Urban mobility indicators in the Metropolitan Region of São Paulo based on the Origin and Destination Metro survey

Indicadores de mobilidade urbana na RMSP a partir da pesquisa OD-Metrô

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Abstract

The results of the 2017 Origin and Destination (OD) Metro survey for the Metropolitan Region of São Paulo (acronym in Portuguese: RMSP) were published in 2019. Through a spatial analysis of open data from the OD survey, this article aims to identify characteristics of the daily commuting performed by RMSP residents, investigating spatial patterns of travel time, mode choice, motorization rate, mobility and immobility index, considering population distribution according to different income ranges and disaggregated by OD zone. The 2017 results are compared to those of 2007 to investigate what changed and what remained during the decade.

Keywords: urban mobility; Metropolitan Region of São Paulo; Origin and Destination survey; daily journeys.

Resumo

Em 2019, foram publicados os resultados da pesquisa Origem Destino 2017 do Metrô-SP para Região Metropolitana de São Paulo (RMSP). Este artigo objetiva, por meio de análise espacial dos dados abertos da pesquisa, identificar características dos deslocamentos diários realizados pelos moradores da RMSP, verificando padrões espaciais quanto a tempo de viagem, divisão modal, taxa de motorização, índice de mobilidade e de imobilidade, considerando a distribuição da população de acordo com as diferentes faixas de renda e de forma desagregada por zona OD (origem destino). Os resultados de 2017 são comparados aos de 2007, buscando verificar mudanças e permanências ao longo da década.

Palavras-chave: *mobilidade urbana; Região Metropolitana de São Paulo; pesquisa origem-destino; viagens diárias.*

Introduction

São Paulo's Metropolitan Region (SPMR) consists of 39 municipalities with an estimated population of 21.252.384 inhabitants.[1] Since 1967, São Paulo's Metropolitan Company (Metrô) has conducted the Origin-Destination (OD) survey to depict the daily commute characteristics of the metropolis. In 2017 the survey was carried out in over 32,000 households to collect detailed information on the daily commute of people: who travels, for what purpose, how they travel, whether they use one or more transport modes, how much time they spend in travel, what are the Origin-Destination of the commute, apart from those questions about income, age, schooling, place of residence, work or study. The results of the last edition of the survey were published in 2019:

> In a general way, the OD survey reveals an increase in the number of commutes, surpassing population and employment growth in SPMR in the past ten years. There was a 10.3% increase in daily commutes from 38.1 million to 42 million, whereas the population went from 19.5 million to 20.8 million (6.6%). And employment, both formal and informal, went from 9.1 to 9.4 million (3.3%). (Metrô, 2019, p. 15)[2]

In Brazil, that decade was marked by the end of a period of a more stable economy, the expansion of access to credit, and the improvement of the income of the population. But it was also a period in which the consequences of the international 2008 crisis prevailed (Maringoni and Medeiros, 2017). As for urban dynamics, the period was characterized by the "real estate boom", in which the SPMR was the stage of an intense housing production (Sígolo, 2014) sponsored by the "Minha Casa Minha Vida" program of the federal government. There were urban infrastructure works as well as part of the PAC (Programa de Aceleração do Crescimento) and the preparations for the 2014 World Cup (Maricato e Royer, 2017). In what concerns urban mobility there was an increase in motorization indexes and car and motorcycle ownership; the emergence of new transport services by mobile application, the expansion of the Metrô and railway networks in SPMR,[3] and the increasing number of bike and bus lanes networks, especially in São Paulo city.

This article's goal is to identify patterns in the 2017 SPMR residents' commutes, according to their residence zone, and compare them to the patterns of 2007 through urban mobility indicators.[4] Based on the maps produced with these data, the article illustrates the intra-urban differences in mobility conditions in SPMR.

It is important to mention that the approach of this article takes the principles, directives, and goals of the Urban Mobility National Policy (federal law n. 12.587/2012) as a premise. Above all, the need to 'reduce inequalities and promote social inclusion' and to "improve the population's urban conditions in terms of accessibility and mobility". This is because it is understood that urban mobility conditions are related to social exclusion (Lucas, 2012), and that Brazilian cities are

marked by inequality in their access to transportation services (Vasconcellos, 2001 & 2006). In SPMR, even though the importance of public transport for social inclusion (Sardinha Neto, 2012), is possible to verify inequalities in the distribution of rail transport (Villaça and Zioni, 2005), the precariousness of mobility due to a historic preference for the highway model (Silva, 2014), and the imposition of immobility for society as a whole (Rolnik and Klintowitz, 2011), amongst other aspects that surpass the limits of this work.

In addition to this Introduction and the Conclusions, this article presents (1) methodological notes; (2) a brief characterization of the SPMR population based on the Metrô OD survey; and (3) an analysis of characteristics of SPMR residents' commutes through the use of urban mobility indicators, disaggregated by OD zone in thematic maps.

Methodological notes

The present analysis used the data from OD 2007 and 2017 surveys.[5] The indicators for each OD zone were calculated based on that information and then the maps that spatialize the data in a disaggregated way by OD zone. All analyses use the residence zone as a basis for the answers to show a characterization of the zone's residents.

The definition of the urban mobility indicators to produce the analysis and the maps took under consideration some criteria: indicators widely used in the urban mobility field[6] capable of being calculated using the OD Metrô survey data,[7] in addition to the possibility of spatialization in maps.[8] Thus, the defined indicators are mobility index, immobility indicator, daily trips by mode, the average travel time, and cars and motorcycles motorization rate. Chart 1 summarizes the used indicators with their respective definition and calculation method based on the OD Metrô-SP survey database.

To compare the indicators' variations between the 2007 and 2017 surveys, it was necessary to make their zoning compatible. In 2007 SPMR was divided into 460 zones and 517 in 2017 (Figure 1). The OD zones are

> [...] defined by their urbanistic and socioeconomic homogeneity, amongst other technical criteria. These zones are the basis for the survey's sample sizing and to determine the extent of the collected information. The OD zone is the smallest geographic unit from which the statistical representativeness of the data is ensured. (Metrô, 2019, p. 17)

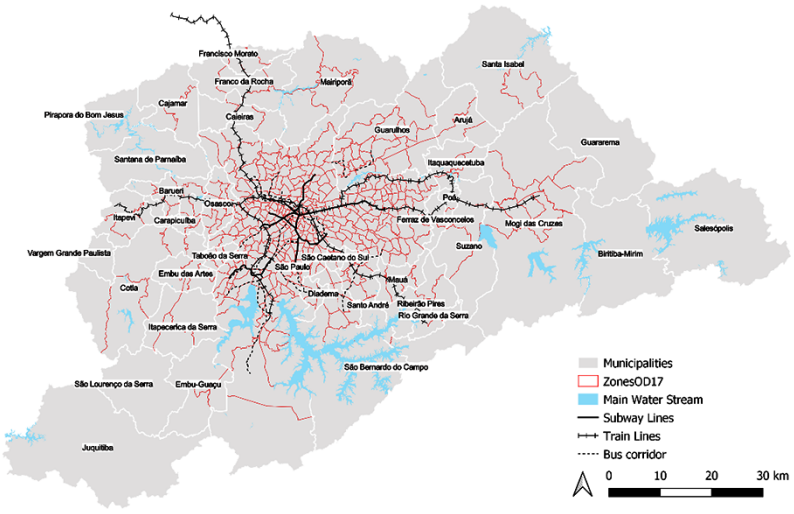
The zoning spatial analysis of the surveys shows that the configuration of zones remained the same between 2007 and 2017. Or that the 2007 zone was divided into two parts, as shown in zone 64 which was divided into zones 64 and 65 in the 2017 edition. Or as it happens with zone 121 which was divided into zones 122 and 123. Due to this particular zoning, an equivalence factor was created, proportional to the zone's total area. This was applied to the total number of families, people, trips, cars, and motorcycles in the 2007 survey. This article uses 2017 zoning.

