Revista Brasileira de Estudos Regionais e Urbanos
v. 19, n. 1, p. 1-23, 2025
DOI: 10.54766/rberu.v19i1.947

Determining variables for transport mode choice: An integrated and descriptive analysis in the São Paulo Metropolitan Area, Brazil

Luciana Ferreira Leite Leirião[1] | Simone Georges El Khouri Miraglia[2]

[1] Dra., Universidade Federal de São Paulo. E-mail: luciana.leiriao@gmail.com
[2] Prof. Dra., Universidade Federal de São Paulo. E-mail: simone.miraglia@unifesp.br

ABSTRACT
Strategies to promote sustainable means of transportation can emerge from the understanding of how people choose travel modes. Studies about it are focused on developed countries, where people have more alternatives to commuting. Using an origin-destination survey database, this study investigated how access and egress distances, car ownership, household income, and travel distance influence people from São Paulo Metropolitan Area on their choice between railway transportation, bus, and car. 81% of the trips performed by railway transportation have the origin and the destination close to a station. Car ownership increases car choice, but it also depends on household income. Finally, cars are preferred for short travels and railway transportation for longer ones. The study indicates that expanding the railway network has a high potential to promote modal shifts, especially in long travels. It supports railway network expansion, which is constantly downgraded due to the high associated cost.

KEYWORDS
Mobility, Modal share, Mode choice

Variáveis determinantes para a escolha do modo de transporte: Uma análise integrada e descritiva na Região Metropolitana de São Paulo, Brasil

RESUMO
Entender como as pessoas escolhem se deslocar pode subsidiar estratégias para meios de transporte mais sustentáveis. Estudos desse tipo concentram-se em países desenvolvidos, onde existem mais opções de modais. Com base nos dados da pesquisa origem-destino, investigou-se como as distâncias de acesso e egresso, a posse de automóvel, o nível socioeconômico e a distância da viagem influenciam a escolha por modal de transporte na Região Metropolitana de São Paulo. 81% das viagens realizadas por transporte sobre trilhos possuem tanto a origem quanto o destino próximos a uma estação. A posse de automóvel promove seu uso, no entanto isso também é influenciado pelo nível socioeconômico. Por fim, automóveis são preferidos em viagens curtas e o transporte sobre trilhos em viagens longas. Este estudo indica que o acesso ao transporte sobre trilhos pode promover a mudança para esse modal, encorajando políticas de expansão, que costumam ser despriorizadas devido aos elevados custos associados.

PALAVRAS-CHAVE
Mobilidade, Matriz de transportes, Escolha de modal

JEL CLASSIFICATION
R41

Recebido: 18/10/2022. Aceito: 25/11/2024
e-ISSN: 2447-7990 | https://revistaaber.org.br/rberu

1. Introduction

Industrialization and urbanization are strictly associated; thus, urbanization began earlier in countries pioneers in industrialization. In the USA, 40% of the population lived in urban areas in 1900 and, within 90 years, this percentage reached more than 75%. The process was later in other countries, but more accelerated. In Korea, the same growth observed in the USA in 90 years happened in 20 and, in Brazil, in 30 years (Henderson, 2002). This accelerated urbanization observed in developing countries does not allow public policies to be experimented and adjusted to ensure better environmental and social conditions (Henderson, 2002).

One of the most evident consequences of urbanization is that the concentration of people and activities in the city increase the travel demand. The increase in the number of vehicles per capita results in a series of externalities, such as higher levels of road accidents, congestion, environmental issues and oil dependence (Santos et al., 2010).

In large metropoles, the growing environmental concern and the excess of traffic congestion promote the seek for alternative modes to use the car in commuting (ECMT, 2000; Williams, 2017). It has been an international challenge since there is common sense that the car is a more comfortable and convenient mode than the other options (Anwar, 2009; Grdzelishvili e Sathre, 2011).

The implementation of new mobility policies is often preceded by studies that aim to predict how the transport mode share would be after these policies. In order to do this, it is fundamental the understanding of how people choose their travel mode (Ko et al., 2019).

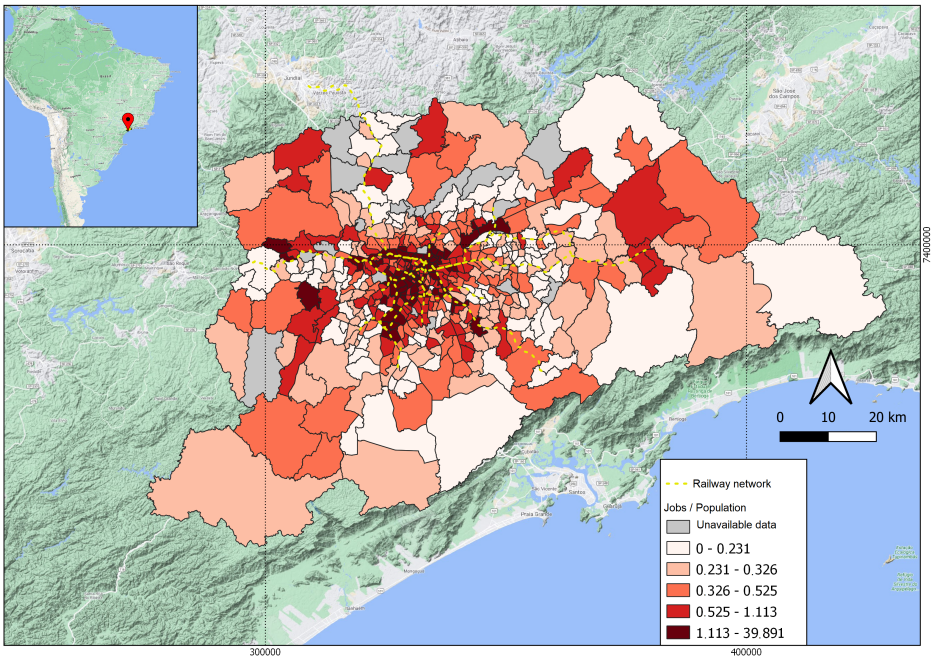
There are several studies conducted in the past 20 years describing the explanatory variables behind the transport mode choice. Some of these studies are descriptive. The lack of statistical analyses did not compromise the quality or the relevance of the studies. Chakrabarti (2017) took advantage of a travel survey to explore contexts in which commuters belonging to car-owning households use transit. He found that car ownership strongly influences the choice for this mode in Los Angeles (USA). Qualitative analyses were also performed by Beirão e Cabral (2007) when they analyzed interviews about transportation mode choice in Porto (Portugal) and found that travel time, cost, and comfort are the main factors affecting citizen choice. Also, through interviews, Chee e Fernandez (2013) found gender and income as determinants to modal choice in a megacity of Malaysia, and Grdzelishvili e Sathre (2011) found time issues, comfort, and safety as determinants in a small city in the USA. Finally, Corpuz (2007) analyzed the Sydney (Australia) Household Travel Survey database to understand the factors that affect the transportation mode choice in the country and found that public transport use is most viable where there are parking restrictions, when people don´t have a vehicle and when the travel cost is lower.

