URBAN MOBILITY OF THE ELDERLY IN THE METROPOLITAN REGION OF SÃO PAULO: AN APPLICATION OH THE MULTINOMIAL LOGIT MODEL

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Abstract: Elderly population growth has become a worldwide concern in recent years. For that matter, it is important to think about the current state of cities in a way to ensure a safe and independent transportation for the daily mobility of the elderly. Therefore, this study aimed to identify differences in the urban mobility of the elderly and non-elderly population based on travel characteristics. Data was obtained from a mobility research conducted within the metropolitan area of São Paulo, from which five variables were selected and treated for the study. The methodology was based on an analysis with a multinomial logit model. Results indicated that elderly and the non-elderly people tend to choose the individual transport mode first, followed by the public transport mode and lastly the walking mode. Moreover, non-elderly people tend to travel longer distances in their daily commutes, while the elderly people are more likely to do shorter trips in their daily commutes. In sum, the comprehension of mobility differences between elderly and non-elderly population allows a better understanding of challenges faced by the elderly in their daily mobility, as well as adequate planning for more inclusive cities.

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INTRODUCTION

Population aging has become a common reality in many countries worldwide. According to the report "Aging in the 21st Century", one out of nine people in the world is aged 60 or older, and predictions show an expected growth to one person out of five for the year of 2050. Moreover, statistical data shows that one person turns 60 years in every second worldwide (UNFPA, 2012).

By the year of 2050, UN data predict an increase of 5% in the population aged 65 years or older in Europe and North America. In Asia, Latin America, the Caribbean, and Oceania, it is predicted that there will be an increase of 18% in this aging population (UN, 2017). It is also important to mention that in developing countries the elderly population is increasing faster lately, which reinforces the need for new measures in helping the aging population in their daily activities in developing countries (UN, 2015).

Brazil is expected to become the sixth largest country by 2025, with 31.8 million people aged 60 or older (WHO, 2015). Brazilian cities must predict and plan the urban environment in order to serve this population accordingly by finding ways of allowing the elderly to access services and activities safely and independently. Mobility becomes a fundamental tool to guarantee access to the different locations and various activities that satisfy elderly population needs within cities.

Hence, this study performed a comparison of urban mobility between the elderly (aged 60 and over) and non-elderly. Data used in this comparison was retrieved from the survey of urban mobility in the Metropolitan Region of São Paulo (2012). The comparison allowed a better understanding of differences in transport mode choice based on trip distance, gender, age and income

Finally, besides being a right stated by the Federal Constitution (1988), ensuring good mobility for the elderly is a way of encouraging people to perform new activities, especially after retirement. Furthermore, mobility allows for access to health services, education, leisure, shopping, and also shapes social interaction and consequently the quality of life.

URBAN MOBILITY OF THE ELDERLY

The development of this study was based on studies evaluating issues related to elderly mobility and comparing mobility between elderly and non-elderly. Initially, it is necessary to emphasize that in Brazil an elderly person is the one who reaches the chronological age of 60 years (BRASIL, 2003). However, the elderly chronological age classification may vary by country, so some studies presented in this research have adopted as elderly person the one aged 65 or older.

As the number of elderly population increases, so do concerns about vulnerabilities that aging brings. According to Gomes and Camacho (2017), elderly vulnerability refers to the way people's body responds to their daily activities, which can lead to a loss of independence, and health conditions. Additionally, an increasing in the elderly population vulnerability sparks an increase in the need of public and health services, which reinforces the importance of adequate elderly mobility.

The lack of adequate mobility harms the social interactions of the elderly and leads to social isolation, which may discourage them of doing outdoor activities. Under these circumstances, there may be a decrease in muscle mass, decreased range of motion, loss of balance and strength, and isolation that in some cases can trigger depression (Fischer and Filho, 2010).

In that case, adequate mobility is important to secure access to different services and activities and autonomy of a person. Unfortunately, cities can be a hostile environment to the elderly when lacking in appropriate urban furniture, accessibility, multimodal transport and boarding systems not well linked or of difficult understanding for the elderly, among others (Gomes and Camacho, 2017). For these reasons, mobility can be stated as an important quality of life factor for the elderly people (Strohmeier, 2016).

Böcker, Amen and Helbich (2016), presented a study on the mobility of the elderly (aged 65 or older) based on trip data from greater Rotterdam, in Holland. In the study, analyses were done considering the effect that socio-demographic characteristics, health status, trips aspects, spatial location, and weather attributes have on elderly mobility. Trip frequencies and transport mode choice were compared between trips made by the elderly and non-elderly population using the zero-inflated negative binomial and multinomial logit regression models.