Chart 1 – Urban mobility indicators

Indicator	Definition	Calculation Method[9]
Mobility index	Total amount of trips per inhabitant per day (the higher, the better).[10]	$\frac{\sum_{i=1}^{n} FE\_VIA_i}{\sum_{i=1}^{n} FE\_PESS_i}$
Immobility indicator	Amount of individuals in the population that did not travel (the higher, the worse).	$\frac{\sum_{i=1}^{n} FE\_PESS(sem\ viagens)_i}{\sum_{i=1}^{n} FE\_PESS_i}$
Daily trips by mode	Amount of trips by public transport modes and by individual modes (the higher by public transport modes, the better).	$\sum_{i=1}^{n} FE\_VIA_{COL_i}$ $\sum_{i=1}^{n} FE\_VIA_{IND_i}$
Average Travel Time	Average Travel Time by public transport modes and by individual modes (the higher, the worse).	$\frac{\sum_{i=1}^{n} (FE\_VIA * DURACAO)_i}{\sum_{i=1}^{n} FE\_VIA_i}$
Car motorization rate[11]	Amount of cars per inhabitant (the higher, the worse).	$\frac{\frac{\sum_{i=1}^{n} (FE_{FAM} * QT_{auto})_i}{\sum_{i=1}^{n} FE\_PES_i}}{1000}$
Motorcycle motorization rate	Amount of motorcycles per inhabitant (the higher, the worse).	$\frac{\frac{\sum_{i=1}^{n} (FE_{FAM} * QT_{moto})_i}{\sum_{i=1}^{n} FE\_PES_i}}{1000}$

Source: prepared by the authors.

Figure 1– São Paulo's Metropolitan Region and 2017 OD zones



Source: prepared by the authors, based on data from the OD Metrô Survey.[12]

After their calculation, indicators were spatialized by OD zone through a geoprocessing software resulting in the maps presented here that also show the high and medium-capacity transport systems of SPMR.[13]

The analysis of the maps uses two criteria. First characterizes the population by density, income, and workplace, identifying large homogeneous areas with predominant high or low density, high or low income, and job concentration. Secondly, urban mobility indicators were crossed and superimposed with those of socioeconomic characterization. Therefore, the analysis of the maps with urban mobility indicators focuses on the most densely populated areas, where low and high-income populations concentrate, the proximity of high-capacity public transport services, and workplace concentration. The comparison between 2017 and 2007 sought to verify changes and permanence in mobility and immobility of people throughout the decade.

It is important to note some characteristics of the OD Metrô survey. The sample of 32,000 households was calculated using the stratified sampling method in five different household income strata based on the 2010 database of the Cadastro Nacional de Endereços para Fins Estatísticos (Cnefe). The sample is statistically representative of the universe of the population of SPMR. It has a margin of error of less than 6% and a confidence level of 92%. Based on the expansion factors[14] it is possible to identify the behavioral pattern of the daily trips of the population residing in SPMR.

Moreover, the OD Metrô survey uses the 'primary mode' concept, which means there is a hierarchy among the different transportation modes that can be used on a single trip.[15] Thus, in a multiple-mode trip, the primary mode will be that of superior hierarchy.[16]

Finally, it must be noted that the OD survey data have multiple analysis possibilities other than the ones explored here. All the mapped indicators can be differently addressed using age, gender, active modes, income rate groups, and trip purpose, among others.[17] Hence, this article presents solely one of the possible research analyses of the OD survey. It is also important to consider the limitations of the research since

> [...] travel demand reflected in origin-destination surveys represents only the visible part, manifest, of people's need to travel. These trips are those that became possible within their existing conditions: individual, household, economic, and physical. If different conditions were present, different trips would be made. [...] However, being aware that only possible trips are reflected in research does not diminish their importance. (Vasconcellos, 2001, p. 38)

Characterization of SPMR population based on the Metrô OD survey

Before analyzing the trips performed by the residents in SPMR, their distribution, characteristics, and the changes that took place between 2007 and 2017 must be brought to attention, as must the distribution of workplace, which conditions a large part of these trips. The OD survey shows that

the population of SPMR increased by 6.6% between 2007 and 2017, reaching 20.8 million inhabitants in 2017 (Metrô, 2019, p. 25). Their distribution is heterogeneous throughout the metropolitan area, with variations in population density and family income rates.[18] The urban area of SPMR is shown in Figure 2 to aid in the interpretation of thematic maps.

Population density

The average population density of SPMR changed little between 2007 and 2017. It went from 25 ppl/ha to 26 ppl/ha. However, the distribution of the population is not homogeneous. There are very dense areas (with more than 150 ppl/ha), especially in the capital and in some municipalities in the metropolitan region (Diadema, São Bernardo do Campo, Mauá, Osasco, Carapicuíba, Barueri, and Guarulhos); and less dense zones (with up to 25 ppl/ha), as in the municipalities of the east, northeast and southwest regions (Figure 3).

Among the high-density zones, there are those with infrastructure and urban services, as in the central region of the capital on the one hand, and on the other dense and distant areas from downtown with less infrastructure and urban services, either in the metropolitan region or in the capital (in districts such as Brasilândia, Mandaqui, Jd. Ângela, Capão Redondo, Grajaú, Sapopemba, São Mateus, Cidade Tiradentes, and Itaim Paulista). A great part of the metropolitan region has less dense areas, especially the most distant sectors of the capital, and some areas close to the central region along the Tietê and Pinheiros rivers, place of big urban equipment such as the facilities of the University of Sao Paulo, Ceagesp, Anhembi, Jockey Club, and some residential areas (Pacaembu, Jardim Lusitânia, Alto de Pinheiros, Butantã, Jardim Europa, Jardins, among others).

Comparing the population density between 2017 and 2007, densification in the central region of the capital can be observed (especially near lines 1-Blue, 2-Green, 3-Red, and 4-Yellow of the Metro), but also in Butantã, Iguatemi, and São Lucas). And, in SPMR, the areas close to the train Line 7-Rubi (north of SPMR), as well as parts of Diadema, São Bernardo do Campo, Mauá and Taboão da Serra. At the same time, there was a reduction in the densification of downtown Guarulhos; in the east of São Paulo, Vila Curuçá, and Vila Jacuí (between train Lines 12-Sapphire and 11-Coral) and in the Sacomã region.

Family income

In 2017 the average monthly family income for SPMR as a whole was R$3,607.00, which is 11.5% lower than the average income in 2007, considering the evolution of the minimum wage during the period (Metrô, 2019, p. 28). The OD survey organizes the data into five income strata shown in Chart 2.