The results found when using statistical analyses (as probit and logit models) tend to corroborate the qualitative studies. Car owners are more likely to use the car in commuting, and as the age and income increase, the choice for the car also increases; men are the most inclined to use the car, and the higher the travel distance the higher the choice for public transportation (Ashalatha et al., 2013; Buehler, 2011; He e Thøgersen, 2017; Ko et al., 2019; Kuhnimhof et al., 2012; Tyrinopoulos e Antoniou, 2013).

The bibliography exploring how some factors affect the choice for public transportation, car, or active transportation is focused mainly on the behavior of individuals from urban centers of developed countries. However, the dynamic of an urban center in developing countries is very distinct. Buehler (2011) suggests that "demographic variables may be more relevant determinants of mode choice in wealthy countries".

The São Paulo Metropolitan Area (SPMA), localized in Brazil, is the largest South America urban center, comprising 7,947 km^2 and 22 million inhabitants (IBGE, 2010; SEADE, 2021a) . The SPMA GDP in 2020 was R$1.23 trillion, which 56.8% was from the services sector and 34.6% from industry (SEADE, 2021b). Since the 90s, the region has experienced reduction in the number of industries and the economy has been based on the service sector and business management (Lencioni, 1998). The SPMA can be considered a typical case of an urban center with mobility issues (Jacobi, 2013; Rolnik e Klintowitz, 2011; Scaringella, 2001) (Figure 1). According to the most recent origin-destination survey, it is estimated that more than 42 million trips are made in the region and that the proportional growth in the number of trips is greater than that of the population and jobs (Metro, 2019). Considering all types of travel, 32.7% are carried out by active transport (on foot or bicycle), 36.4% by public transport (metro, train or bus) and 30.9% by individual transport (private car, motorcycle or taxi) (Metro, 2019). The high dependence on road transport in São Paulo is a consequence of the prioritization of this type of transport by different political administrations since 1930 (Rolnik e Klintowitz, 2011). The incentive for individual transport resulted in a sharp drop in the use of public transport, that used to be 68% in 1967 (STM, 2015).

Figure 1. The map illustrates the mobility issues in the SPMA. The darkest areas indicate where job opportunities are concentrated and the clearest areas indicate where people live. The dotted yellow line represents the railway system. The map was created in QGIS 3.12 software based on the origin-destination survey database



Source: Author.

The first origin-destination research in the SPMA was conducted in 1967 and it allowed the first studies about travel patters (Swait e Ben-Akiva, 1987). However, even counting with the 40 years data base, the number of investigations about modal choice in the region can be considered incipient in comparison with the amount found for metropolitan regions in developed countries.

Among the most recent studies, de Brito et al. (2018) took advantage of 2007 origin-destination data to conduct an extensive investigation about travel patterns in SPMA. The authors concluded that the low accessibility to mass transit implies in higher chose for individual transportation. In addition, they noted that as the income level increase, the travel distance and duration decrease (de Brito et al., 2018). Although very relevant to support the understanding of the choice of transport mode in the SPMA, as the most studies conducted worldwide, the authors did not distinguish rail transport from bus in their analysis. Considering that rail transportation is more attractive than bus (Hu et al., 2015; Scherer e Zurich, 2012), it would be important to know the specific variables related to the choice of each of these types of public transport.

The present study was conceived considering that the knowledge of the variables which influence the transport mode choice can support policies aiming at more sustainable mobility and also that the predictions about transport mode choice on new policies scenarios need a previous understanding about which variables induce peo-

ple to choose a transport mode in their commuting. So, this study described how four variables influence people from the SPMA on their choice between car and public transportation, distinguishing the bus from the rail transport.

2. Material and Methods

This study performed descriptive analyses of the transportation mode choice in the São Paulo Metropolitan Area. All analyses were based on an origin-destination survey database. This survey was taken by São Paulo's Metro Company in 2017 and reports 157,993 trips with a margin of error of less than 6% and a 92% of confidence level (Metro, 2019).