In the aforementioned study, results indicated that the elderly tend to travel less, while traveling they prefer more often to walk and have a reduced use of cars. Nevertheless, it has been found that elderly women choose to walk, cycle or use public transportation more often than the elderly men, who tend to use cars. When analyzing trip distances, the greater the distance leads to an increased use of motorized modes, both for the elderly and the non-elderly.

Hirsch et al. (2016) assessed the influence of walkability on the mobility of middle-aged (aged 45 or above) and elderly (aged 65 or above) Canadians by creating the Mobility Over Varied Environments Scale (MOVES). For the development of this scale, socio-demographic and health characteristics were considered, and used data from the Canadian Community Health Survey - Healthy Aging. It this study, variables related to urban mobility were assessed using the Street Smart Walk Score (an app that evaluates walkability quality).

Based on the data from the health survey and Street Smart Walk app, the relevant variables were identified and calibrated into the MODES model with a linear regression. Results from the mobility scale model showed that the youngest, married, with higher socioeconomic

level, and better health were the ones presenting greater mobility. Results from the mobility scale also showed the neighborhood design as important factor to stimulate elderly and middle-aged people to walk (Hirsch *et al.*, 2016)

Yang (2018) studied the elderly behavior related to the mobility in Hong Kong, the study aimed to identify needs for future planning and a way of guaranteeing and encouraging the elderly mobility. The study was based on data collected from the trip characteristics survey carried out in 2011. Two models were calibrated, a mixed binary logit model and a conditional logit model. In the model socio-demographic characteristics, mode of transportation, origin, and destination were considered variables to identify trips that were likely to be made and the mode of transport chosen.

In the Yang (2018) study, results indicated that car ownership and driver's license did not affect elderly trips, contrary to the previous expectations. However, travel time and the destination of trip are significant factors affecting transportation mode choice. Because of that, the author states that encouraging the use of public transportation and multimodal terminals are important tools for the transport planning and an inclusion factor for a present and growing elderly population.

THE METROPOLITAN AREA OF SÃO PAULO

The city of São Paulo is located in the state of Sao Paulo, southeastern region of Brazil, and is the most populous city in Brazil with a population over 12 million people. The city is notable for being a financial center of Brazil, home to the Sao Paulo Stock Exchange and for having the largest GDP (Gross Domestic Product) in Brazil and the 10th largest in the world. Under these circumstances, São Paulo has economic and cultural importance in Brazil, and is also considered the most influential city in Latin America (EMPLASA, 2018).

Considering the 39 surrounding cities that make up the Metropolitan Area of São Paulo, the area becomes the most important business hub in Brazil. The population living in this area represents 50% of the entire population of the state of Sao Paulo, which is represented by approximately 21.4 million of people (IBGE, 2017).

In 1980, the city of São Paulo had a population of elderly people corresponding to 6.33% of the total population. At the year of 2010, the elderly population represented 11.89% of the total population in the city of Sao Paulo, an expressive increase in elderly population ratio in such a short time (IBGE, 2010). According to Silva, Nobrega and Côrte (2015), the elderly population ratio found in the Metropolitan Area of São Paulo is similar to the one seen in the city of São Paulo and has also observed an increase in the elderly population in the last decades.

The increasing number of elderly people in Metropolitan Area of São Paulo reveals the need of understanding the daily mobility and trips performed by them. Especially, how trips are done and whether or not they have similarities with the trips made by the non-elderly people. An understanding of this matter can be used as base of measures stimulating the mobility of the elderly within the metropolitan area of São Paulo.

The Metropolitan Area of São Paulo offer a variety range of modes of transport, such as the subway, railway, cab, and bus system. The subway system stands out among all of the available modes of transport and operates 5 lines and 30 stations with a ridership of 7.8 million people daily. In addition, there is also a railway system that connects to these stations in transfer stations within the greater São Paulo integrated transport system (São Paulo, 2018).

The area also has bus, trolleybus and BRT lines system, which serve as an important system to relieve the very often-jammed traffic. The greater São Paulo area has approximately 12 million vehicles circulating daily on its streets, which results in a daily scenario of traffic jam, specially in peak hours (SEADE, 2014).

METHODOLOGY

The methodology used in this study was the discrete choice modeling to analyze factors that influence on transportation mode choice between elderly and non-elderly people in the Greater São Paulo. The model performed in the study was the Multinomial Logit; since the transport mode choice is categorical variable that does not have any order among the categories. For the analysis, walking was taken as the transport mode for reference since it is the mode present in most of the daily trips made within cities.