Figures 4, 5, and 6 depict the distribution of average family income in SPMR between 2007 and 2017; concentration of lower-income population (Stratum 1); and concentration of higher-income population (Stratum 5), respectively. As for average income, the distribution of population in Stratum 2 across the metropolitan region in

Chart 2 – Income strata according to OD survey

	2007 – R$	2017 – R$
Stratum 1[19]	up to 760	up to 1.908
Stratum 2	760 to 1.520	1.908 to 3.816
Stratum 3	1.520 to 3.040	3.816 to 7.632
Stratum 4	3.040 to 5.700	7.632 to 11.448
Stratum 5	over 5.700	over 11.448

Source: prepared by the authors.

2017 opposes that of the downtown area of the Capital, with an average income in Strata 3, 4, and 5. In 2007 population in Stratum 3 was distributed all over the territory, and more zones had an average income equivalent to Strata 4 and 5. Three zones show an average income in Stratum 1 in 2017, which did not happen in 2007.

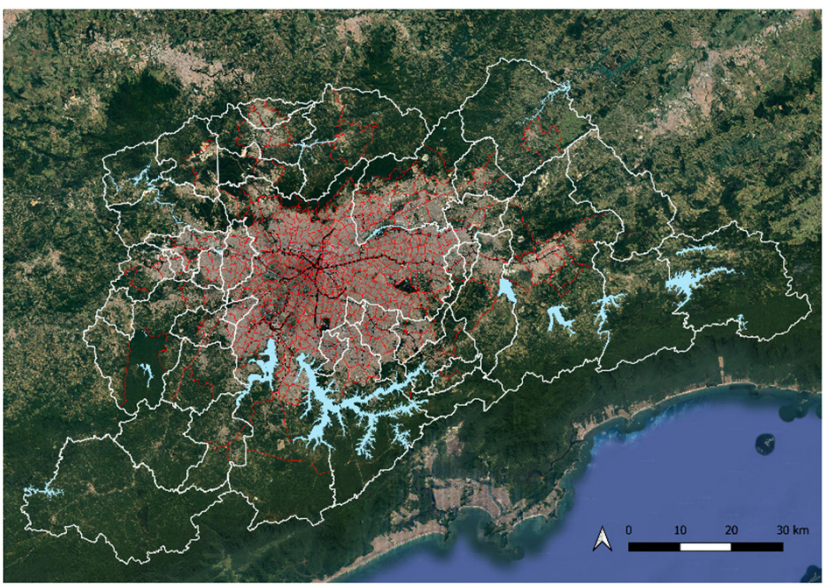
The areas in which the highest income stratum predominates, Stratum 5, correspond to a well-defined geographical space with highlights on the southwest quadrant of the capital (from Higienópolis to Vila Andrade, passing through Jardins, Pinheiros, Morumbi, and Moema) and parts of some municipalities in the western region, such as Barueri, Jandira, and Itapevi. Comparing the concentration of families in Stratum 5 in 2007 and 2017, a reduction is verifiable in the period under analysis. And in 2007, there were areas with more than 60% of families in Stratum 5, which did not occur in 2017.

As to the areas with a low-income predominance (Stratum 1), it is worth noting that, in 2007, the concentration of this stratum per OD zone was no more than 44%, but 2017 shows several zones with 40% to 60% of the households in Stratum 1: in the capital, they refer mainly to the southern borders (especially Bororé and Riviera), north (especially Vila Souza) and east (Vila Jacuí, Laranja da China and Fábrica Bandeirantes); and the highest concentrations in the lowest-income stratum occur in Mogi das Cruzes and Guarulhos, but also Salesópolis, Biritiba-Mirim, Santa Isabel, Suzano, Santo André, Itaquaquecetuba, Arujá, Ferraz de Vasconcelos, Mauá, Embu-Guaçu, Itapecerica da Serra, Cotia, Cajamar, Francisco Morato, Franco da Rocha, and Mairiporã. In addition, in 2017, Cumbica, in Guarulhos, and Itapeti, in Mogi das Cruzes, surpassed 60% of households in Stratum 1; while Santana de Parnaíba, Caieiras, and Guararema stand out for the lowest proportion of households in Stratum 1 (no more than 20%).

Workplace

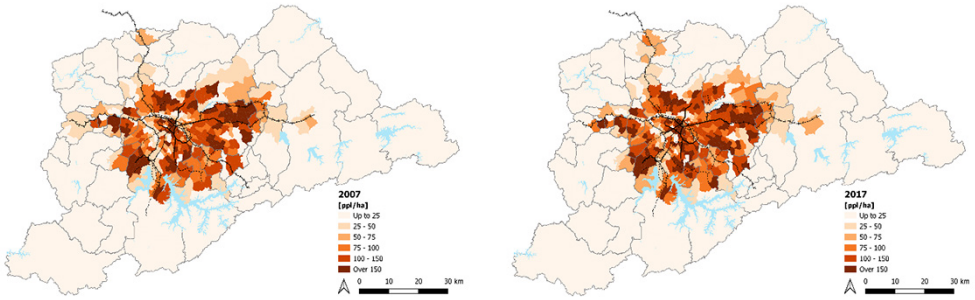
According to the 2017 OD survey, the main reason for travel is work (44%), followed by education (35%). Commutes are related to the distribution of the workplace, which in the case of SPMR is strongly concentrated in the capital, especially in the downtown area (Sé, República, Bela Vista, Liberdade, Consolação, Santa Cecília, Bom Retiro, Brás and Pari), expanding to Avenida Paulista, Faria Lima, and Luis Carlos Berrini, and also to the region of Barra Funda and Ana Rosa/Vila Mariana. All regions with more than 150 jobs/ha. In the other municipalities of SPMR, the highest density of jobs is in Guarulhos' downtown (above 150 jobs/ha); followed by areas in Osasco, Santo André and São Caetano do Sul (more than 100 jobs/ha) (Figure 7). Regions with higher job densities are generally accessible by medium and high-capacity transport systems, including subway connections, train, and bus corridors.[20] There was no significant change in the pattern of job concentration between 2007 and 2017 in SPMR.

Figure 2 – Urban area of SPMR – 2020



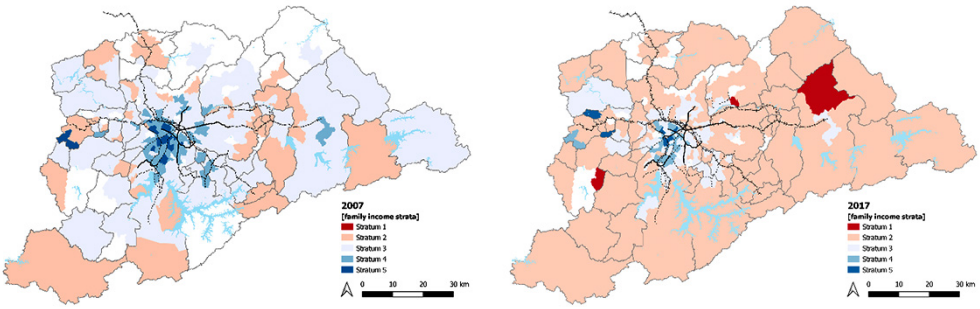
Source: prepared by the authors, based on an image from Google Earth and the OD Metrô survey zoning.

