Journal of Psychiatry 2002;180:411-415.
20. McAuley E, Shaffer S, Rudolph D. Self-efficacy and affective responses to exercise testing in older males. International Journal of Aging and Human Development 1995;41:13-27.
21. McAuley E, Konopack JF, Motl RW, Morris KS, Doerksen SE, Rosengren KR. Physical Activity and Quality of Life in Older Adults: Influence of Health Status and Self-Efficacy. Annals of Behavioral Medicine 2006;31(1):99-103.
22. McAuley E, Rudolph D. Physical activity, aging, and psychological well-being. Journal of Aging and Physical Activity 1995;3:67-96.
23. McAuley E, Katula J. Physical activity interventions in the elderly: influence on physical health and psychological function. New York (NY): Springer; 1998.
24. Katzmarzyk P, Janssen I. The economic costs associated with physical inactivity and obesity in Canada: an update. Canadian Journal of Applied Physiology 2004;29(1):90-115.
25. Katzmarzyk PT. The Economic Costs Associated with Physical Inactivity and Obesity in Ontario. Health & Fitness Journal of Canada 2011;4(4):31-40.
26. Canadian Society for Exercise Physiology. Canadian Physical Activity Guidelines Canadian Sedentary Behaviour Guidelines. In; 2012.
27. Tremblay MS, Warburton DER, Janssen I, Paterson DH, Latimer AE, Rhodes RE, et al. New Canadian Physical Activity Guidelines. Appl. Physiol. Nutr. Metab. 2011;36:36-46.
28. Healthy Ageing and Physical Activity. Healthy Ageing and Physical Activity - for the international year of older persons. Gladesville: The Better health Centre; 1999.
29. U.S. Department of Health and Human Services. Physical Activity and Health: A Report of the Surgeon General. Atlanta, GA; 1996. Report No.: S/N 017-023-00196-5.
30. Alberta Center for Active Living. Stepping Up Your Physical Activity: Walking to Improve Your Health; 2007.

31. Morency C, Páez A, Roorda MJ, Mercado RG, Farber S. Distance traveled in three Canadian cities: Spatial analysis from the perspective of vulnerable population segments. Journal of Transport Geography 2011;19(1):39-50.
32. Mercado R, Páez A. Determinants of distance traveled with a focus on the elderly: a multilevel analysis in the Hamilton CMA, Canada. Journal of Transport Geography 2009;17(1):65-76.
33. van den Berg P, Arentze T, Timmermans H. Estimating social travel demand of senior citizens in the Netherlands. Journal of Transport Geography 2011;19(2):323-331.
34. Train K. Discrete Choice Methods with Simulation Cambridge: Cambridge University Press; 2003.
35. Bhat CR, Srinivasan S. A multidimensional mixed ordered-response model for analyzing weekend activity participation. Transportation Research Part B 2005;39:255-278.
36. Moniruzzaman M, Páez A, Habib KN, Morency C. Mode use and trip length of seniors in Montreal. Journal of Transport Geography 2013;30:89-99.
37. Greene WH, Hensher DA. Modeling Ordered Choices. 1 ed: Cambridge University Press; 2010.
38. Montufar J, Arango J, Porter M, Nakagawa S. Pedestrians' Normal Walking Speed and Speed When Crossing a Street. Transportation Research Record: Journal of the Transportation Research Board, 2007(2002):90-97.
39. DMTI Spatial Inc. CanMap® RouteLogistics. Markham, Ontario, Canada; 2009.
40. Tacken M. Mobility of the elderly in time and space in the Netherlands: An analysis of the Dutch National Travel Survey. Transportation 1998;25(4):379-393.
41. Schmocker JD, Quddus MA, Noland RB, Bell MGH. Estimating trip generation of elderly and disabled people - Analysis of London data. Transportation Research Record 2005(1924):9-18.
42. Roorda MJ, Páez A, Morency C, Mercado RG, Farber S. Trip generation of vulnerable populations in three Canadian cities: A spatial ordered probit approach. Transportation 2010;37(3):525-548.
43. Pettersson P, Schmöcker J-D. Active ageing in developing countries? – trip generation and tour complexity of older people in Metro Manila. Journal of Transport Geography 2010;18:613-623.
44. Sehatzadeh B, Noland RB, Weiner MD. Walking frequency, cars, dogs, and the built environment. Transportation Research Part A: Policy and Practice 2011;45(8):741-754.
45. Nagell CL, Carlson NE, Bosworth M, Michael YL. The Relation between Neighborhood Built Environment and Walking Activity among Older Adults. American Journal of Epidemiology 2008;168(4):461-468.
46. Lesliea E, Coffee N, Frank L, Neville Owend, Baumane A, Hugo G. Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes. Health & Place 2007;13:111-122.
47. Naess P. Accessibility, activity participation and location of activities: Exploring the links between residential location and travel behaviour. Urban Studies 2006;43(3):627-652.
48. Krizek KJ, Johnson PJ. Proximity to Trails and Retail: Effects on Urban Cycling and Walking. Journal of the American Planning Association 2007;72(1):33-42.
49. Kim S. Transportation Alternatives of the Elderly After Driving Cessation. TRANSPORTATION RESEARCH RECORD 2011;2265:170-176.