ACCESSIBILITY TO JOB OPPORTUNITIES IN RIO DE JANEIRO BASED ON THE SPATIAL ANALYSIS OF THE BRT SYSTEM

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Accessibility to job opportunities in rio de janeiro based on the spatial analysis of the brt system

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ABSTRACT

Socio-spatial inequality is a core concern in Geography. Understanding the relationship between place of residence and job availability – through accessibility analysis – is a geographical issue of paramount importance for urban planning. This study examines job accessibility via the BRT system in the city of Rio de Janeiro, considering travel-time windows (30, 60, 90, and 120 minutes) and socioeconomic variables (income and race/ethnicity). Employing business registry data to map firms, census tract data from the 2010 Census, and route simulations in a GIS environment using GTFS data, we computed cumulative job accessibility for residents located within a 15-minute walk of BRT stations. The results reveal a strong correlation between average income and accessibility in shorter time windows (30 minutes), with higher access levels observed in subcenters such as Madureira and Barra da Tijuca. Although coverage expands in longer time windows (60–120 minutes), persistent inequalities remain: peripheral tracts (e.g., Santa Cruz, Campo Grande), which have lower-income populations, continue to exhibit poorer access even during extended commutes. This analysis highlights socio-spatial inequities, exacerbated by the uneven distribution of opportunities and the prioritization of central corridors in the BRT network. We conclude that transport policies must explicitly integrate equity considerations—

by expanding peripheral connections and accounting for temporal and socioeconomic dimensions—to mitigate urban segregation.

Keywords: Accessibility; Public Transit; Brt System; Socio-Spatial Inequality; Urban Analytics.

Introduction

While not yet among the most prominent themes in studies shedding light on urban space, studies of public transit accessibility often reveal important patterns regarding how different population groups access key locations in daily urban life. Facilitated spatial access to retail, services, healthcare, leisure, education, and job has the potential to yield gains in quality of life.

The urbanization process, especially in semi-peripheral countries, led to rapid urban growth starting in the mid-20th century. This surge in city populations bolstered a growing labor reserve for a Brazil undergoing intensifying industrialization, primarily in metropolitan regions. This labor reserve, which maintained low wages, coupled with real estate speculation in central areas, resulted in a housing deficit for this mass of urban workers. This process pushed them toward peripheral areas of the cities, which often lack urban services and infrastructure.

Within this context of urban socio-spatial segregation, difficulties in daily access to work erode the quality of life for the population with the least access to public mass transit – which is already degraded by incipient and/or non-existent public policies for the sector. This occurs, among other reasons, due to policies incentivizing individual transportation, which was also a significant factor in the internal (re)organization process of cities (CARDOSO, 2007). Regarding this, Cardoso (2007) notes that these policies were leveraged by a discourse surrounding the democratization of circulation space and, therefore, the improvement of accessibility in rapidly expanding cities. However, what has been – and still is – observed, according to the author, is a distribution of inequities in access to points of interest within the urban space, leading to a circulation structure that maintains privileges to this day. These privileges are observed both regarding individual transportation and the social strata that can afford its costs, to the detriment of the most vulnerable segments of society.

The processes described above have also shaped the spatial structure of Rio de Janeiro and continue to influence its urban development. One of the most urbanized cities in Brazil, it has, according to the IBGE (2022), 6,211,223 inhabitants (compared to 6,320,446 in 2010) distributed across a territory of 1,200 km², representing the 18th highest population density in the country. Considering these data, added to the history of spatial segregation experienced by the most vulnerable population, investigations into accessibility to job opportunities become necessary. It is important to clarify that the IBGE has not yet released the values for the variables used in this study aggregated by census tracts from the 2022 Census. Thus, the alternative chosen was to work with the results of the 2010 Census.

In this sense, this article aims to analyze the accessibility to job opportunities for residents located within a 15-minute walk of the stations of Rio de Janeiro's BRT (Bus Rapid Transit) system. Since only firms that are also within a 15-minute walk of the stations will be considered here, only the BRT system and walking were considered, in addition to walking. In this context, this work takes into account only population figures referring to the census tracts that meet the aforementioned criterion; thus, it concerns 1,276,948 inhabitants in 2010, which corresponds to 20.2% of the total population of the municipality in that year.

A public transportation mode such as the BRT seeks to provide greater speed and efficiency in moving through the city, given that articulated buses (which have a higher capacity than regular buses) circulate in dedicated lanes, accessible only to them and, occasionally, official vehicles. Another important characteristic of the system, which also promises greater speed, is that fare payment occurs upon entering the station and not inside the articulated buses, allowing for smoother boarding. Venter et al. (2017) state that this mode has been receiving significant attention in several countries; however, management problems in Rio de Janeiro's BRT constantly generated bus circulation issues, resulting in passenger dissatisfaction (G1 Rio, 2022).

Although every mode has advantages and disadvantages, whether in implementation or operation, it is important to note the evaluation of the BRT system, regarding its service to the diverse groups of the population of Rio de Janeiro, is pertinent. This is because a public mass transit mode should always contribute to facilitating movement within the city. Therefore, attention should focus not only on the continuous evaluation of the cost–benefit of accessibility provided by the existing system, but also on new investments aimed at promoting greater socio-spatial equity

(Ciommo & Shiftan, 2017; Lucas, 2012). Figure 1 shows the distribution of census tracts within 15 minutes of the stations, corridors, and stations in the city of Rio de Janeiro.