Figure 3 – Population density (ppl/ha) in 2007 & 2017 in SPMR



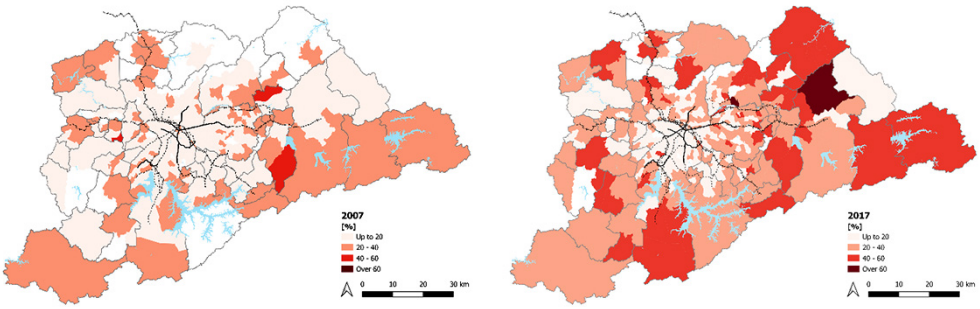
Source: prepared by the authors, based on data from the OD Metrô Survey.

Figure 4 – Predominant Family Income Strata in 2007 & 2017 in SPMR



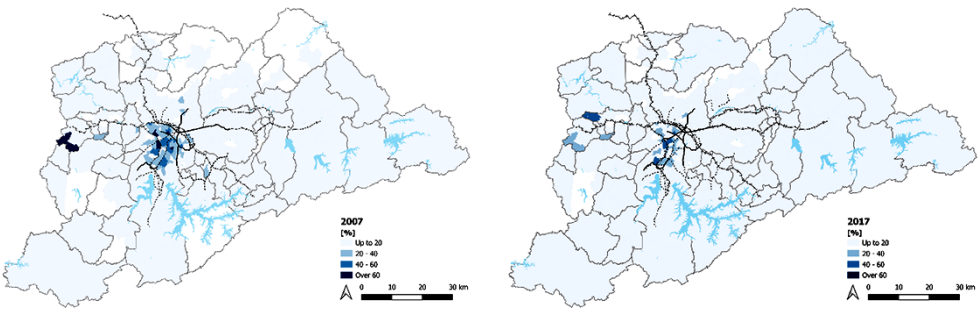
Source: prepared by the authors, based on data from the OD Metrô Survey.

Figure 5 – Concentration of low-income population (Stratum 1) in 2007 & 2017 in SPMR



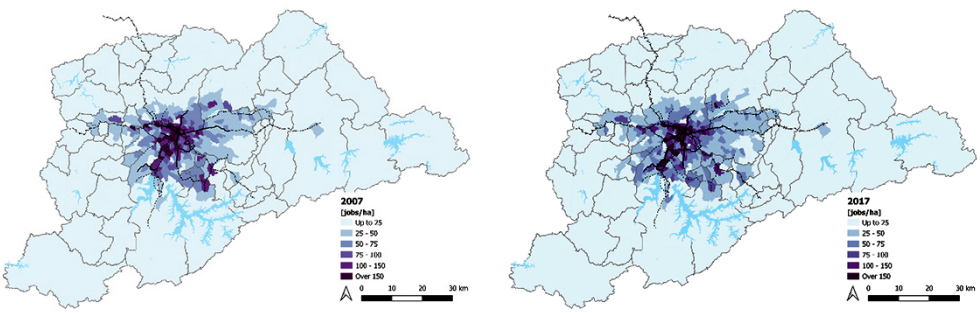
Source: prepared by the authors, based on data from the OD Metrô Survey.

Figure 6 – Concentration of high-income population (Stratum 5) in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô.

Figure 7 – Job density (jobs/ha) in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Urban mobility indicators in São Paulo's Metropolitan Region

Here follows the spatialization of urban mobility indicators considering the population distribution in the metropolis with its variations in density, income pattern, and concentration of workplace.

Mobility index

The mobility index refers to the number of trips per inhabitant per day. The National Association of Public Transport estimated Brazil's mobility index in 2017 at 1.64, less than 2 trips per day per inhabitant (ANTP, 2020). For SPMR, the OD 2017 survey showed that the mobility index increased from 1.95 in 2007 to 2.02 trips/ppl in 2017.[21] However, the 2.02 trips/ ppl index refers to the average for SPMR, which presents different results when analyzed by OD zone.

Regarding the situation in 2017 (Figure 8), it is visible that, while SPMR has several areas and municipalities where the mobility index is less than 2 trips/day/ppl, there are areas in the capital in which the index exceeds 3 trips/day/ppl. In the metropolitan region, the highest rates are in Guarulhos, Poá, Santo André, Itapecerica, and Jandira, with indexes between 2.5 and 3 trips/day/ppl. Zones with the highest mobility rates are in areas served by high-capacity public transport (train and subway) and also in sectors not reached by it, such as neighborhoods in the northern part of the capital.

SPMR shows high urban mobility rates in places with job concentration, as well as in those with higher-income populations. Regarding population density, there are areas with high population density and high mobility rates, such as those located along Metro's Line 1-Blue, between Luz and Jabaquara stations, or in the western section of Line 3-Red; and areas with low mobility rates and high population density in the east of the capital, like Vila Curuçá, Itaquera, Cidade Tiradentes, and Sapopemba, in part of Osasco, Carapicuíba and Jandira, to the west; and, in part of Guarulhos and Diadema.

Comparing the results of the 2007 & 2017 surveys (Figure 8) is observed that in areas like Sumaré, Vila Buarque, Glicério, Vila Olímpia, Jabaquara, and Cidade Vargas, all in the capital, the mobility index increased and surpassed 3 trips/ ppl. There was also a significant improvement in the mobility index in Belenzinho, Santa Efigênia, Granja Julieta, Jardim Jussara, and Eng. Goulart station, in the capital, and Poá and Taboão, in Guarulhos; however, in Clínicas and Berrini the mobility index dropped from 3 trips/ ppl to 2.2, and there was a significant drop in Vila Esperança, Vila Gumercindo, Bosque da Saúde, and Zaki Narchi, in the capital, and Itapevi. On the edges of SPMR where the mobility index had a maximum of 1.5 trips/ ppl in 2007, the pattern remained the same or raised up to 2 trips/ ppl in 2017.

Immobility indicator

According to the OD Metrô survey, the immobility indicator[22] refers to the proportion of individuals in the population who did not travel on the reference day of the survey. For SPMR the immobility indicator decreased from 31.7% to 29.9% between 2007 and 2017. However, the distribution of the indicator in the metropolitan area shows large disparities (Figure 9).

Regarding the immobility indicator, it must be considered that

> although not traveling may be an option, especially for individuals with higher incomes and no physical limitations, immobility can be an indication of exclusion, either for lack of transport options, accessible activities, time availability, or some social disadvantage such as lack of income, disability, fear, etc., that prevent an individual from moving around and thus engaging in activities. (Lima and Portugal, 2019, s.p.)