2.1 Qualitative analyses

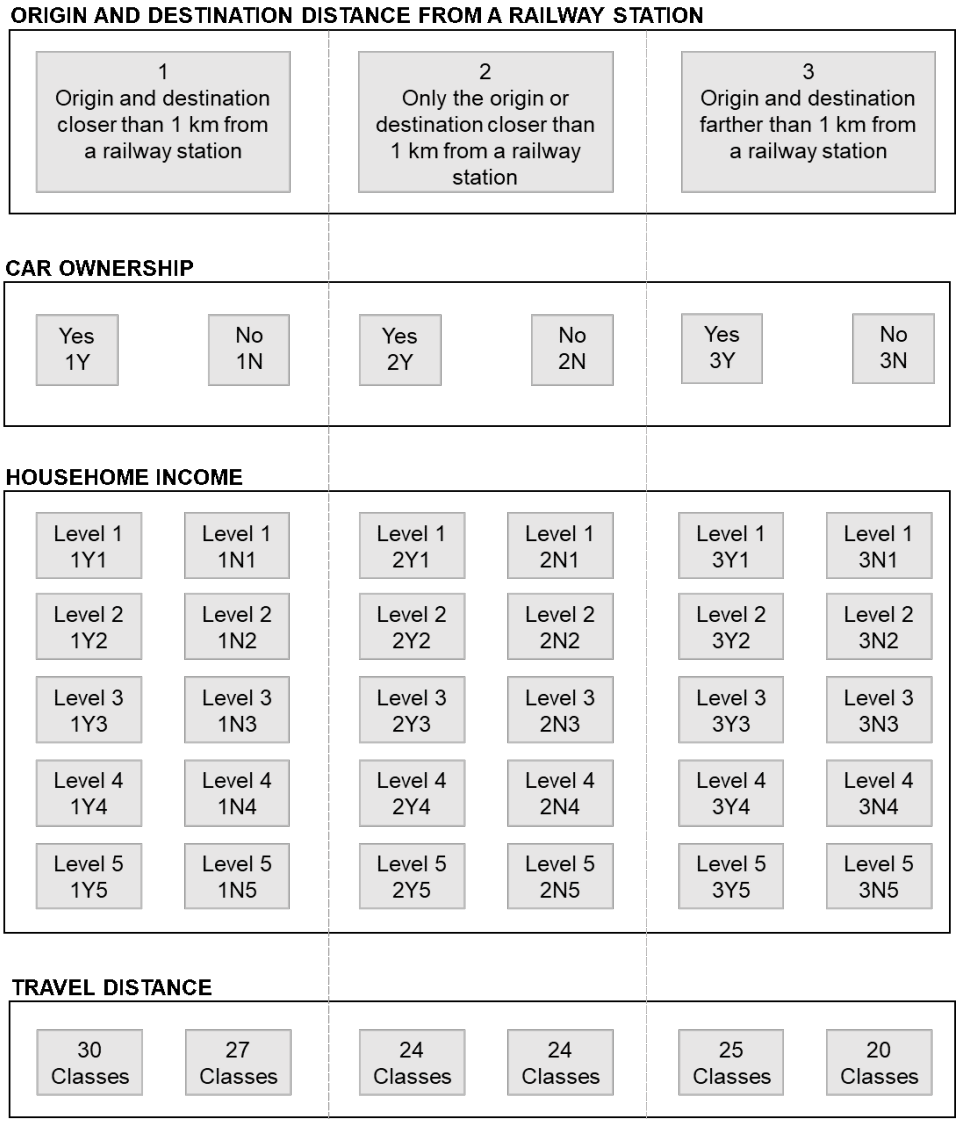
The importance of qualitative analyses of commuting practices has been highlighted by Cass e Faulconbridge (2016). This kind of analysis is ideal for exploratory studies and may be tested independently by further quantitative research. Qualitative analyses per se can promote discussions, support discourses, and justify social actions (Cass e Faulconbridge, 2016).

To identify behavior patterns in the mode choice between railway transportation, bus, and car, the database of the origin-destination survey was delimited. Only the trips taken by railway transportation (train, subway, and monorail), bus (lines from all SPMA municipalities and intercity lines), and car (driver or passenger) modes were selected. Regarding the trip reason, only trips to "work" and "study" were considered. Thus 55,124 trips were analyzed. 9.1% of these trips were reported as multimodal, however only the main mode reported was considered (Metro, 2019).

The scope was restricted to motorized modes because they are primarily responsible for mobility and air pollution issues. Other motorized modes as motorcycles and taxis were not considered because they represent less than 4% of travel for work and study reasons (Metro, 2019). Moreover, motivations for motorcycle use in Latin American cities have already been reported (Hagen et al., 2016).

Based on previous studies and considering the data restrictions, the influences of four variables on the transport mode choice were investigated: the origin and the destination distance from a railway station (also known as access and egress distance), the car ownership, the household income, and the travel distance. Figure 2 presents an overview of how these variables were conjointly analyzed.

Figure 2. Diagram illustrating how the four variables were considered in this study



Source: Author.

2.1.1 Variable 1: Origin and destination distance from a railway station

This analysis emerged from the hypothesis that trips taken by railway transportation have their origin and destination in the proximities of a railway station.

It was considered a 1 km radius around the subway and train stations to verify the modal share in three travel categories: (1) trips with both the origin and the destination within the radius, (2) trips with only the origin or the destination within the radius, and (3) trips with both the origin and the destination beyond the radius. Besides the modal share on these three categories, an analysis considering only the trips taken by railway transportation was conducted to verify how they are distributed in (1), (2), and (3). The distance of 1 km was defined based on Walker (2011) which affirms that for "rapid transit (usually rail) we can expect people to walk up to 1000m".

The distance to a bus stop was not considered because almost all origin and des-

tination coordinates were less than 0.5 km from a bus stop.

To perform the analyses, a vector file containing the coordinates of the subway and the train stations of SPMA in 2017 was obtained from the Geosampa platform. Using the QGIS 3.12 software, a 1 km buffer was designed around each station. A vector file containing the origin and the destination coordinate of each trip was created based on the survey database. Still using QGIS 3.12 software, the coordinates were confronted with the perimeter around the stations using the "cut" tool. The points inside and outside the perimeter were saved as a text file and, on Excel (2016), the trips were segregated into three categories (1, 2, and 3) so the modal share of each category could be calculated.

2.1.2 Variable 2: Car ownership

This analysis emerged from the hypothesis that the choice for the car is more frequent among individuals who own at least one car. The origin and destination survey database presents how many cars the individual who takes each trip has. This information was converted to car ownership ("yes" or "no") and the modal share was estimated in six categories named as 1Y, 1N, 2Y, 2N, 3Y, and 3N (as presented in Figure 2).