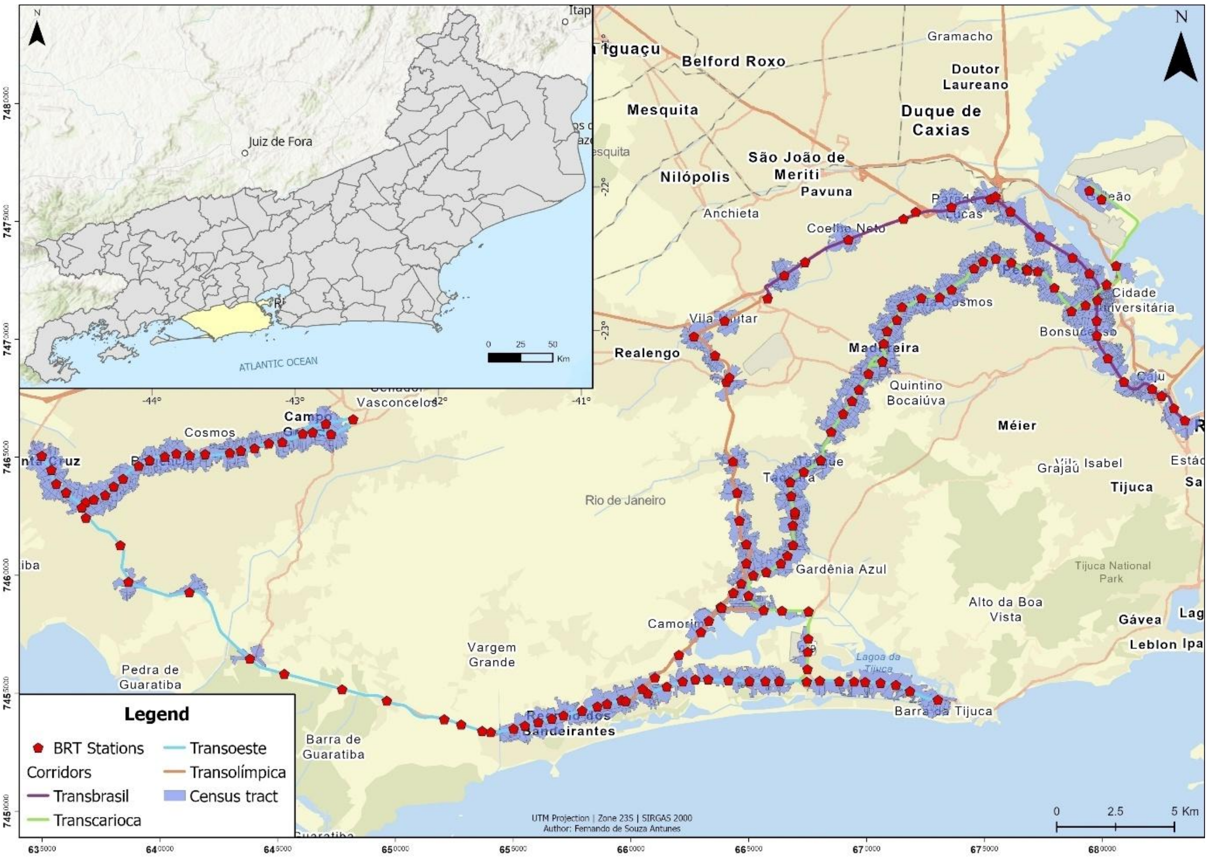

Figure 1 - Presentation of the study area and the BRT system. Source: elaborated by the author.

Rio de Janeiro's BRT system has a total length of 157 km, combining all corridors (Trans carioca, Transolímpica, Transoeste, and Transbrasil). It features a total of 157 stations and 31 lines, with both express and local services.

In addition to this introductory section, the theoretical foundations that support the analysis and discussion of the results will be addressed. All data used will also be presented, detailing the correction and adaptation methods necessary for processing in a Geographic Information System (GIS). Subsequently, the results will be presented and discussed, followed by the final considerations at the end of this text.

THEORETICAL REVIEW

Emphasis should be given in this work to the discussion on the concept of accessibility and some of its details, as well as its differentiation from the concept of mobility. According to Ulysséa Neto and Silva (2004), literature frequently confuses mobility and accessibility by prioritizing only the ease of movement. Accessibility requires considering the attraction potential of destinations, avoiding treating the concept as an exclusive attribute of the transportation system.

It is understood that mobility is directly related to the capacity or ease of movement between an origin and a destination; it is, therefore, an attribute that responds to the characteristics of a transportation system. These characteristics notably include: travel speed, the frequency of the mode at stops/stations, fare cost, and physical barriers (topography or, as has been very common in the city of Rio de Janeiro, barricades installed by organized crime). Commonly, mobility measures focus on travel time or distance as impedance – that is, the capacity for movement used as a measure to evaluate this mobility.

Accessibility, for its part, is a measure that also adopts the idea of the capacity or ease of movement, as well as using time, distance, or other travel properties as impedance. However, what differentiates this measure from the former is the attraction potential of opportunities at the destination: services in general, commerce, educational or health institutions, leisure, and, in this case, jobs. An accessibility measure directly addresses how many opportunities will be reached within a certain impedance (travel time and/or distance, financial cost of the trip, etc.). In this context, when the focus is on impedance, it is understood that there is a reduction in the possibilities for analysis and discussion regarding movements – especially intra-urban ones – since people move motivated to reach an opportunity that is important to them. In short, what Ulysséa Neto and Silva (2004) point out is that accessibility is more than reaching a destination quickly; it is the result of traveling to locations that truly matter to the population or segments of it.

This work approaches accessibility as an index reflected by each of the origins of the movements: census tracts. In this way, accessibility to job opportunities refers to the population's places of residence and how many jobs can be reached within certain time windows, with regular departures from the origin. The aim was to relate the accessibility index values for jobs to the socio-economic variables of the 2010 Census.

More specifically, following the example of previous research (FAN et al., 2012; MANAUGH AND EL-GENEIDY, 2012; GOLUB AND MARTENS, 2014; BOISJOLY AND EL-GENEIDY, 2017; PEREIRA, 2019), the decision was made to use the cumulative accessibility index. This measure is one of the most direct ways to quantify the accessibility of a location (as the origin of the trip) to opportunities, whatever they may be, at a given travel cost (time window or distance). In the case of this work, cumulative accessibility sums all opportunities reached within the travel time window between origin and destination, in all accepted modes. The travel time windows used here are 30, 60, 90, and 120 minutes. The choice of these travel times followed Pereira (2019), mainly due to the data collected by the author, who argues that 46% of the Carioca population has a travel time exceeding the average of 57 minutes and 20% spend at least 90 minutes traveling from one point of the city to another. In this sense, it is clear that time windows varying by 30 minutes make sense in this analysis. Equation 1 refers to the cumulative accessibility index:

$$\mathrm{A}_{o,sc,t} = median\left(\sum_{o=1}^{n} P_d\, f(t_{odr})\right) \qquad f(t_{odr}) = \begin{cases} 1, \text{if } t_{odr} \leq \mathrm{T} \\ 0, \text{if } t_{odr} > \mathrm{T} \end{cases} \tag{1}$$

Where A_(o,sc,t) is the accessibility in the census tract of origin, at departure time t; P_d is the quantity of jobs at the destination, which, in the case of this article, will always be 1, since we consider that every company will have one and only one job opportunity; todr is the travel time from the centroid of the census tract to the destination station, in minutes; and f(t_odr) is a function that varies between 0 and 1, depending on whether the travel interval between origin and destination is less than or equal to, or greater than, the time window T (30, 60, 90, and 120 minutes) – if less than or equal, the value is 1; if greater, the value is 0. The final value verified when using the formula refers to the total quantity of job opportunities within the time window used. For example, one of the analyzed census tracts presents a cumulative accessibility index of 34,899 in 30 minutes. This means that, from the location of said tract, it is possible to access this quantity of jobs within the travel time in question.

Boisjoly and El-Geneidy (2017) point out that some limitations must be considered when using the cumulative accessibility index. According to the authors, these limitations refer, above all, to (i) discontinuity in the time window: opportunities just above the time window are not included in the calculation, even if a few seconds or minutes could be tolerated by an average person; (ii) disregard for the distance of opportunities: all opportunities are treated the same way, even though some are very close to the origin and others take nearly the threshold time to be reached, all will have the same weight at the time of calculation, which leads to the third limitation; (iii) some people have different tolerances to travel, whether by travel time or distance (including walking), which is also not considered by the cumulative accessibility index.Since the impedance of the accessibility analysis in this study is based on time, some considerations must be made. Cheng and Adepeju (2014) refer to the discussion on the modifiable temporal unit problem (MTUP), which can be considered the temporal counterpart of the modifiable areal unit problem (MAUP). The MAUP is a question commonly found in the literature as a point of attention, unlike the MTUP, since geographical analyses that have time as the main factor are not as common. Fernandes (2009) already drew attention to limitations in the use of different geographic units of analysis, which fall within the scope of MAUP's points of attention: how to relate socioeconomic data, aggregated in census tracts, and geomorphological data, aggregated for river basins, even though these two types of data are intrinsically related in analyses of landslide or forest fire risks, for example.

Specifically regarding MTUP, the aim is to draw attention to the fact that the results of any spatio-temporal analysis may vary as the ways of aggregating and segmenting the temporal units of the data are altered. Regarding this, Cheng and Adepeju (2014) provide details on the aforementioned points. When data collected at fine time intervals, such as seconds, minutes, or hours, are aggregated into larger intervals, such as weeks and months, it is necessary to understand that, beyond the loss of short-term variation, some basic but relevant statistics, such as mean, variance, and correlation, also change. This occurs because the number of intervals decreases. Furthermore, larger time windows, also a result of this aggregation, can bring to light or hide important clusters of the studied phenomena.