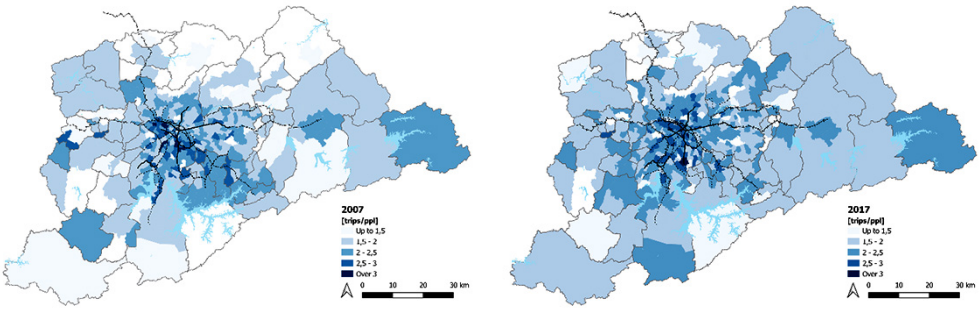
Since the lowest immobility percentages are in zones of the capital with the highest concentration of high-income population and employment rates, as well as better served by high-capacity transport infrastructure, SPMR immobility seems to indicate exclusion. Itapevi's less dense area is an exception, with high immobility (over 35%) and population in the highest stratum of family income (among 20 and 40% of the population) overlapping.

There are high rates of immobility in metropolitan municipalities, especially in the north (Francisco Morato, Franco da Rocha, Mairiporã, Cajamar), east (Ferraz de Vasconcelos, Poá, Itaquaquecetuba, Arujá, Santa Isabel, Biritiba-Mirim, and Guararema) and southwest (São Lourenço da Serra and Juquitiba). In these, not necessarily dense areas, immobility can conjugate with less intense metropolitan dynamics. But there is one sector in the capital's southeast and extreme east that, in addition to Ferraz de Vasconcelos and Poá, have high rates of immobility, high population density, and low family income, simultaneously.

Comparing immobility rates from 2007 and 2017, it is verified that regions such as Bororé, in the capital; Juquitiba, part of Mariripora, Santa Isabel, and Biritiba-Mirim (all of them less dense areas), maintained high rates of immobility. And rates over 35% also remained the same in more dense areas on the east like Itaquaquecetuba, Poá, Suzano, Ferraz de Vasconcelos, and Mauá.

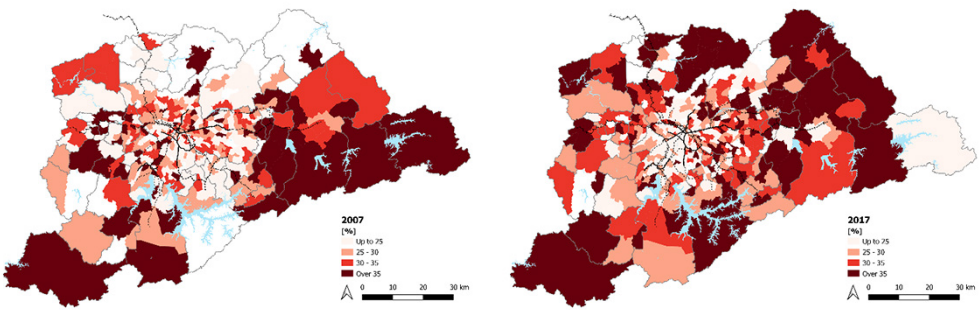
There was a significant reduction in immobility rates in certain zones of the capital like Jardim Europa, Jardim Paulista, Chácara do Jóquei, Granja Julieta, Vila Cordeiro, Jardim São Luís, Jardim Miriam, Jaguaré, Belém, Bom Retiro, Santa Efigênia, and Consolação (some of these located along Line 4-Yellow of the Metrô put in service during the period of the study). And zones near Train Line 11-Coral, in the metropolitan region, especially at Brás Cubas in Mogi das Cruzes, and in a part of Suzano. Moreover, the rate of immobile people at the border with Guarulhos municipality grew in Vila Medeiros/Ponte Grande, as well as in Pimentas; and some sectors in the east zone like Itaquera, Parque do Carmo, Vila Matilde, and Aricanduva; and in Santo André, Diadema, and Carapicuíba; also along Train line 7-Ruby, in Perus, in the capital, and Caieiras, Franco da Rocha, and Francisco Morato.

Figure 8 – Mobility index (trips/ppl) in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Figure 9 – Population Immobility indicator in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Daily trips by mode

Growth in total trips made in the SPMR in 2017 differs according to the mode analyzed. In general terms "trips by motorized modes grew by 12.4%, and by non-motorized modes, 6.2%". Among the motorized modes, the individual mode grew the most with 15%, while collective modes grew 10%. Bicycle trips grew by 24%, and walking trips grew by 6% (Metrô, 2019, p. 37).

In 2017, SPMR had the following modal split: 37% of trips by collective mode, 31% by individual motorized mode, and 32% by active mode.[23] That division changed little from the one of 2007 with 37% of trips by collective mode, 30% by individual motorized mode, and 34% by active mode. But there is a spatial difference. In the city of São Paulo, for example, trips by collective mode grew by 15%, whereas in the other cities of the metropolitan region, the participation in collective mode decreased (ibid., p. 43).

To analyze the evolution of modal split during the period,[24] maps in figures 10 and 11 show the differences among zones in which there was considerable growth or reduction in trips by mode (collective modes or individual motorized modes) and zones with no significant variation.[25]

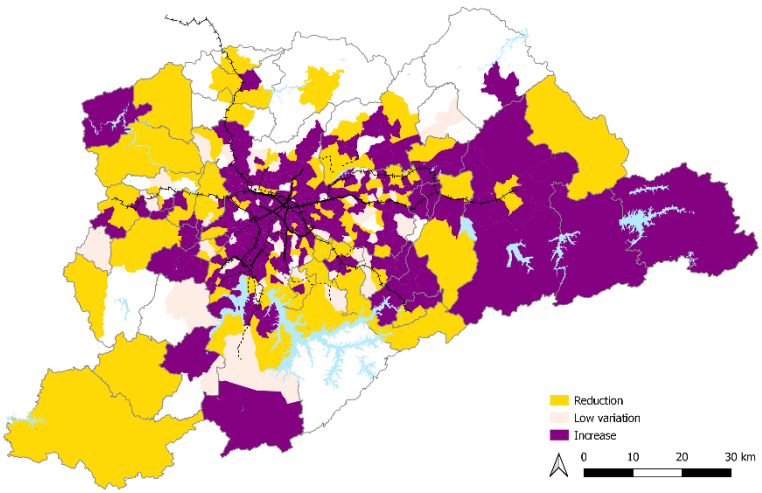
Regarding collective modes (Figure 10), there is a general growth in participation in the west sector of the capital, including the dense areas along the bus corridors, train and subway lines, especially along Line 4-Yellow, as well as in the north and part of the east, nearer to downtown. Among the municipalities in SPMR, there was a reduction in trips by collective modes in the west region and an increase in sectors to the east (Mogi das Cruzes, Poá, Itaquaquecetuba, Ribeirão Pires, and Guarulhos).

Zones with the highest job densities increased their trips by collective transport, except for downtown Guarulhos. It is to note that the few zones with the highest concentration of high-income households grew in trips by collective transport, except for Barueri and Alto de Pinheiros.

Concerning individual motorized modes (Figure 11), multiple zones around the capital increased their trips, most remarkably in a vast sector on the west (Embu-Guaçu, Itapecerica da Serra, Embu das Artes, Cotia, Jandira, Itapevi, Barueri, Santana de Parnaíba, and Cajamar), on other sectors on the east (Biritiba-Mirim and Guararema; part of Mogi das Cruzes, Suzano, Itaquaquecetuba, and Ribeirão Pires), as well as many areas in Guarulhos city.