2.1.3 Variable 3: Household income

Although the fares to use railway transportation and bus were equivalents in the SPMA in 2017, the costs of a car trip are variable, involving fuel, mechanical deterioration, parking, insurance costs, etc. So, this analysis emerged from the hypothesis that individuals from the upper household income choose the car more frequently than individuals from lower household income.

The household income is quantitatively presented in the origin and destination database. The values were classified into five ranges following the same intervals as used in the origin and destination survey report: Level 1 (household income lower than R$ 1,908), Level 2 (household income between R$ 1,908 and R$ 3,816), Level 3 (household income between R$ 3,816 and R$ 7,632), Level 4 (household income between R$ 7,632 and R$ 11,448) e Level 5 (household income higher than R$ 11,448) (Metro, 2019).

Considering the household income along with the distance from a railway station and the car ownership, 30 modal shares were calculated. They were named as 1Y1, 1Y2, 1Y3, 1Y4, 1Y5, 1N1, 1N2, 1N3, 1N4, 1N5, 2Y1, 2Y2, 2Y3, 2Y4, 2Y5, 2N1, 2N2, 2N3, 2N4, 2N5, 3Y1, 3Y2, 3Y3, 3Y4, 3Y5, 3N1, 3N2, 3N3, 3N4, 3N5 (Figure 2).

2.1.4 Variable 4: Travel distance

This analysis emerged from the hypothesis that, on longer trips, there is an effect of the time spent in congestion that may promote the choice for railway transportation. Furthermore, long trips imply higher monetary costs for car users, so it would result in the least preference for this transportation mode.

The travel distances are not presented in the origin-destination database, so they were calculated from the origin and destination coordinates. The estimation was made considering the distance through the roads instead of the simple connection between points.

To enable the calculation of the travel distance, a vector file of the SPMA's road network was downloaded from the Metropolitan Center of Study of São Paulo University (Centro de Estudos da Metrópole da Universidade de São Paulo – USP, in Portuguese). The distances between the origins and the destinations were calculated by GRASS 7.8.1 processing tools using the QGIS 3.12 interface. The loaded files to perform the analysis were the vector file of the road network and a vector file containing the origin and the destination coordinates (produced from the origin-destination survey database). The performed algorithms were: `v.net` and `v.net.path`. A file containing the travel distances was exported as a text file and, using Excel (2016), the distances were converted from meters to kilometers and rounded to the nearby integer.

The distances were clustered into categories according to the modal share. For instance, if the modal share in the 1 km, 2 km, and 3 km trips had divergence lower than 10%, the category "1 to 3 km" was created. The general trends of the modal share considering the travel distance were analyzed for (1), (2), and (3). Hereafter, modal shares were calculated considering all the four variables (distance from a railway station, car ownership, household outcome, and travel distance).

2.2 Multinominal regression model

After the investigation about the modal share considering the four variables above, a multinominal regression model (logit model) was conducted. The model considered mode choice as a dependent variable and origin and destination distance from a railway station, car ownership, household income, and travel distance as explanatory variables. In this analysis, the travel distance was considered as a numerical variable instead of categorical.

The analysis was performed in SPSS 20 software and considered a confidence interval of 95%. The results were analyzed considering the car choice as the reference category.

3. Results

3.1 Qualitative analyses

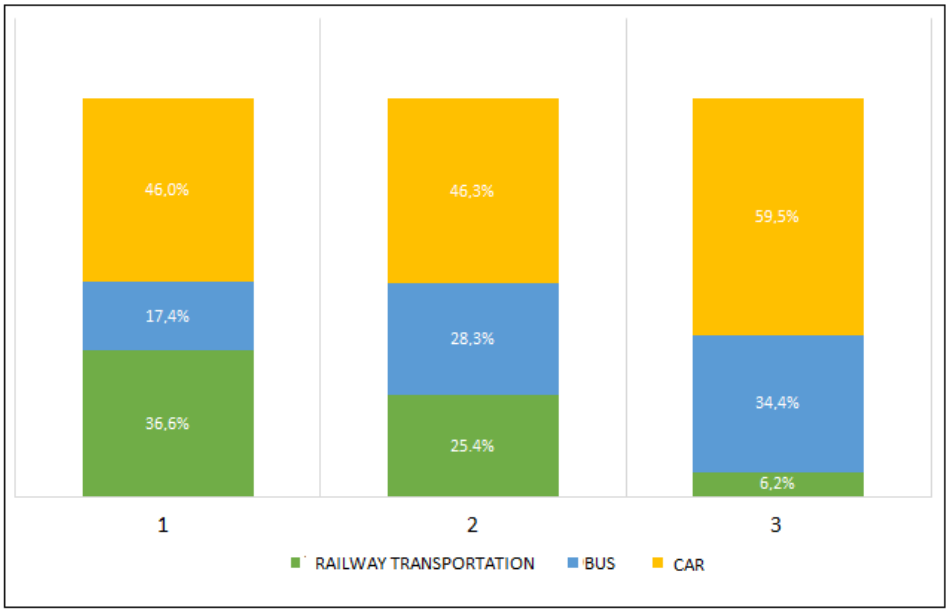
3.1.1 Variable 1: Origin and destination distance from a railway station

The trips categorization based on the distance from a railway station resulted in 18.0% of the trips with both the origin and the destination within the 1 km radius from a railway station (1), 40.1% with only the origin or the destination within this radius (2), and 41.9% with both the origin and the destination beyond this radius (3).

Considering exclusively the trips taken by railway transportation, 81.7% have both the origin and the destination closer than 1 km from a station (1), 18.2% have at least the origin or the destination closer than 1 km from a station (2), and only 0.1% have both the origin and the destination farther than 1 km from a station (3).

The modal shares of the three categories confirm that railway transportation is more used when the origin and the destination of the trip are both close to a railway station. Considering the trips with both the origin and destination closer than 1 km from a railway station (1), 36.6% are taken by railway transportation (Figure 3). When only the origin or the destination is close to a railway station (2), the choice for the railway transportation decreases to 25.4%, and when neither the origin and the destination of the trip are close to a station (3), only 6.2% of the trips are taken by this mode (Figure 3). The share of trips taken by car is similar among (1) and (2), which indicates that the preference for railway transportation when both the origin and the destination of a trip are close to a station occurs at the expense of the bus (Figure 3).