When turning to temporal segmentation, Cheng and Adepeju (2014) explain that, by considering the possibility of various starts for counting equal time intervals, there may be inconsistencies caused by the differences observed at each of the starting points. Data collected over a week starting on Monday may have differences when compared to surveys started on Sunday. As is the case in this work, even if the total period of two and a half hours is taken into account, with 30-minute intervals between departures, starting the routing of displacements between census tracts and firms at 06:30 a.m. certainly brings different results than starting at 07:30 a.m. This happens because traffic intensity is higher at the second time, which can result in considerably lower accessibility for certain origins.

It is important to understand that there is no single correct temporal scale, where investigation results may present themselves differently according to the decisions, almost always arbitrary, in the aggregation or segmentation of this scale. In this context, Fernandes (2009) brings to light the need to evaluate the multiscalarity of spatial phenomena observed from data, considering that structural elements of urban space and their intrinsic processes act simultaneously across various operational scales. Menezes and Coelho Netto (1999) state that this simultaneous action across several operational scales has the potential to influence the relationship of structural elements, the location, pattern, and even the operational scale itself of the spatial phenomenon under investigation. It is supported by this theoretical framework that this work sought to structure its methodology, analyze the obtained results, and discuss them in light of best practices.

MATERIALS AND METHODS

The research that enabled the development of this article involved four well-defined stages, as can be seen in Figure 2: data acquisition, their corrections and adaptations, processing, and, finally, the pertinent analyses.

Regarding the materials used, four different types of data were acquired: (i) the CNPJ (National Registry of Legal Entities) database refers to February 2020 – that is, before the COVID-19 pandemic, which resulted in numerous business closures in the registry; (ii) the street network extracted from the OpenStreetMap database, a collaborative worldwide cartographic database; (iii) the census tract grid and the socioeconomic variables linked to them; (iv) data concerning the city's public transportation in the GTFS (General Transit Feed Specification) format, which is a set of textual data referring to the entire public transportation system, provided by the Rio de Janeiro city government.

The CNPJ includes various registration data related to each active, inactive, or suspended legal entity, or any other registration status: the firm's CNPJ number, address, phone numbers, and, among others, the primary type of activity for which a given company was registered with the Brazilian Federal Revenue Service (RFB). The type of activity is presented as a numerical code, also present in the National Classification of Economic Activities (CNAE). In this way, it is possible to know exactly what the primary type of activity of each legal entity is.

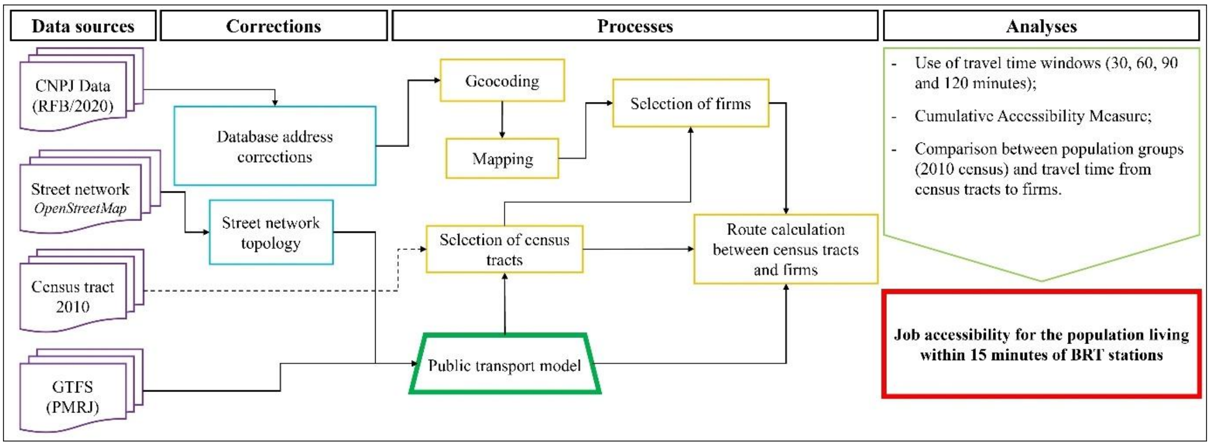

Figure 2 – Data sources and research operational stages. Source: elaborated by the author.

Pereira (2019) used data from the Annual Social Information Report (RAIS), from the Ministry of Labor, to evaluate how and by how much the then-future Transbrasil corridor could increase job accessibility in the city of Rio de Janeiro. Georeferenced data by the exact location of employers are not freely accessible, requiring special authorization from the Federal Government. Since the CNPJ database is open-access and can be downloaded directly from the RFB website, it was decided to use it and consider that, for each company considered, there would be at least the possibility of one job. It is understood that this generalization underestimates the number of jobs and disregards nuances such as wages, required qualifications, and weekly work hours; however, given the impossibility of using RAIS, this alternative was used for the spatialization of formal job locations. Another important decision regarding these data is that Individual Microentrepreneur (MEI) registrations were disregarded, since, as a rule, their registration addresses refer to the residence of the person responsible for the CNPJ. The aim here is to identify types of activities that operate in locations properly intended for that purpose.

The first selection of CNPJ in Rio de Janeiro returned a total of 502,312 active firms in February 2020. They were then geocoded – that is, their addresses were converted into geographic coordinates – and plotted in the ArcGIS Pro® Geographic Information System (GIS). Since the objective of this work is to evaluate job accessibility using exclusively the BRT system, a spatial selection was performed, resulting only in firms located within a 15-minute walk (or 1,000 meters) of the stations. This travel time is considered by authors such as Sevtsuk (2020) to be a reasonable time for walking between origins and destinations.

In order to provide greater accuracy and proximity to reality in the subsequent analysis, the aforementioned spatial selection of firms was based on network distance rather than Euclidean distance. Figure 3 shows the company selection process, where the orange points refer to all types of activity (non-MEI), the red hexagon represents the Taquara station (Transcarioca corridor), and the blue lines represent the routes within a 15-minute walk. It is possible to notice that not all firms are covered by the routes, especially in the peripheral areas of the figure, as they are located more than 15 minutes away on foot from the Taquara station. This second selection resulted in a final total of 102,082 firms.

Figure 3 - Demonstration of the selection of firms located within a 15-minute walk of the BRT stations. Source: elaborated by the author.

The street network, extracted from the OpenStreetMap database, is necessary for creating a public transit travel simulation model built in ArcGIS Pro®. In such a model, the road network serves to anchor the BRT stations and simulate walking routes from the origin point to a station and from the station to a destination point. In this way, it is possible to calculate the 15-minute walking distance and time from each station to the centroids of the census tracts. Figure 3 also shows part of the street network in question. It is important to emphasize that another positive factor of the network used is that each road is represented as a single line, exactly as required by the public transit travel simulation model used.

The census data used in this article, as previously mentioned, are from the 2010 Demographic Census, since, until the finalization of this text, the results of the population census for census tracts, as well as other socioeconomic variables used in this article, had not yet been made available by the Brazilian Institute of Geography and Statistics (IBGE). In this sense, even at the risk of presenting outdated results, this is the possible scenario at the present moment. The spatial selection of the census tracts was carried out using the same process already mentioned: based on 15-minute walking routes (1,000 meters) measured in a network, starting from the stations. The centroid of each census tract was considered.

For each selected census tract, variables of average household income and the number of people according to color (yellow, white, brown, and black) were considered. The analysis was also conducted taking into account the number of Black (negra) people, based on the sum of the number of brown (parda) and black (preta) people. Indigenous people were not considered in this analysis, since, in the entire group of selected census tracts, only five individuals were found, and with this quantity, the analyses would not be representative. The use of census tracts as a geographic unit of analysis is important not only due to the aggregation of quantitative census data, but because it represents, within the urban space, a small area where it is possible to consider a relatively small number of households in each generalization. This allows for considerably detailed results.