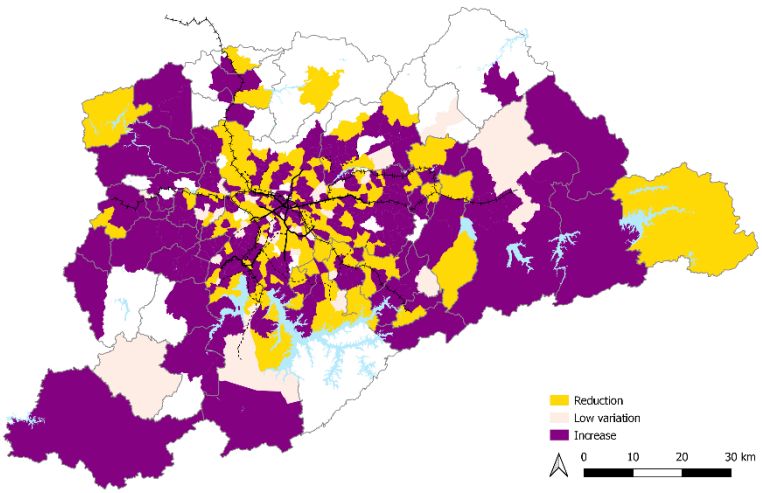
Some localities had a reduction in both individual and collective trip modes, as happened in part of Suzano and Ferraz de Vasconcelos; São Bernardo do Campo and Santo André; São Lourenço da Serra, part of Caieiras, Francisco Morato, Mairiporã, and Guarulhos. And there were zones that grew in both modes, like part of Mogi das Cruzes, Suzano and Ribeirão Pires; Embu-Guaçu and Embu das Artes, and the west and central region of the capital.

Figure 10 – Variation in total trips by collective modes between 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Figure 11 – Variation in total trips by individual motorized modes between 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Average travel time

In Brazil, the time spent commuting from home to work is longer in metropolitan regions than in non-metropolitan areas (Ipea, 2013), and the portion of the population that spends 1 hour or more commuting from home to work is concentrated in metropolitan municipalities, especially in Rio de Janeiro and São Paulo (Ministério das Cidades, 2018). Such indicators are related to situations that can be characterized as social exclusion:

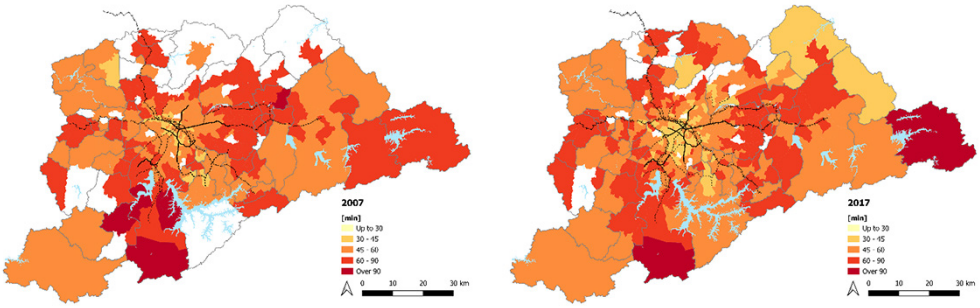
> And this is because excessive travel times can prevent users from commuting (especially those with time restrictions) and thus from engaging in activities. These numbers can also indicate unavailability or precariousness of transport options, as well as insufficiency of connections and time limitations of transport services. Also, lack of activities nearby or inadequate urban design for access to public transport and the promotion of active transport. (Lima and Portugal, 2019, s.p.)

The average travel time in 2017 for SPMR was 34 minutes, less than in 2007, which was 39 minutes. This drop was bigger for the average travel time of active modes (Metrô, 2019, p. 57). Both in 2007 and 2017, the population with the lowest family income had the longest travel times. Since travel times in public transport are much higher than those in individual motorized modes, travel time maps illustrate each mode (Figures 12 and 13).

Regarding collective modes (Figure 12), it is noteworthy to mention that average travel times are longer than 30 minutes, with zones that exceed 1h30min. The shortest travel times by public transport in the capital (between 30 and 45 minutes) are concentrated in the southwest quadrant, near Metrô and Train lines; and in SPMR on the axis São Caetano do Sul-São Bernardo do Campo and in part of Guarulhos and Mairiporã, in addition to Guararema, Santa Isabel and Arujá, to the northeast. However, the longest average travel times by public transport (over 1 hour) are concentrated in the east of the capital and in its neighbors: Ferraz de Vasconcelos, Itaquaquecetuba, Suzano, Mauá, and southeast of Guarulhos; in the extreme south and southwest of the capital and in its neighbors: Embu-Guaçu, Itapecerica da Serra, Embu das Artes and Taboão da Serra; in the north of the capital, Tremembé, Cachoeirinha, Brasilândia, Pirituba, Jaraguá and neighboring Caieiras, followed by Franco da Rocha and Francisco Morato; in addition to the extreme west of SPMR, where travel times by public transport are also high in Carapicuíba, Barueri, Itapevi, Vargem Grande and Cotia. Most of these zones with the longest average travel times were already like this in 2007.

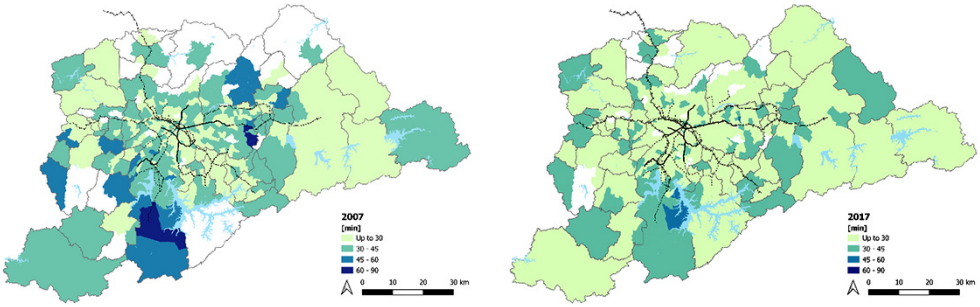
With regard to individual motorized modes (Figure 13), most zones record average travel times of less than 30 minutes. In 2017, there were no zones with an average time over 1 hour, and rare exceptions are between 45 minutes and 1 hour. Thus, the average travel time by individual motorized transport generally does not exceed 45 minutes. Between 2007 and 2017, there was a reduction of the average in areas with travel times above 45 minutes for individual motorized transport, and many of the areas with an average time between 30 and 45 minutes reduced it to a maximum of 30 minutes.

Figura 12 – Average Travel Time in collective modes in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Figura 13 – Average Travel Time in individual motorized modes in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Zones with the highest average travel times by public transport generally match those that concentrate the lowest strata of family income and job concentration. Densely populated zones are included (mainly in the capital), but less dense areas too.