Figure 3. Modal share of (1) trips with both origin and destination within 1 km radius from a railway station, (2) trips with only the origin or the destination within the 1 km radius, and (3) trips with both origin and destination without the 1 km radius

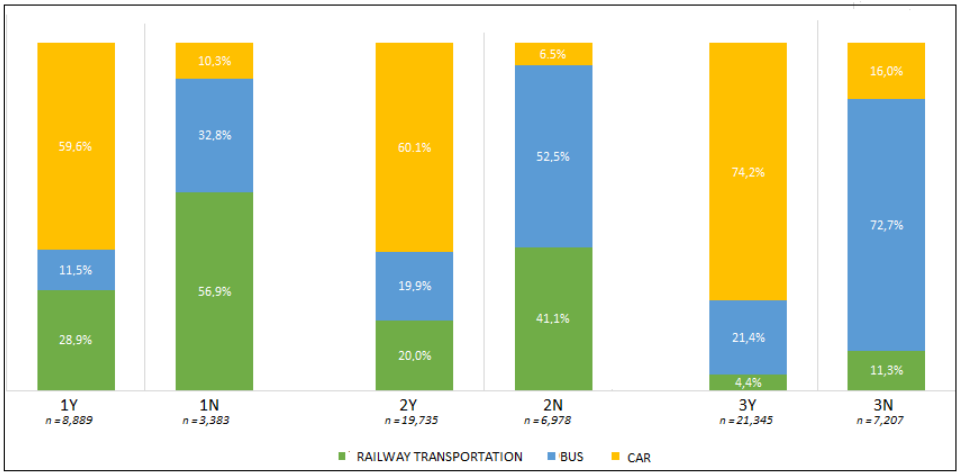


Source: Author.

3.1.2 Variable 2: Car ownership

Individuals who have at least one car were 73.9% of the population considered in the study and car ownership could be considered a determinant for the choice for the car on commuting (Figure 4). Even when the individual's origin and/or destination is closer than 1 km from a railway station, people who own a car are inclined to use it for commuting (about 60% in 1Y and 2Y on Figure 4). Regarding the trips with both the origin and the destination farther than 1 km from a railway station (3Y and 3N in Figure 4), car ownership seems to be even more determinant for the choice for this mode of transportation. In this case, the car is used in 74.2% of the trips taken by individuals who have it and 16.0% among individuals who don´t have it.

Figure 4. Modal share considering the car ownership (Y – yes or N – no) for (1) trips with both the origin and the destination closer than 1 km from a railway station, (2) trips with only the origin or the destination closer than 1 km from a station, and (3) trips with both the origin and the destination farther than 1 km from a station



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3.1.3 Variable 3: Household income

Besides the influence of the distance from a railway station and the car ownership, it was found that, the higher the household income of the individual who travels, the more likely the trips to be taken by car.

The analysis of the modal share for the trips taken by individuals who own at least one car (left graphs in Figure 5) reveals that this transportation mode is more frequently chosen by individuals with higher household income levels. Observing the trips with the origin and the destination closer than 1 km from a railway station (1Y), the choice for the car as a transport mode is 55.9% among individuals from household income Level 1 and gradually increases until 71.3% among individuals from household income Level 5 (first left graph in Figure 5). For the trips with only the origin or the destination closer than 1 km from a railway station (2Y), the choice for the car also gradually increases from 42.2% among individuals from household income Level 1 until 79.3% among individuals from household income Level 5 (second left graph in

Figure 5). To conclude, for the trips with both the origin and the destination farther than 1 km from a railway station (3Y), the choice for the car is already high among individuals from household income Level 1 (67.3%) and becomes even higher among individuals from household income Level 5, exceeding 93% of the trips (last left graph in Figure 5).

The pattern of increasing the car use as the household income level increases is also observed when analyzing the modal shares for the trips taken by individuals who don't have any car (right graphs in Figure 5), except for the 1N trips. For the trips with only the origin or the destination closer than 1 km from a railway station (2N), the choice for the car as transport mode gradually increases from 5.0% among individuals from household income Level 1 to 28.8% among individuals from household income Level 5 (second right graph in Figure 5). About the trips with both the origin and the destination farther than 1 km from a railway station (3N), the choice for the car is 9.7% among individuals from household income Level 1 and reaches 69.2% among individuals from household income Level 5 (last right graph on Figure 5).

Figure 5. Modal share considering the car ownership (Y – yes or N – no) and the household income level (1 to 5) for (1) trips with both the origin and the destination closer than 1 km from a railway station, (2) trips with only the origin or the destination closer than 1 km from a station, and (3) trips with both the origin and the destination farther than 1 km from a station

Source: Author.

3.1.4 Variable 4: Travel distance

As well as for the other variables, it was possible to detect the influence of the travel distance on the choice of a transport mode. The general pattern is that as the travel distance increases an increase in the choice of railway transportation and a decrease in the choice of car occurs (Figure 6). Regarding bus transportation, it seems to be a preference for intermediary distances (Figure 6).

In trips with the origin and the destination closer than 1 km from a railway station (1), when the travel distance is less than 2 km, railway transportation is chosen in less than 15% of the trips (first graph in Figure 6). The choice for this mode becomes more frequent as the travel distance increases.

Still about trips with the origin and the destination closer than 1 km from a railway station (1), the choice for the car is inversely related to the travel distance; that is, as the travel distance increases, the choice for the car as transport mode decreases (first graph in Figure 6).

The curve of the choice for the bus as a function of the travel distance reveals that this mode is chosen more often in travels with distances between 2 and 5 km (first graph in Figure 6). For shorter and longer distances, the bus is less frequently chosen.