Using the ArcGIS Pro® GIS, it was possible to create a public transit travel simulation model that utilizes numerous modes of displacement throughout the study area. Such a model requires a detailed and accurate street network, since it simulates, in detail, the trips on foot and of all public transportation modes under the responsibility of the federative entity that creates the GTFS data – the main data source for creating the model. It is possible to simulate travel between origins and destinations based on numerous pre-configured scenarios: departure and arrival time (planned); walking speed and maximum walking distance; street restrictions due to the absence of sidewalks or any other road structure; crossing only at pedestrian crosswalks and entering stations only through formal accesses (which increases walking distances); etc.

Regarding public transit travel simulations, the model uses the GTFS dataset to identify which lines of each mode are available for each bus stop/station in the system, and the times each vehicle will pass through each of them. The GTFS dataset can be understood from Figure 4, which shows each of the data components of the set and the key fields that establish the relationship between all the data.

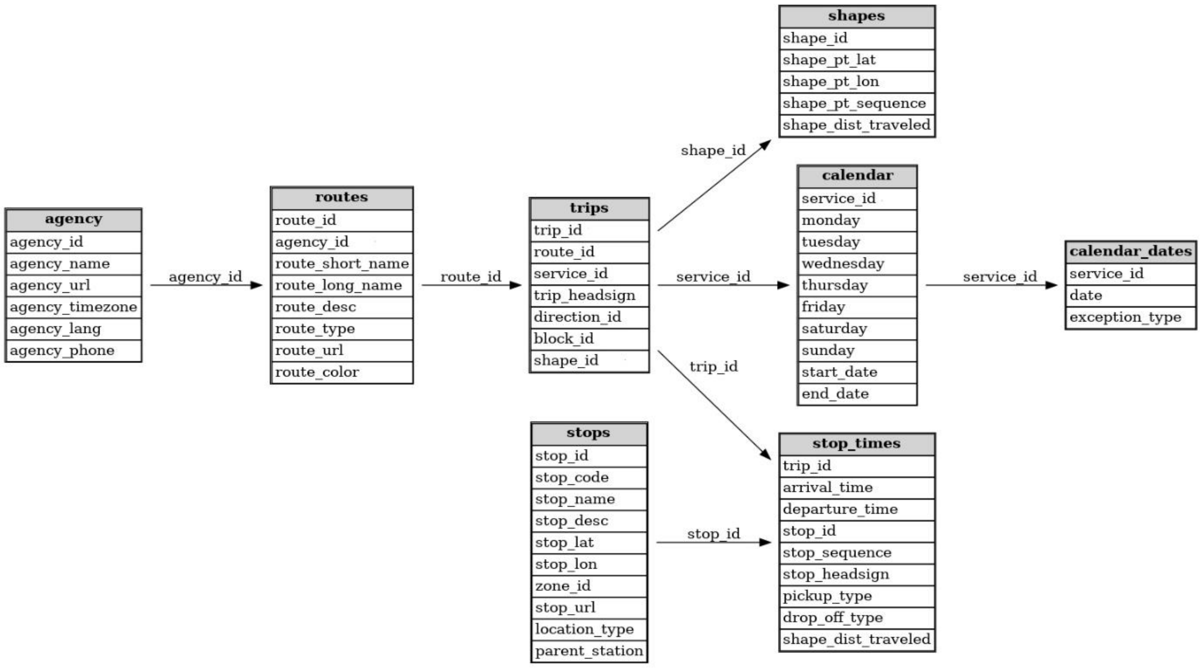

Figure 4 - Structure of the GTFS (General Transit Feed Specification) dataset. Source: elaborated by the author.

Since the entire dataset is interconnected, it is possible for the model to use time as impedance in calculating routes rather than just the distances between origins and destinations. Distance is commonly not the factor that best explains the travel problems faced by the population, especially in large cities such as Rio de Janeiro. Even for short distances, travel time by bus, for example, can vary considerably at different periods of the day and even days of the week due to increased traffic. By considering time as impedance, it is possible to bring the analyses closer to the way people actually plan their daily commutes, therefore providing analyses more aligned with reality.

Based on the objectives of this article, the need to edit the GTFS was identified so that it contained only information regarding the BRT system (stations, schedules, lines, etc.). Thus, the constructed model included only the BRT mode, and all evaluations were conducted as if walking and the mode in question were the only travel possibilities. With the routes calculated between the centroids of the census tracts and the previously selected firms, travel times were stored, taking into account in the simulations the displacements from origin to destination – that is, the walks to the stations, the wait for the scheduled time when the articulated bus will pass the station, its movement to the alighting station, and the walk to the exact location of the company under analysis.

Cumulative accessibility to job opportunities, according to Pereira (2019), calculates the total quantity of jobs accessible to a given origin (in this case, census tracts) within a certain time limit. In an attempt to reduce the effects of arbitrariness in choosing the travel time limit, since this can vary considerably across different parts of the city, Pereira (2019) defined, as previously mentioned, four door-to-door travel time windows: 30, 60, 90, and 120 minutes. As pointed out earlier, the author argues that such time windows are important because, in the city of Rio de Janeiro, 46% of the population has a travel time exceeding the average, which is 57 minutes, and another 20% of the population exceeds 90 minutes. Thus, arbitrarily choosing only a single time limit may not represent the reality of significant portions of the Carioca population.

Still in the search for a simulation closer to reality and following the method proposed by Pereira (2019), it was decided to use varied departure times. Defining only one departure time (07:00 a.m., for example) does not account for the movements of the population, especially those living farther from job opportunities. In this context, six different times were used, with 30-minute intervals between them: 06:30 a.m., 07:00 a.m., 07:30 a.m., 08:00 a.m., 08:30 a.m., and 09:00 a.m. The routes were then calculated, resulting in this time matrix.

Based on the route calculations between all origins and destinations, with all travel times already stored, it was then possible to use Equation 1 for the evaluations that this work addresses.

RESULTS AND DISCUSSION

In this section, the results of the analyses mentioned in the previous section will be presented and discussed. Chart 1 presents the relationships between some variables of the 2010 Demographic Census and the job accessibility intervals for sectors, across the 30, 60, 90, and 120-minute time windows. It is important to remember that the intervals refer to the quantity of jobs reached from the origin; that is, the first interval refers to an accessibility of up to 5,280.5 jobs.

These results, obtained through the use of Equation 1, could be compared with the socioeconomic variables of the 2010 Census because both the job accessibility values and the variable values are associated with census tracts, the geographic unit of analysis of this work. It is important to remember that the census tracts used in this investigation are located within a 15-minute walk of the BRT system stations. For an aggregate comparison, intervals were defined for the job accessibility values using the Natural Breaks method, in order to avoid subjectivity. The 2010 Census variables were compared with the mean value of the accessibility intervals using the Pearson correlation coefficient. Table 1 presents the classification of the Pearson correlation coefficient for a better interpretation of Chart 1. The Pearson correlation coefficient (r) identifies and measures the degree of the dependency relationship between two quantitative variables. The values range from -1 to +1, with the correlation being null when the coefficient is 0. The closer to the extreme values, the stronger the correlation between the variables. A negative coefficient indicates that when one variable increases in value, the other decreases. A positive coefficient indicates that when one variable increases in value, the other also increases.

Value of *r* (+ or -)	**Interpretation**
0	Null
0,01 a 0,20	Very weak
0,21 a 0,40	Weak
0,41 a 0,60	Moderate
0,61 a 0,80	Strong
0,81 a 0,99	Very strong
1	Perfect

Table 1 – Classification of the Pearson correlation coefficient – r (adapted from Lopes, 2018).