Motorization rate

The motorization rate corresponds to the number of vehicles in relation to the population. In the 2000s and 2010s, there was a significant increase in the fleet of motor vehicles in Brazil,[26] as well as in the car motorization rate, especially in the largest cities and metropolitan regions; motorcycles increased more significantly in smaller cities and metropolitan outskirts (Observatório das Metrópoles, 2019).[27]

According to data from the OD survey, the fleet of private cars increased by 22.8% in SPMR between 2007 and 2017, which triples the growth in population. And the motorization rate grew 15% during the period reaching 212 car/1000 ppl (Metrô, 2019, p. 29). The motorcycle fleet increased by 26.06%, and the motorcycle motorization rate grew by 18.27%, reaching 27 mc/1000 ppl.[28]

In 2017, as shown in Figure 14, the car motorization rates are higher in the capital (over 350 car/1000 ppl) in the southwest quadrant, including in areas well served by high-capacity public transport (metro and train), corresponding to areas where the highest income population concentrates. Outside the capital, the areas with the highest motorization rates are in Itapevi, Barueri, Cotia, Jandira, and Osasco (to the west); and in São Bernardo do Campo and Santo André (in the ABCD).

In 2007, the areas with the highest car motorization rates (over 350 car/1000 ppl) were restricted to the southwest quadrant of the capital, and to Jandira, Itapevi, Santo André, and Guarulhos in SPMR. The increase in the motorization rate between 2007 and 2017 was widespread throughout the metropolitan area, especially in peripheral areas and distant from downtown.

In 2017, the lowest car motorization rates (up to 150 car/1000 ppl) in the capital are in the central region: Sé, República, Bom Retiro, and Pari; in the north region: Brasilândia and Tremembé; in the extreme east: Itaim Paulista, Lajeado, Cidade Tiradentes, and Iguatemi, as well as areas in the extreme south: Grajaú, Parelheiros, Cidade Dutra, and Jardim Ângela. In the metropolitan area, the lowest rates are concentrated in the east: Mogi das Cruzes, Santa Isabel, Itaquaquecetuba, Suzano, and Poá. There is also a reduction in the car motorization rate in areas along medium and high-capacity public transport routes, but not exclusively.

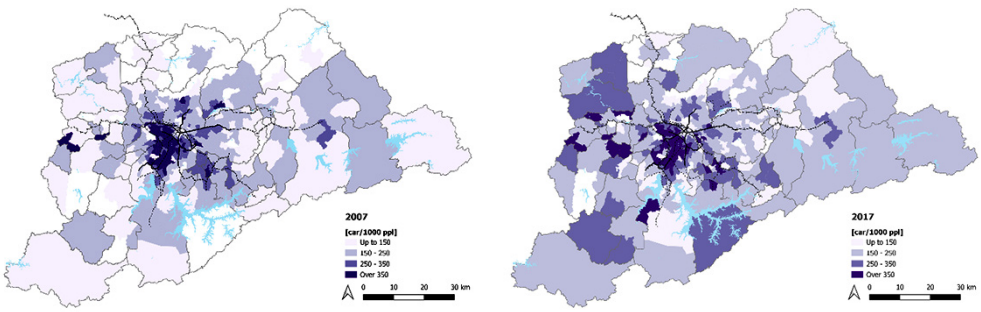
As shown in Figure 15, in 2017 the motorcycle motorization rate in the capital is higher (over 60 mc/1000 ppl) in areas scattered in the south and southwest sectors, including areas well served by high-capacity public transport (subway and train). Outside the capital, the places with the highest motorcycle motorization rates are in Santa Isabel, Mairiporã, Cajamar, Barueri, Embu das Artes, Itapecerica da Serra, Diadema, São Bernardo do Campo, and Santo André.

The zones with the highest motorcycle motorization rates in 2007 (over 60 mc/1000 ppl) were restricted to Água Funda (south of the capital) and part of Itapevi, and Jandira in SPMR. The growth of the motorcycle

motorization rate between 2007 and 2017, expanded across the central and peripheral areas of metropolitan space.

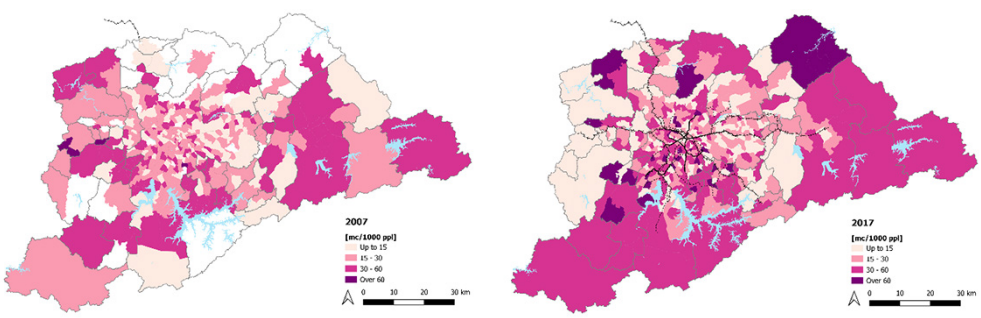
Finally, the lowest motorcycle motorization rates (up to 15 mc/1000 ppl) in 2017, are in the capital's east and extreme north; whereas in the metropolitan area they concentrate to the west in Pirapora do Bom Jesus, Santana do Parnaíba, Itapevi, Vargem Grande Paulista, Cotia, and part of Osasco, as well as in sectors to the east in Guarulhos, Arujá, Itaquaquecetuba, Suzano, and Ribeirão Pires. In these sectors, there was a reduction in the motorcycle motorization rate.

Figure 14 – Car Motorization Rate in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Figure 15 – Motorcycle Motorization Rate in 2007 & 2017 in SPMR



Source: prepared by the authors, based on data from the OD Metrô Survey.

Conclusions

The Metrô-SP report for the publication of São Paulo's Metropolitan Region 2017 Origin--Destination survey results (Metrô, 2019) informs that the total number of trips grew more than population and employment. Compared to the results of the 2007 survey, the increase was 10.3% in daily trips, 6.6% in population, and 3.3% in employment. As for the average population density in SPMR, the report states that the rate went from 25 ppl/ha in 2007 to 26 ppl/ha in 2017; the average family income in 2017 is 11.5% less than the average in 2007; the mobility index raised from 1.95 in 2007 to 2.02 trips/ppl in 2017; the portion of the population that did not perform any trips (immobility indicator) reduced from 31.7% to 29.9%; trips by motorized modes grew by 12.4% and trips by active modes by 6.2%; individual motorized trips raised by 15% and by public transport 10%; average travel time in 2017 is 34 minutes, whereas it was of 39 in 2007; the motorization rate of the period grew by 15% with an average of 212 car/1000 ppl.

OD surveys of SPMR provide multiple analysis possibilities. This article chose to disaggregate and synthesize indicators by OD zone to show their differences in the metropolitan area. Identifying what changed or did not change during the interval of the last two surveys, and crossing this information, revealed how mobility indicators articulate with population distribution by demographic density, income stratum, and workplace. It is an exploratory analysis that facilitates the observation of differences in the metropolis' urban mobility conditions but with no intention of explaining the observed commuting patterns at the moment.

By comparing and superimposing the set of indicators presented, it is possible to weave a synthesis of this analysis into some conclusions that won't certainly exhaust the matter. The identified growth in trips by individual motorized mode is related to the motorization rate increase, which is visible even in areas well served by medium and high-capacity public transport. Despite the general reduction in average travel time, there is a vast difference between collective and individual modes and among SPMR zones. These differences are of the order of 3 to 4 times. Another noteworthy aspect is that the immobility indicator shows scattered growth in the metropolitan region when observed by OD zone, despite the reduction of its average in SPMR.