Data description

Data on travelers' characteristics and transport mode choice within the Greater São Paulo area were obtained in an origin-and-destination (O-D) survey from the São Paulo's Metropolitan Area, carried out in 2012. The survey contains information about respondent's profiles and daily trips characteristics, and the population investigated in the survey is composed of 32.400 people from in 8.115 households (São Paulo, 2012).

Each trip presents commute information of residents in the greater São Paulo on a typical day. Trips considered were only the ones performed in the 24 hours preceding the interview and each commute performed was treated as an individual trip. For this research, were retrieved qualitative and quantitative data from this survey that were relevant to the scope of the present study.

The multinomial Logit Model

On a daily basis, the urban commute consists of selection of transport modes available to the travel needed. This

selection represents the trip maker's preferences regarding the selection of the mode. Preferences can be considered as a function of utility presented by each mode among a set of possibilities. According to Papacosta and Prevedouros (2001), utility functions measure the trip-maker satisfaction in a transport mode choice; in other words, it represents the benefits and disadvantage of each mode in a specific trip considering the trip-maker's perception.

The utility function is expressed as a linear function of independent variables. The independent variables represent a set of characteristics or attributes that any individual consider in their process of choice; these attributes can be socio-demographic, environmental, costs, and others characteristics inherent to each mode (Greene, 2010), as shown in **Eq. (1)**, bellow:

$$U = \beta_{i0} + \beta_{i1}x_{i1} + \beta_{i2}x_{i2} + \cdots + \beta_{ik}x_{ik} + \varepsilon_{im} \quad (1)$$

where x is the magnitude of an attribute or characteristics considered in the model, β is a vector to be estimated which represents the weight of that attribute in the model, and ε corresponds to the random error of the utility function of which is immeasurable only from the independent variables.

The most usual way to represent the relationship between utility of a mode and probability of its choice is using the logit model, which can be applied for 2 or more competing transport modes (Papacosta and Prevedouros, 2001). Among the model applied to more than 2 competing modes is multinomial logit model (MNL). This model is based on a probability function to choose a transport mode (option) in a finite group of competing modes greater than two, which are in a non-ordered set of options.

In a 3 competing transport scenario, the probability function of choosing a transport mode using the MNL can be represented according to the **Eq. (2)**, bellow (Greene, 2010):

$$Prob(Y_i = j) = \frac{e^{\beta'_j x_i}}{\sum_{k=0}^{2} e^{\beta'_k x_i}}, \; j = 0, 1, 2 \quad (2)$$

where, *Prob (Y_i = j)* is the probability of choosing one of the transport modes j relative to the exponential of the utility of each mode, represented in the equation in terms of attributes *x* and weight of attributes β.

Description of variables used in the study

Variables used in the analysis are listed in **Table 1**. Each variable type and category are described as they were used in the model.

The dependent variable "transport mode" is composed of three categories: public transport, individual transport,

Table 1. Variables calibrated in the Multinomial Logit Model.

Variable	Name	Type	Description	%
Dependent	Mode	Categorical	1- Public Transport	39.4%
			2-Individual Transport	36.4%
			3-Walking	24.2%
Independent	Income	Categorical	1- Upper Class	25.7%
			2-Middle Class	57.0%
			3- Low Class	17.3%
	Age	Dummy	0 - Non-Elderly	88.4%
			1- Elderly	11.6%
	Gender	Dummy	0 - Female	50.3%
			1- Male	49.7%
	Distance	Continuous	In kilometers	Mean 6.8 km

and walking. Trips performed by bicycles were not considered in this study since there were not a significant number of trips performed by this mode.

The variable "income" is considered the personal income, which refers to the average monthly income of the person making the trip. The categories in this variable are based on the criteria of classification by income level proposed by ABEP (Associação Brasileira de Empresas e Pesquisa, 2018). Categories were divided into 3 groups: upper class composed of ABEP income level A1, A2 and A3; middle class composed of ABEP income level B2 and C1; and low class composed of ABEP income level C2, E, and D.

The variable "age" was composed of two groups: the elderly and non-elderly people. The cutting age diving these two groups is 60 years, according to the Brazilian classification of elderly people. In the group of non-elderly people, the trips performed by a person younger than 15 years old were not considered in the analysis, since this age might not be old enough to make a transport mode choice.