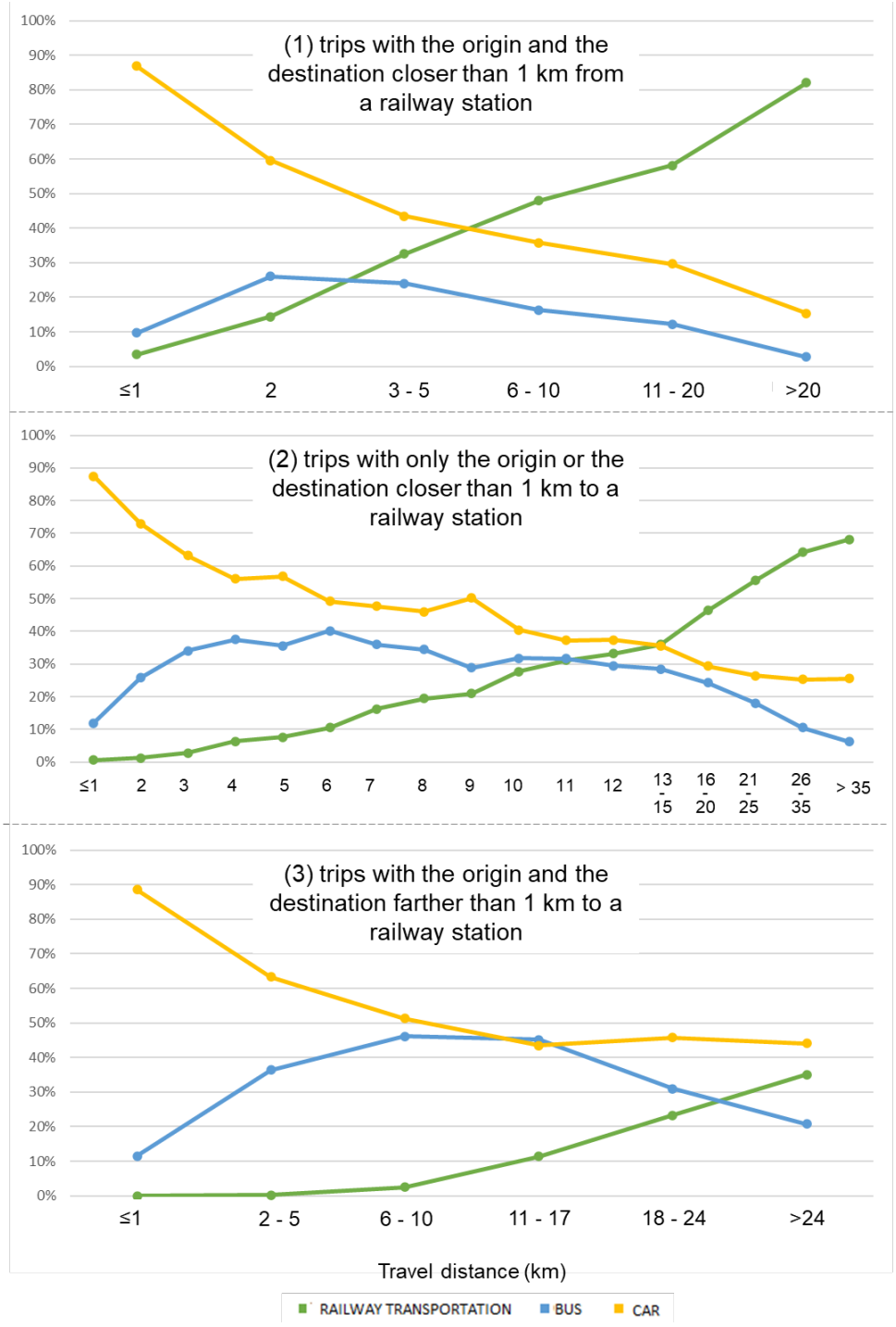
In the trips with only the origin or the destination closer than 1 km from a railway station (2), the patterns for the railway transportation and the car choices are the same observed in (1) (Figure 6). The choice for the bus as a transportation mode is also higher for trips with intermediary distances, but it is chosen in a similar share for trips between 3 and 11 km (second graph in Figure 6).

The travel distances tend to be higher in trips with only the origin or the destination close to a railway station (2) than in trips with both the origin and the destination close to a station (1). Even having longer trips, in (2), the choice for railway transportation occurs in more than 50% of the trips only when the travel distance is higher than 20 km (second graph in Figure 6). In (1) it occurs when the travel distance is about 10 km (first graph in Figure 6). In trips longer than 20 km, railway transportation represents 82% of the (1) trips but only 60% of the (2) trips. For this same travel distance, the car is chosen in 15% of the (1) trips and 25% of the (2) trips (Figure 6).

The analysis for the trips with the origin and the destination farther than 1 km from a railway station (3) reveals similar patterns to the ones presented for (1) and (2). However, the decrease for the car choice is lower and the choice for this mode stabilizes around 45% for travels longer than 11 km (third graph in Figure 6). The increase in the choice for railway transportation occurs mainly at the expense of the choice for the bus in trips with distances higher than 11 km and it reaches 35% of the trips when the travel distance is higher than 24 km (third graph in Figure 6). The choice of railway transportation, even for longer trips, is much inferior in (3) in comparison with (1) and (2).

As found in (2) trips, concerning trips with both the origin and the destination farther than 1 km from a railway station (3), the choice of the bus as a transport mode is preferable even for travel distances higher than 5 km and it decreases only when the travel distance is superior to 17 km (third graph in Figure 6).

Figure 6. Modal share as a function of the travel distance in (1) trips with the origin and the destination closer than 1 km from a railway station, (2) trips with only the origin or the destination closer than 1 km from a railway station and (3) trips with both the origin and the destination farther than 1 km from a railway station



Source: Author.

3.2 Multinominal regression model

The multinominal regression model confirmed the influence of the four variables in the mode choice (p-value <0.0000 for all variables; Table 1). The main variables that explain the modal choice in RMSP are the proximity to a railway station which promotes railway transportation (β = 2.987 and 1.933 for classes 1 and 2 respectively) and car ownership which has the major influence in not choosing a public transportation in commuting (β = - 2.341 and - 2.445 for railway transportation and bus respectively).