It was verified that typically, zones with the highest concentration of high-income population have medium to high population density and are near areas with high job density, where medium and high-capacity transport routes are also concentrated. These zones have the highest mobility rates (trips/ppl/day), over 2.5, low immobility rates, growth in trips by collective modes, and the shortest travel times, whether by public transport or individual motorized transport, as well as high motorization rates.

The east side of the capital, Jd. Ângela (in the south), and Brasilândia (in the north) all have high population density rates, low-income families concentration, and low job density. These areas are not served by the Metrô and are only partially served by trains and bus corridors. Their mobility rates are low (between 1.5 and 2 trips/ppl) and their

immobility rates are high (over 35% in some areas). Their travel times by public transport exceed 1 hour, and travel by individual modes grew in these areas despite not having the highest car motorization rates, which increased during the period of analysis, especially in the east side.

Along the Metrô lines predominate high employment and demographic densities, especially downtown at the junction of the 4 lines. In these areas, the rates of low-income families (Stratum 1) do not reach 20%, with exceptions for parts of Line 1-Blue to the north, Line 3-Red to the east, and Line 5-Lilac in the extreme southwest of the capital. The zones along the Metrô lines have high mobility rates and low immobility. Between 2007 and 2017, these zones experienced significant growth in trips by collective modes and by motorized individual transport in some areas. Their travel times for collective modes are between 30 and 60 minutes and for individual motorized transport, the average does not exceed 30 minutes. Some of these areas have high motorization rates.

Thus, the analysis shows that despite the positive results in terms of mobility indicators for the whole SPMR (reduction of travel time, mobility rate growth, and reduction of immobility), these reveal the existing intra-urban inequalities in the metropolis and their impact on population's quality of life if analyzed by OD zone. For other periods, these aspects were addressed by Villaça and Zioni (2005), Silva (2014), and Sardinha Neto (2012), among other authors.

Finally, trips within São Paulo's Metropolitan Region are associated with broader economic and social processes, as well as intra-urban dynamics like real estate, land use and occupation, and infrastructure availability, among others, all of which can be explored using the indicators presented here.

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Notes

(1) According to data from Fundação Seade for 2021, available at: https://www.seade.gov.br.

(2) All citations are free adaptations from Portuguese originals made by the authors.

(3) Between 2007 and 2017, the Metro network increased its length by 28.4 km and that of the CPTM (trains) by 16.4 km, with the inauguration of 27 stations (Metrô, 2019, p. 12).

(4) Urban mobility indicators are an important analysis and planning tool for urban public policies. Of note, for example, are those for monitoring and evaluating the effectiveness of the Urban Mobility National Policy and those for monitoring the Sustainable Development Goals 11.

(5) Available at: https://transparencia.metrosp.com.br/dataset/pesquisa-origem-e-destino.

(6) For example, the indicators of commuting time from home to work and ownership of private vehicles were collected by the PNAD/IBGE until 2015; the number of trips, mobility index, and modal split are estimated annually for all Brazilian cities by the ANTP; the Urban Mobility National Policy uses indicators of average travel time, modal split, among others; the Urban Mobility Plan of São Paulo's City uses modal split, average travel time by mode, and mobility index, among others indicators.

(7) Some commonly used urban mobility indicators, such as accident rates or travel costs, were not used because they are not part of the information provided by the OD survey.

(8) Indicators such as modal split are difficult to visualize on a map at the scale and disaggregation used in this article.

(9) All formulas are compatible with the Metrô database and therefore were maintained as in the original.

(10) *A priori*, it is considered that the higher the urban mobility index, the better. However, as the indicator increases, especially above 2, the improvement depends on the modal split. The increase in travel, predominantly in cars and motorcycles, for example, has negative consequences, such as congestion, pollution and increased travel time (Ipea, 2011).

(11) An adjustment in the OD Metrô Survey database was made to calculate the car motorization rate. In the section called “household conveniences”, 1 car was assigned to all households in which at least 1 family member with an "Auto driver" trip was found, and whose family refused to declare ownership of the car. This, in addition to the total number of cars declared by household in the survey.

(12) All maps are based on the data of the Metrô OD 2007 and 2017 surveys. Transport systems are based on data from the Mobilidados platform of the ITDP (https://mobilidados.org.br/) and from the Geosampa site of São Paulo City (http://geosampa.prefeitura.sp.gov.br/PaginasPublicas/_SBC.aspx).

(13) Medium and high-capacity transport systems (metro, train, and bus corridors) depicted according to the ITDP Mobilidados platform.

(14) The expansion factors can be understood as weights that, applied to the sample, complete the universe.

(15) Travel is defined as “movement of one person, for a single purpose, from one point to a second point (origin and destination), using one or more transportation modes” (Metrô, 2019, p. 22).

(16) The hierarchy in descending order is: 1. Subway; 2. Train; 3. Bus; 4. Chartered transport; 5. School transport; 6. Taxi; 7. Auto Driver; 8. Auto passenger; 9. Motorcycle; 10. Bicycle; 11. Others; 12. On foot (Metrô, 2019, p. 22).

(17) The publication “Informes Urbanos” of the Department of Urban Development of São Paulo City, for example, presents in its numbers 40, 42, 43, and 44 some analyses based on the OD Metrô survey focusing on the trips of the elderly, women, and by bicycle. Available at: https://www.prefeitura.sp.gov.br/cidade/secretarias/licenciamento/desenvolvimento_urbano/dados_estatisticos/informes_urbanos/?page=1.

(18) Due to the cancellation of the last census, scheduled for 2020, which would make it possible to analyze the recent characteristics of the spatial distribution of the population in the metropolis, interpretations made using the OD survey gain relevance, despite the enormous methodological differences compared to the census.

(19) Stratum 1 is equivalent to 2 minimum wages during the analysis period.

(20) This article was written during the Covid-19 pandemic when part of the commuters represented in the maps analyzed here were forced into remote work. This change in the pattern of travel is not reflected in these figures since it is not yet possible to assess the extent to which such habits will be imposed in the coming years.

(21) By way of comparison, the urban mobility index in Barcelona in 2006 was 3.3 trips/day/person, with a predominance of active mode (45% of trips), followed by public transport (32%) and individual transport (23%) (Marquet Sardá e Miralles Guasch, 2017).

(22) According to the Report “Characterization of Population Immobility” (Metrô, n. d.)

(23) The term “active” is used by the authors instead of “non-motorized”, used by Metrô.

(24) The differentiation between collective and individual motorized vehicles takes under consideration the objective of prioritizing collective transport, as part of the Urban Mobility National Policy, the Sustainable Development Goals, and concerns related to climate change.

(25) Cases with variations of less than 5%, positive or negative, were considered as “low variation”.

(26) The rise of the motorization rate is related to the macroeconomic context of the 2000s: stability, increase in income, financial access, and affordable prices (in the case of motorcycles), but also, after the 2008 international financial crisis, due to the exemption policy that reduced the Tax on Industrialized Products (IPI) on automobiles.

(27) The report by the Observatório das Metrópoles uses data from Denatran (Brazilian National Traffic Department) to calculate the vehicle fleet.

(28) It is important to remember cars and motorcycles' negative impact on cities through congestion, air and noise pollution, accidents, and consumption of space, including parking space (Vasconcellos, 2006).

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