Still regarding Chart 1, it is important to pay attention to the different values of the accessibility intervals for each time window, since, as the travel time between origin and destination increases, the job opportunities accessed from the origin also increase. Thus, different accessibility intervals had to be calculated, and for each set of them, the correlation was calculated.

The results regarding the 30-minute time window show the highest correlation coefficients between the intervals and the Census variables, whether positive or negative. This gradient was already expected, since a total travel time of 30 minutes between origin and destination is considerably shorter than the average of 57 minutes that almost half of the Carioca population takes to move through the city (PEREIRA, 2019). In this sense, what is perceived is that few people have this level of accessibility from their immediate neighborhood, even though the mode under investigation has exclusive lanes and, therefore, is less subject to the effects of traffic, which is intensified at certain times of the day.

	Job accessibility interval	Average Income (R$)	No. of white people	No. of black people	No. of white people	No. of brown people	No. of Black people
30 min	1 - 5280,5	R$ 1.232,20	135.457	42.572	2.575	148.879	191.451
	5280,51 - 10366	R$ 1.688,75	141.175	36.318	2.356	105.199	141.517
	10366,1 - 15801	R$ 2.069,56	168.386	34.631	2.556	112.851	147.482
	15801,1 - 21831	R$ 2.423,69	128.619	21.817	1.480	76.633	98.450
	21831,1 - 34899	R$ 3.078,38	73.071	10.490	860	34.212	44.702
	Correlation	0,992	-0,756	-0,985	-0,932	-0,967	-0,975
60 min	1 - 17882,5	R$ 981,20	88.718	28.686	2.033	103.851	132.537
	17882,51 - 33194	R$ 623,42	61.055	20.712	1.070	58.530	79.242
	33194,1 - 43536	R$ 1.458,25	159.187	33.271	2.382	119.398	152.669
	43536,1 - 55437	R$ 4.928,99	267.369	48.612	3.210	147.174	195.786
	55437,1 - 80263	R$ 2.532,66	70.379	14.547	1.132	48.821	63.368
	Correlation	0,571	0,151	-0,167	-0,098	-0,239	-0,223
90 min	1 - 35481	R$ 1.103,53	80.982	26.628	1.849	94.254	120.882
	35481,1 - 61081	R$ 1.373,49	155.695	38.105	2.683	133.837	171.942
	61081,1 - 74497,5	R$ 4.078,43	136.674	14.124	1.443	48.395	62.519
	74497,51 - 86371	R$ 2.159,86	85.636	21.510	1.104	60.625	82.135
	86371,1 - 94976	R$ 1.683,66	187.721	45.461	2.748	140.663	186.124
	Correlation	0,365	0,516	0,188	0,010	0,012	0,053
120 min	1 - 41899,5	R$ 1.245,81	39.273	11.076	798	39.029	50.105
	41899,51 - 68296	R$ 991,53	44.966	16.292	1.134	58.677	74.969
	68296,1 - 86960	R$ 1.780,50	48.633	10.517	846	41.511	52.028
	86960,1 - 94732	R$ 1.630,03	360.692	89.401	5.484	271.080	360.481
	94732,1 - 101980	R$ 3.846,18	153.512	18.600	1.565	67.606	86.206
	Correlation	0,673	0,587	0,418	0,466	0,438	0,433

Chart 1 - Job opportunity accessibility intervals for the selected census tracts and their means for monthly income and race/color variables of residents.

Observing the results of the window of up to 30 minutes in detail, it is easily perceived that the increase in job accessibility is strongly linked to the increase in average income, evidencing a correlation coefficient of 0.992. That is, those with higher incomes enjoy greater job accessibility within a 30-minute commute. People of all colors/races show a strong negative correlation, which shows that, in general, fewer people live in the census tracts where job accessibility is higher. This interpretation serves as further evidence of the strong influence of income as the variable that best explains the level of accessibility in this travel window. Although inequity in job accessibility affects all color/race groups, it impacts more strongly yellow (-0.932), black (preta) (-0.985), brown (parda) (-0.967), and Black (negra) individuals – the group formed by black and brown people (-0.975). In this sense, 62% of people living in census tracts with the highest level of job accessibility within 30 minutes are white, compared to 38% of Black (negra) people. These results show that living close to work opportunities requires a higher income, being even more unequal for certain groups of people. It is in this time window that inequalities appear most evident.

Figure 5 shows the distribution of census tracts located within a 15-minute walk of at least one of the BRT system stations and their classifications regarding job accessibility within a commute of up to 30 minutes, considering walking and BRT times. From Figure 5, it is possible to perceive that the census tracts with the highest accessibility are in areas where retail trade is most active: Madureira, Cascadura, Taquara, and Ramos/Bonsucesso. Beyond these, there are also many tracts classified in the highest accessibility interval in Recreio dos Bandeirantes and, especially, in Barra da Tijuca. In these two neighborhoods, the BRT corridor follows Avenida das Américas – an important thoroughfare in the region – where major shopping centers are located along with numerous retail and service firms, as well as corporate office buildings. In this context, higher-income people living in this region have facilitated accessibility to jobs within a travel window of up to 30 minutes via BRT.

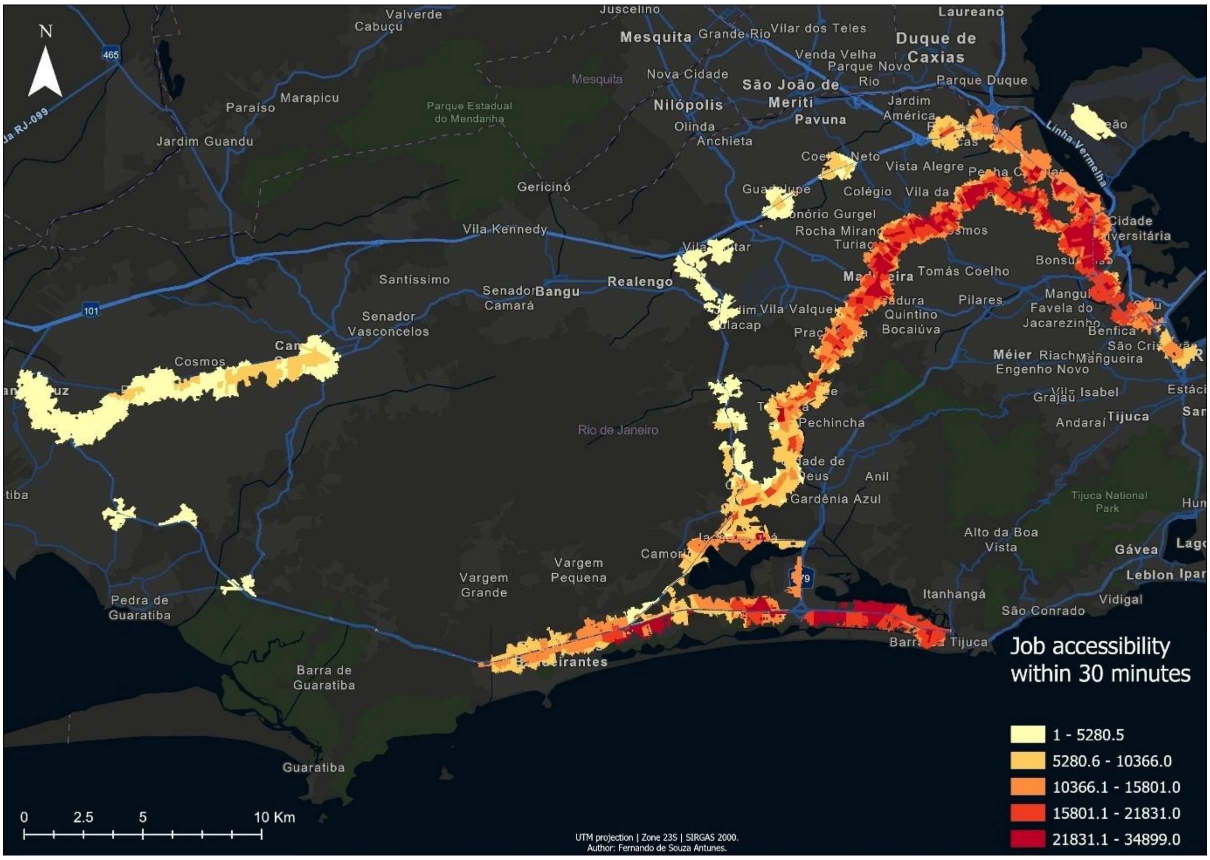

Figure 5 - Distribution map of job accessibility within a 30-minute commute by walking and BRT. Source: elaborated by the author.