Lastly, the variable "distance" is presented in kilometres and refers to the distance travelled in each trip performed. Trips considered in the study were the ones within the Metropolitan Area of São Paulo.

RESULTS AND DISCUSSION

Data were treated and analysed using the Microsoft Excel, Bison Biogeme and R Studio. Initially, a descriptive analysis was performed aiming the identification of characteristics and behaviour of the two groups (non-elderly and elderly) regarding their daily commute. Following, the Multinomial Logit Model was

performed aiming to identify major characteristics of the transport mode choice between elderly and non-elderly trip-makers.

Table 2 presents a summary of sample analysis and its major and general characteristics. The sample is composed of 88.4% people in the group of non-elderly and 11.6% people in the group of the elderly.

The descriptive analysis was done in order to identify commute characteristics and population distribution in trips performed within the metropolitan region of Sao Paulo. For this descriptive analysis, the variable age was into two groups, the elderly and non-elderly people. The analysis showed that the elderly tends to use individual transport modes in the majority of their trips, while the similar income level, with a predominance of people in the middle class. However, the elderly group presents a non-elderly people use public transport. Regarding the income level, elderly and non-elderly groups showed a slightly bigger proportion of people in the upper class than the non-elderly group. Women are the majority in the group of elderly people, while in the group of non-elderly people men are the majority. Lastly, the descriptive analysis indicated an average of distance travelled shorter for the elderly group than the non-elderly.

MNL Calibration and results

Analyses were conducted in a trip level, there were 35842 trips and seven parameters were estimated after the model calibration (Table 3). A correlation analysis was perfumed and rejected any problem with multicollinearity among the predictors proposed in the model.

Estimated values show a positive effect in the transport mode choice for every variable considered in the calibration, excepting the low-income category. For the low-income category, a negative estimated value shows a negative effect of this category in choosing individual transport and public transportation over the walking mode. The variable distance was the one showing the highest effect in the transport mode choice. The variable showing the lower effect in the transport mode choice is gender, which was not expected considering that women tend to found themselves more insecure, depending on the mode of transport.

Following, the estimated values in the model calibration were inserted in the utility function (**Eq. 1**) for each one of the transport mode considered in this study. Utility results allowed a better identification of the way each group of trip-makers perceive the transport modes available for them, especially in terms of their income level and gender.

Table 2. Characteristics of the sample analyzed.

Name	Description	Elderly	Non-elderly
Mode	1 – Public Transport	34.16%	40.07%
	2 – Individual Transport	44.97%	35.32%
	3 – Walking	20.87%	24.61%
Income	1 – Upper Class	32.68%	24.86%
	2 – Middle Class	48.42%	58.10%
	3 – Low Class	18.90%	17.04%
Gender	0 – Female	48.76%	50.51%
	1 – Male	51.24%	49.49%
Distance	In kilometers	5.03 km	6.80 km

Observation: total trip elderly = 4165 (11.6% of trips),and total trip non-elderly = 31677 (88.4% of trips).

Table 3. Results for the multinomial logit model (reference category = walking).

Variable Name	Value Estimated	t-test	p-value
ASC1	-3.15	-48.57	0.00
ASC2	-2.56	-38.58	0.00
ASC3	0.00 (FIXED)	-----	----
BETA_DISTANCE	1.98	38.31	0.00
BETA_ELDERLY	0.662	7.96	0.00
BETA_UPPER	0.727	11.06	0.00
BETA_LOW	-0.567	-7.21	0.00
BETA_MALE	0.249	4.48	0.00
Final log likelihood	-10500.475		
Likelihood ratio test	4248.386		
Rho-square	0.168		
Adjusted Rho-square	0.168		

Analyzing these utilities, it was observed that short distance trips tend to demonstrate greater variation in the transport mode utilities, variation not observed in long distance trips. In general, trip distances over 3 kilometers tend to present the utility value tending to a fixed value, and so, do not show significant variation with the increasing of distance.

Income level also affects utility values, and consequently the transport mode choice. However, it behaves differently between men and women. Women in the low-income category have higher utility value for walking, while in middle and high income the utility value for walking present lower values. Thus, women in upper and middle-income categories tend to choose individual modes or the public transport to perform shorter distances commute. Utility values behave similar for men and women considering the trip distances, however, men tend to present changes in transport mode utilities in shorter distances than women.