Table 1. Parameter estimates from multinominal regression model analysis.

Mode choice[a]		β	Sig.	Exp(β)	95% Confidence Interval for Exp(β) Lower Bond	Upper Bond
Railway Transportation	Intercept	-1.314	0			
	Travel Distance	0.122	0.000	1.130	1.126	1.133
	Household income	-0.267	0.000	0.766	0.747	0.785
	Origin and destination within 1 km radius from a railway station	2.987	0.000	19.826	18.307	21.471
	Only the origin or the destination within the 1 km radius	1.933	0.000	6.913	6.456	7.402
	Both origin and destination without the 1 km radius	0[b]	0.000			
	Car ownership=yes	-2.341	0.000	0.096	0.090	0.103
	Car ownership=no	0[b]	0.000			
Bus	Intercept	2.600	0.000			
	Travel Distance	.011	.000	1.011	1.008	1.014
	Household income	-.541	0.000	.582	.569	.595
	Origin and destination within 1 km radius from a railway station	-.032	.340	.969	.908	1.034
	Only the origin or the destination within the 1 km radius	.367	.000	1.443	1.379	1.510
	Both origin and destination without the 1 km radius	0[b]				
	Car ownership=yes	-2.445	0.000	.087	.082	.092
	Car ownership=no	0[b]				

a = The reference category is: car.
b = This parameter is set to zero because it is redundant.

4. Discussion

Most predictive models on transport choice are from the aggregate discrete choice type. These models disregard individual characteristics (such as household income, gender, age, etc.) and consider only the travel-related features (such as costs and distance) (Ashalatha et al., 2013). This work can be considered quite complete as it provides information regard modal choice from three perspectives (Buehler, 2011): socio-economic and demographic characteristics (car ownership and household income), spatial development patterns (travel distance), and policies that affect travel behavior (the origin and the destination distance from a railway station).

Expanding the analysis beyond travel-related features revealed the importance of considering individual characteristics. Santos e Lelis (2018) have already drawn attention to the commuting movements carried out by car by white men with higher education in the metropolitan regions of southeastern Brazil. The presented results

reinforce the role of these individual characteristics, since pointed the car ownership as an elementary factor in choosing this type of transport over any other. Car ownership is a characteristic that has been neglected in the models applied in Brazil, including the model used in the São Paulo Integrated Urban Transport Plan (STM, 2006b).

Beyond the variables considered in this study, there are others that can be future added. For instance, the transport mode choice has already been related to gender, age, cars per household member, population density, household employment status, land use, and weather conditions (Böcker et al., 2016; Boulange et al., 2017; Buehler, 2011; Chee e Fernandez, 2013; Corpuz, 2007; Heinen e Chatterjee, 2015). Even momentary situations can influence the transport mode choice, as in the case of the increase in car use at the expense of public transport in São Paulo and other Brazilian cities during the Covid-19 pandemic (ANPTrilhos, 2020; Ponciano Voz, 2020).

As mentioned in Section 1, other limitation noted in the previous studies conducted in the SPMA is to consider buses and railway transportation as a unique group named public transport. These two modes have very distinct features that justify their segregation for the analysis. In SPMA, the railway network is insufficient and restricted mostly within the São Paulo city central zone, aggravating the social segregation and preventing equalitarian access to it (Zandonade e Moretti, 2012). During electoral campaigns, the expansion of the railway network is often emphasized, but in practice, constructions are canceled and are always delayed. For considering the railway network expansion fundamental to mobility improvement in SPMA, in this study, this transport mode was segregated from the bus and the first variable considered in the analyses was the origin and the destination distances from a railway station.

In SPMA, the subway network has already been studied in order to measure its associated impacts related to air quality and socioeconomic features (da Silva et al., 2012; Haddad et al., 2015; Leirião et al., 2023, 2024). The results found in the present study indicated that, when access to a station is facilitated (less than 1 km from the origin and the destination of a trip), railway transportation is always preferred over the bus. They also indicated that the car is used more frequently when both the origin and the destination are far from a railway station. So, the network expansion is essential to increase the number of rail trips and maximize its positive impacts. According to Beirão e Cabral (2007), having a rail station close to the origin or destination of the trip has great potential to make even car owners opt for rail transport. The distance to a public transit station and the quality of public transportation has both negative impacts on car ownership (Ritter e Vance, 2013).

In Brazil, the improvement of the subway system of the Metropolitan Area of Fortaleza provided accessibility benefits even in zones far from the railways (de Souza et al., 2020; Freire et al., 2020). In the station proximities, the subway system proved to increase the number of establishments opening as well as specialization of activities in Salvador (Bahia, Brazil) (de Jesus Rodrigues, 2019). Considering it all, the railway

network expansion in the SPMA, especially towards the periphery, has the potential to improve the local economy and result in benefits in relation to accessibility in adjacent areas. The modal shift from car to railway transportation can also result in benefits in terms of public health since the people use to walk to the stations increasing their physical activity (Lachapelle et al., 2011).

Besides the need to extend the railway network, it is important to emphasize that the improvement in the extension must be followed by quality improvements. The actual railway network in the SPMA admits 5.2 million users per day (Metro, 2019). This elevated number of users in a restricted system results in low comfort and frequent delays due to people trying to enter crowded trains. The service quality has a positive effect on the intention to use more public transport and other sustainable means of transportation as car sharing (Mugion et al., 2018). The quality improvement can be funded by a slight increase in fares without causing discouragement in people to use public transportation (Tyrinopoulos e Antoniou, 2013).