When analyzing the accessibility intervals and socioeconomic variables for the 60-minute travel window, a decrease in the correlation coefficient (0.571) is noticeable, yet the correlation remains moderate according to Lopes (2018) classification. This result allows for the inference that the increase in travel time enables people from other income groups to access more job opportunities. As a rule, as previously discussed, lower-income population groups tend to live further from areas with greater job opportunities, as these opportunities tend to cluster in the central area and subcenters. Residential areas close to such centers tend to house higher-income individuals, as they are closer to urban amenities. Furthermore, in this context, the decrease in the correlation coefficient in the time window in question aligns with the average public transit travel time of 57 minutes for the population (46%) of the city of Rio de Janeiro, as reported by Pereira (2019).

Regarding the correlation analyses between accessibility intervals and population groups of different colors/races, a drastic change in the coefficients is noted: all of them increased in relation to the same variables when compared to the 30-minute time window. Even so, the only population group that shows a positive correlation coefficient (although classified as very weak – 0.151) is that of white people.

It is important to remember that positive correlations indicate a growth trend in the dependent variable (white people) when the independent variable (accessibility) also grows. It can be inferred that, with the increase in the time window, accessibility to job opportunities grows, also increasing the number of white people who benefit from this amenity.

For the yellow, black (preta), brown (parda), and Black (negra) population groups (with coefficients of -0.098, -0.167, -0.239, and -0.223, respectively), the correlations remain negative and are all weak or very weak. Even though these are the classifications, it is necessary to draw attention to the fact that they remain negative; that is, even as accessibility to job opportunities grows due to the increased time window, these population groups (especially Black [negra] people) maintain the tendency of not benefiting from these amenities. In other words, doubling the travel time (compared to the previous scenario) does not guarantee a consistent increase in equity of access to job opportunities for this portion of the Carioca population.

Figure 6 shows the distribution of census tracts located within a 15-minute walk of at least one of the BRT system stations, as well as their classifications regarding job accessibility within a commute of up to 60 minutes, considering walking times and travel by articulated bus. Observing the map in Figure 6, it is noticeable that there is a considerable increase in accessibility in the census tracts located in the center of the entire BRT system, notably around the intersection between the Transolímpica and Transcarioca corridors.

It is noted that there was a shift in the areas classified in the final accessibility interval: from the middle of the Transcarioca corridor to its intersection with the Transbrasil corridor, and from the Transoeste corridor, in the surroundings of the Alvorada terminal. Being in the center of the articulated bus corridor network favors travel within this time window, as it is possible to choose a corridor from common stations that serve as integration points between them, or even to quickly reach one of these transfer stations, increasing accessibility within 60 minutes.

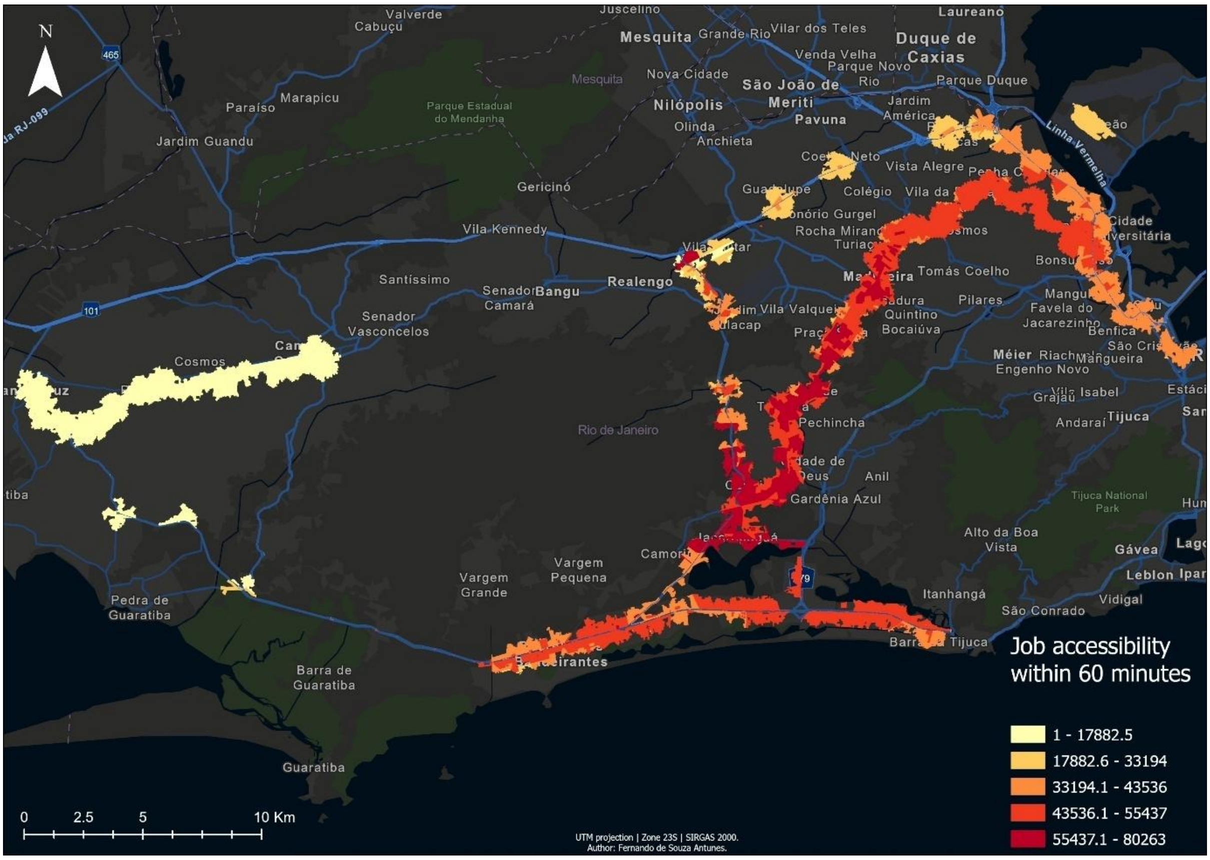

Figure 6 - Distribution map of job accessibility within a 60-minute commute by walking and BRT. Source: elaborated by the author.

Attention must be drawn, however, to the census tracts located at the ends of the Transoeste corridor, in the neighborhoods of Campo Grande and Santa Cruz. These tracts remain classified in the lowest accessibility interval, even taking into account a 60-minute travel time. This observation highlights the spatial inequity of access to job opportunities, as these tracts are located in neighborhoods where the resident population has a lower income.