After the utility analysis, transport mode choice probabilities were calculated using the equation 2, presented in the methodology. The variable distance was the reference to calculate the probabilities of choosing the transport mode among the 3 available (public transport, individual transport, and walking). Calculations were performed for the two genders and for all income levels, and results were plotted in a graph comparing probabilities of the elderly and non-elderly people, as shown in **Fig. 1**.

Results presented in **Fig. 1** show a higher probability of choosing the walking mode in the group of non-elderly people than in the group of elderly people. This behavior was observed in all income level and both genders. In addition, elderly men present a higher probability of choosing individual modes when compared to elderly women, which was also observed in the study of Adler and Rottunda (2006).

Regarding the probability of choosing the walking mode in the three income levels, it was observed that as higher the income level, lower is the probability of choosing the walking mode. This result indicates a higher preference for motorized modes in the elderly group than in the non-elderly group.

As observed in the analysis of utility, the probability of choosing the walking mode is surpassed by the individual transport mode at shorter distances for men than for women, result observed in all income levels studied. A similar thing happens to distances that the probability of choosing the walking mode is surpassed by the public transport mode. Additionally, as the income level increases, decreases the distances in which the probability of choosing the public transport or individual transport modes surpasses the walking mode.
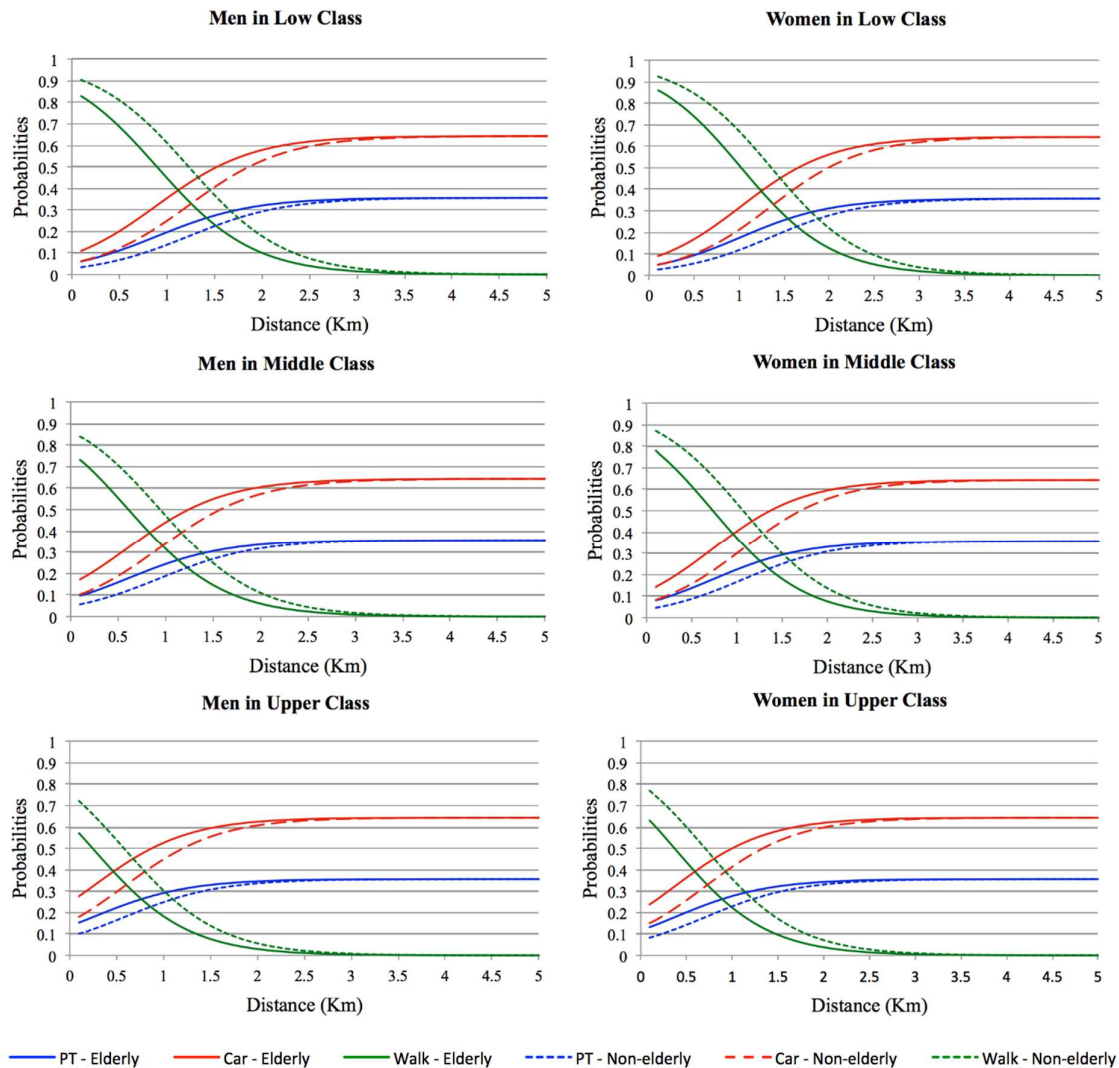

Fig. 1. Curves of probability vs. distance for each mode of transport.