Car ownership was the second variable considered in this study because there is a consensus that it is the primary determinant of transport mode choice (Buehler, 2011; Corpuz, 2007; He e Thøgersen, 2017). Our results corroborate it, since car ownership was indicated as the major influence in not choosing a public transportation in commuting. Household income and car ownership are intrinsically related since higher incomes make it easier to buy and maintain a car. In SPMA, 52.9% of the households have at least one car and the motorization rate is increasing over the last 10 years (Metro, 2019). Despite Brazilian economic incentives providing easier access to the car, when comparing the modal shares of trips made by people who own a car through different household income levels, it is evident that the increase in the household income level positively influences the choice of the car. It indicates that although people from lower incomes are having access to their own vehicle, using it for commuting is still expensive. In fact, previous studies have already mentioned that public transport is encouraged, especially among students and lower-income people, for being the cheaper alternative (Beirão e Cabral, 2007; Corpuz, 2007).

Besides household income, gender must be seen as a related factor to the car choose. According to Macêdo et al. (2020), in SPMA and other Metropolitan Areas in Brazil, the car is more frequently used by men than by women and it can be a consequence of the fewer opportunities for women. This difference between how frequently men and women use the car in commuting was also observed in China (Fu e Juan, 2017). In this context, it is also important to discuss the implementation of measures that make the subway a more comfortable and safer environment for women, such as the already existing campaign against sexual abuse in public transport led by Metrô.

Another interesting aspect revealed in our results is that even people who don't have a car use it in their commuting either as a passenger or as a driver (renting or borrowing the vehicle). Besides the seek for a more comfortable transportation, this choice may be associated with the travel time. According to Liao et al. (2020), in Sao

Paulo, using the public transportation takes on average 1.4–2.6 times longer than driving a car. The car preference is also noted through the increasing use of transit apps. In the last 10 years, the share of the trips performed by "taxis" in the SPMA increased by 414% because of the transit app services (Metro, 2019). Considering all this, driving restrictions alone are not able to promote the shift from cars to public transportation (Liu et al., 2016). So, the governments must to enhance the public transportation quality and to promote other actions such as improving people's awareness of consequences of the car use (Liu et al., 2016). In the SPMA, these measures still absent.

The travel distance was the last variable considered in this study for being less frequently related to the transport mode choice. The results indicated that, as the travel distance increases more attractive railway transportation is. Probably the time spent to access a railway station and to board a vehicle is very expensive for short distances, but they are attenuated for the longer ones. The time spent accessing the train or the subway became more evident when analyzing only the trips with less than 2 km that are performed by public transport. On these trips, the bus is always preferred over railway transportation even being subjected to the traffic (see Figure 6). It may occur because the bus stop density is higher than the railway station density. As the trip distance increases, besides the time spent to access the station becoming less representative in the total time of the trip, railway transportation becomes attractive, because it is not subject to traffic, making the travel time more predictable. Furthermore, the subway is usually considered a more comfortable mode than the bus, especially for long trips and so it is chosen more frequently (Hu et al., 2015). The lesser choice of car on long journeys may be associated with both traffic and associated costs. According to de de Brito et al. (2018), individuals who travel long distances to work tend to have lower incomes, which would proportionally make car use more expensive. Contrary to the results found for SPMA, Buehler (2011) established that in the USA and Germany, as the travel distance increase the choice for the car also increases, but it seems to occur at the expanse of active transportation because the choice for public transportation also increases in smaller proportion.

Some of the variables that explain the transport mode choice for commuting cannot be modified by public policies. However, government actions may be implemented to promote the use of cleaner transportation, such as railway transportation, over private vehicles. This study demonstrates that expanding the railway network, creating new stations, and making this mode an alternative in more trips, may be encouraged. This recommendation is not a novelty for the government. Both the Sao Paulo Municipal Urban Mobility Plan and the Plan of the High and Medium Capacity Metropolitan Transport Network describe the future expansion of the railway network (STM, 2006a, 2015). The network planned for 2030 comprises 30 lines and 420 stations, resulting in 847 km of network (STM, 2006a). The attention to the issue in documents and plans is notable, however it is not observed in practice. The expected network until 2020 was 614 km and the observed one was about 360 km (Metro, 2018). For comparison,

in Shanghai, which has an area and population comparable to that of the SPMA, the rail network began operating only in 1993, but have already 548 km (shentong metro group, 2021).

According to a survey of the ITDP, between 2010 and 2018, the increase in the population living less than 1 km of rail transport network was only 2% (from 10% to 12%) in SPMA (ITDP-Brasil, 2020). According to our results, proximity to a station is the main factor in promoting the use of rail transport, so it is urgent to increase the pace of expansion and the real prioritization of this measure by the government.

5. Conclusions

This study analyzed factors influencing transport mode choices within the São Paulo Metropolitan Area (SPMA), utilizing an extensive origin-destination survey database. Results reveal that proximity to railway stations and longer travel distances significantly encourage railway use, whereas car ownership and higher household income contribute to a stronger preference for cars. This preference is particularly pronounced for shorter travel distances, highlighting a nuanced relationship between distance and transport choice.

The findings underscore the potential of railway expansion as a strategic intervention for promoting sustainable transportation, particularly for long-distance travel where public transit options can replace car reliance effectively. Expanding the railway network could yield substantial shifts in modal choice, contributing to reduced congestion, lower emissions, and more equitable access to mobility. This insight is crucial, as railway infrastructure projects in SPMA often face budgetary and political challenges due to high initial costs. By demonstrating the potential for modal shifts through railway expansion, this study provides evidence to support investment in sustainable infrastructure that could reshape commuter behavior over time.

Furthermore, the research highlights the importance of addressing both social and economic disparities that influence travel behavior. Given that household income and car ownership significantly affect mode choice, policies that subsidize public transportation or improve accessibility to railway stations in lower-income areas could play a role in promoting a more balanced and sustainable urban mobility system. Such targeted policies may not only increase public transit use but also enhance social inclusion by making public transportation a viable choice across different economic segments of SPMA.

Future research should consider additional variables, such as travel time reliability, environmental attitudes, and the role of intermodal connectivity, to develop a more holistic understanding of mode choice. Longitudinal studies could also reveal how infrastructure improvements influence transport habits and urban mobility patterns over time. This research offers a critical foundation for designing policies that prioritize sustainability while addressing the unique transportation needs and economic

realities of SPMA's diverse population.

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