We now proceed to the observations of the results regarding the travel time window of up to 90 minutes. These results show that trips occurring within this time limit, obviously, allow access to a large number of job opportunities, since the lowest accessibility interval ranges from 1 to over 35,000 firms. It is noted that the correlation coefficient between accessibility and average income brackets is weak (0.365), showing a decrease compared to previous windows. This decrease seems to be linked to the fact that a 90-minute commute favors people living in more distant census tracts (as a rule, lower-average-income tracts) who, therefore, require more time to reach jobs located primarily in the centers or their surroundings, as previously discussed. Even if it is a weak correlation, its existence is pertinent to consider, especially given that the BRT system is intended to be a fast transit mode that is not influenced by general traffic.

When observing the correlation coefficient between the accessibility index and the number of white people, it is noted that it continues to increase (0.516). This result shows that, although there is greater accessibility for more distant census tracts, including those where income is lower, white people continue to predominantly occupy the tracts where accessibility is higher. For the population groups that benefit less from accessibility – yellow, black (preta), brown (parda), and Black (negra) individuals – the correlation coefficients reach positive values, although classified as very weak – or nearly null for three of the four groups (0.010, 0.188, 0.012, and 0.053, respectively). These coefficients show a strong trend of socio-spatial segregation for these groups, as they remain the majority – in absolute terms – in the census tracts with the lowest accessibility indices in the time window in question.

Figure 7 shows the distribution of census tracts located within a 15-minute walk of at least one BRT system station, as well as their classifications regarding job accessibility within a commute of up to 90 minutes, considering walking times and travel by articulated bus. It is possible to note that, comparing it to the map in Figure 6 – which shows the distribution of census tracts and their accessibility indices – the tracts located along the Transolímpica and Transcarioca corridors have established themselves as those with the highest accessibility indices. This result aligns with an important discussion regarding centrality in spatial networks presented by Antunes et al. (2023). The aforementioned corridors are at the center of the network formed by the BRT system's exclusive lanes. Thus, when considering only the mode in question, the surrounding areas have an advantage, depending on the time window considered, as they have more options for lines with itineraries in all directions of the system, providing access to more job opportunities.

Beyond spatial network centrality, it is important to consider that a subcenter such as Madureira is located along the mentioned corridors. In this way, in addition to the gain in accessibility from being more central within the corridor network, these census tracts already benefit from the firms located in Madureira and Taquara, two retail and service hubs. Another important observation to be made from the map in Figure 7 – which also aligns with the considerations of the previous paragraphs – is that the census tracts located at the periphery of the network formed by the BRT corridors, notably those located along the Transbrasil (especially between the neighborhoods of Jardim América and Centro) and Transoeste (Barra da Tijuca, Recreio dos Bandeirantes, Santa Cruz, and Campo Grande) corridors, lose accessibility or maintain low indices with a commute of up to 90 minutes. With the exception of the census tracts in Santa Cruz and Campo Grande, which remained classified within the lowest accessibility index interval, the tracts in the other mentioned neighborhoods were classified in lower intervals than in the previous time windows. That is, for certain time frames, being on the periphery of the network results in lower job accessibility than being at the center.

When observing the results for the 120-minute time window, it is possible to notice a departure from the trend observed in the previous time windows. The accessibility index intervals show a considerably smaller increase than in other windows. Regarding the correlation coefficient between the intervals and average income, there is a significant increase (0.673). This coefficient is nearly twice as high as the coefficient for the immediately preceding time window (0.365). This increase is even more significant when considering that there had been successive drops in the correlation coefficient between these variables since the 30-minute window.

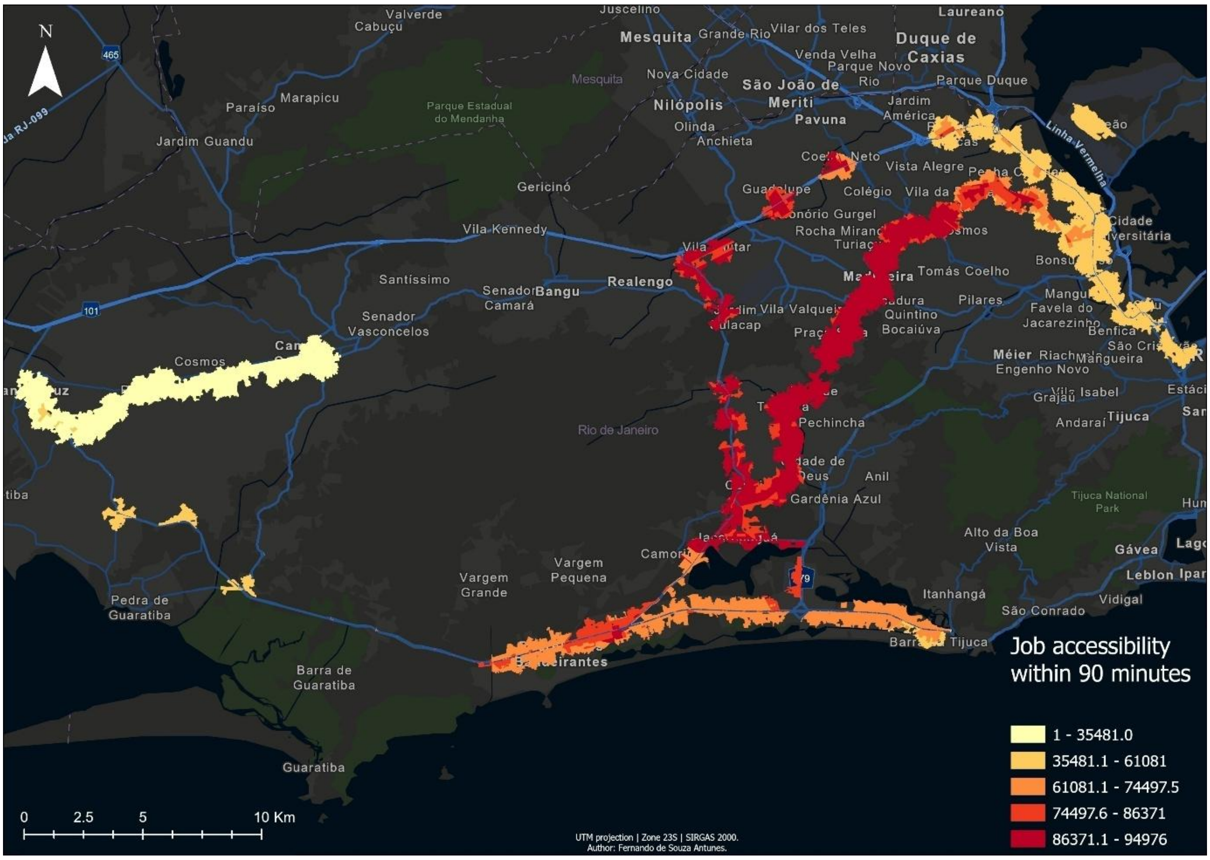

Figure 7 - Distribution map of job accessibility within a 90-minute commute by walking and BRT. Source: elaborated by the author.

Turning attention to the variable itself, a strong correlation is identified between it and the accessibility index intervals (0.673). Thus, it is verified that higher-income groups tend to access more job opportunities more consistently, similar to what occurred in the 30-minute time window, albeit with less intensity. In other words, at both temporal extremes of this analysis, having a higher income considerably favors access to jobs.

When observing the variables related to color/race, an interesting behavior in the correlation coefficients is noted. The coefficient for white people shows a slight positive change, increasing to 0.587. Although it had been trending positively since the 60-minute time window, the growth in this window was much smaller. This result confirms the tendency for white people to be better located in the vicinity of BRT stations.

This understanding is based on the fact that correlations for this group have always trended more strongly toward +1 than the other population groups analyzed.

Although it may seem counter-intuitive, the fact that the correlation between accessibility index intervals and average income rises again can be explained by the fact that, with a travel time of 120 minutes, higher-income people – who benefit from proximity to central areas where most jobs are located – can also reach more distant opportunities.