For a better understanding of the results, the variable distance was marked as points in every 500 meters up to the distance of 2.5 kilometers. These values were defined as the major references to the evaluation of the probabilities of choosing a mode in a certain trip performed and how the transport mode choice utility behaves in each one of these distances.

At 500 meters, only the elderly men in upper class did not present the walking mode as the one with highest probability of being chosen. In all other evaluated trip-makers' profile the walking mode was the mode presenting the higher probability of being chosen. This result can be explained by the behavior of older men who tend to financially maintaining a vehicle even while the cost of living increases caused by aging (Alder; Rottunda, 2006).

For 1 km distances, transport mode choice probabilities presented a greater variation among the trip-makers' profiles evaluated in the research. Gender did not affect the probability of choosing a motorized mode at the expense of the walking while the income level did affect. High-income level men, at any age, are more likely to choose individual transport or public transportation mode at the expense of the walking mode. Elderly women are more likely to choose individual transport or public transport while non-elderly women are still more likely to choose the walking mode. Elderly men and women in middle class are more likely to choose individual transport or public transport compared to the walking mode, while the non-elderly men and women in this income level are still more likely to choose the walking mode. Last, in the low-income class, all trip-makers' profiles are more likely to choose the walking.

For distances of 1.5 kilometers, only non-elderly women are more likely to choose the walking. Distances greater than 1.5 kilometer, all trip-maker's profiles were more likely to choose individual transport or public transport modes.

Differences in trip distances compared to age of the trip maker can be seen in **Fig. 2**, below. On the graph it is possible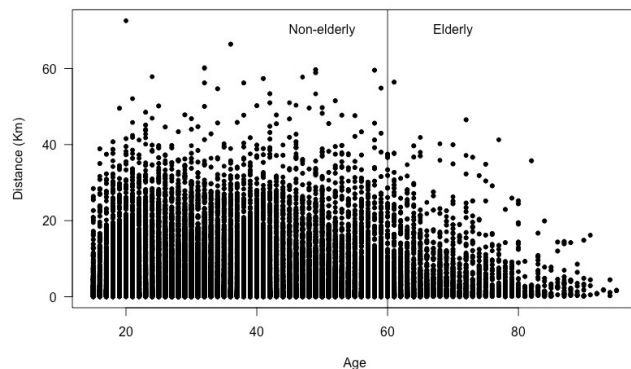 to observe a comparison of the trip distance performed by trip-makers comparing elderly and non-elderly people, in which is shown that the older is the person, shorter are the distances traveled.

The result presented in the **Fig. 2** was expected because as people age, their mobility capacity decreases affected by their biological and physical conditions, like loss of musculature, bone fragility, and others (Fischer and Filho, 2010). Moreover, an impossibility of mobility negatively affects the elderly, isolating them from activities and social interaction offered in cities (Strohmeier, 2016).

CONCLUSIONS

This study aimed to identify trip-makers' characteristics that affect the transport mode choice in a comparison between two age groups, the non-elderly (up to 59 years) and the elderly (60 years old and older).

Five variables were calibrated in the model proposed by this study: income, age (elderly and non-elderly), gender, trip distance and mode of transport. Results showed that for both, the elderly and the non-elderly people, transport mode choice tends to be the individual transport mode first, followed by the public transport mode and lastly the walking mode.

Regarding trip distance by age, is was observed that non-elderly people tend to travel longer distances in their daily commutes, while the elderly people are more likely to do shorter trips in their daily commutes. This result may be related to physical and biological conditions of human aging, as well influenced by the quality of the urban environment present in the city.

In summary, mobility is an important tool to integrate the elderly people into the city and should be constantly planned, especially because of the increasing elderly population that has been observed in many countries lately. Withal, adequate mobility is important to secure access to different services and activities, as well, encourage the elderly population to take advantage of the city and its social environment.

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Fig. 2. Plot of trip-makers' characteristics in age vs. trip distance.

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