Regarding the analysis of the correlation coefficient between the accessibility index intervals and the groups of yellow (0.466), black (preta) (0.418), brown (parda) (0.438), and Black (negra) individuals (0.433), a substantial increase is observed – much higher than the increase for white people. In the context of this result, it can be said that for these population groups, there is a greater tendency to access more job opportunities only after a long period of public transit travel. That is, having to spend more time commuting shows that these groups are segregated in areas further away from job opportunities. This socio-spatial segregation is reflected in both income and color/race, with a certain overlap between these two factors.

Figure 8 shows the distribution of census tracts located within a 15-minute walk of at least one of the BRT system stations, as well as their classifications regarding job accessibility within a commute of up to 120 minutes, considering walking times and travel by articulated bus. It can be observed that a large portion of the census tracts that were classified in the highest accessibility indices in the 30-minute time window, and that had lost this classification in subsequent windows, regained it when the travel time reached 120 minutes. Notably, these sectors are located in Barra da Tijuca, Recreio dos Bandeirantes, and Barra Olímpica (a recently created neighborhood formed by portions of the Jacarepaguá, Camorim, and Barra da Tijuca neighborhoods), where income is higher.

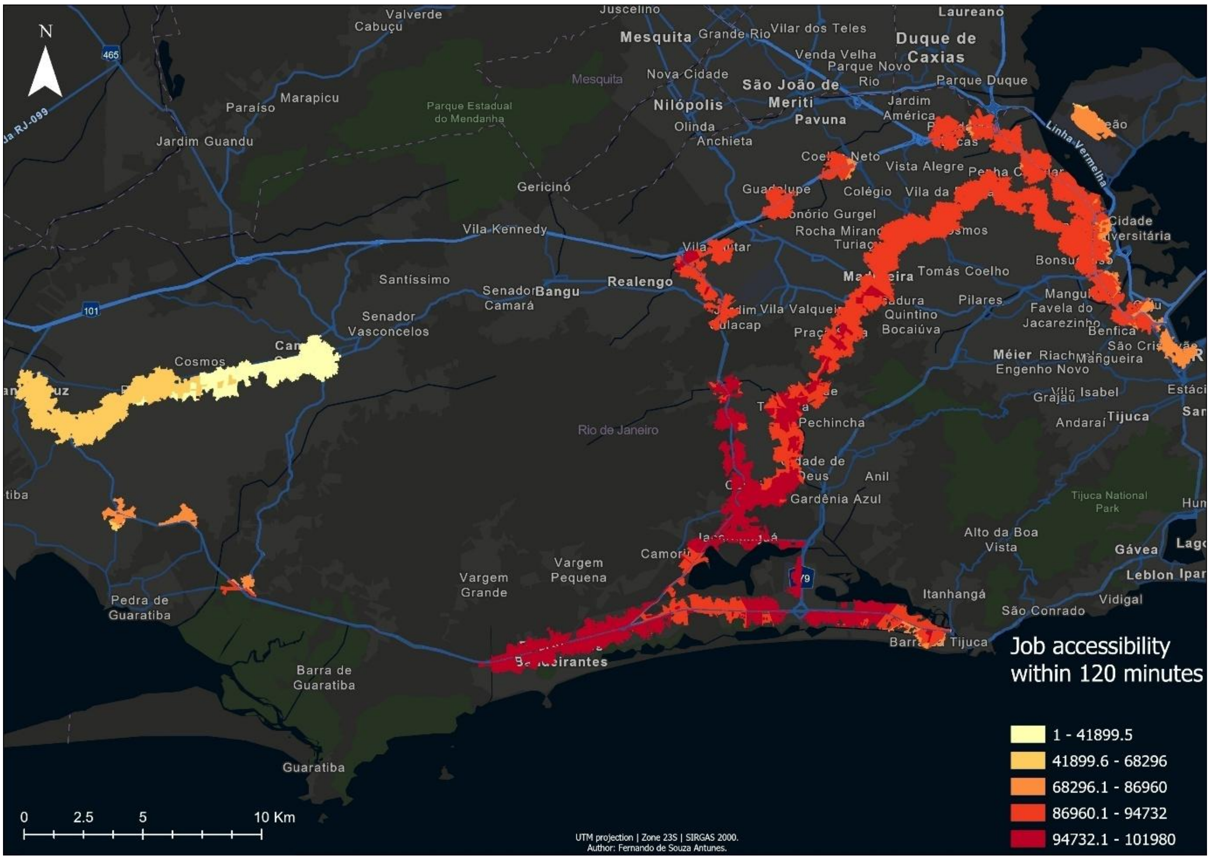

Figure 8 - Distribution map of job accessibility within a 120-minute commute by walking and BRT. Source: elaborated by the author.

The analysis of the map in Figure 8 also highlights that sectors of the Santa Cruz and Campo Grande neighborhoods remain with the lowest job accessibility indices using BRT. Part of the census tracts in these neighborhoods shows some improvement in accessibility, since within this travel time it is possible to reach firms on Avenida das Américas, in Barra da Tijuca, and Avenida Embaixador Abelardo Bueno, in Barra Olímpica. Nevertheless, it remains evident that the population of these areas faces serious displacement problems within the city, which is exacerbated by the poor distribution of job opportunities and continuous investment in road transport. As Cardoso (2007) points out, investment in this type of transport helps intensify traffic congestion, further increasing the travel time required to access important services.

The presentation of the results and their inherent discussions demonstrate that the mobility of the population of Rio presents numerous equity issues. These problems acquire more clearly defined characteristics when considering the average income and the color/race of the population residing within a 15-minute walk of one of the BRT stations.

CONCLUSION

Throughout this study, cumulative accessibility to job opportunities through the BRT system in the city of Rio de Janeiro was investigated, considering travel time windows of 30, 60, 90, and 120 minutes and cross-referencing these results with variables from the 2010 Demographic Census. The results reveal that in the shortest window (30 minutes), areas encompassing subcenters concentrate significant access to job opportunities, while the periphery of the network formed by the BRT corridors appears less connected to job opportunities. On the other hand, in the widest window (120 minutes), although access to jobs increases in all areas near the system, the disparity between higher- and lower-income neighborhoods persists – and even intensifies – confirming the existence of a spatial polarization that links the extremes of travel time to socioeconomic inequalities.

This dual pattern – segregation of part of the network's periphery in the short term and travel overload in the long term – raises important questions of spatial justice. In lower-income census tracts with a high Black (negra) population, the combination of restricted windows and prolonged commutes implies lower availability of job opportunities and higher transport costs (in terms of time). The current structure of the BRT, primarily focused on high-demand axes in central areas and subcenter corridors, reinforces already established privileges, leaving "islands" of low accessibility at the city’s most vulnerable extremes. This result points to the need to rethink not only the physical extension of routes but also their role in ensuring equity in accessibility to all types of opportunities, especially jobs.

The analysis highlighted the relevance of considering the socioeconomic profile of the origins (census tracts) – income and race/color – in interpreting accessibility indices. This speaks directly to the challenges imposed by the MTUP (Modifiable Temporal Unit Problem) and the MAUP (Modifiable Areal Unit Problem): the choices of time windows and spatial units of analysis (census tracts, planning zones) can significantly alter the observed patterns. Thus, the recommendation to test multiple combinations of aggregation and scales is reaffirmed, as is the exploration of the robustness of the results across different configurations.

However, the study presents significant limitations. Using the location of firms based on their CNPJ (National Registry of Legal Entities) as a proxy for at least one job opportunity provides an estimate of formal employment but does not distinguish between salary levels, qualifications, or part-time shifts, as Pereira (2019) successfully did. Nevertheless, due to the difficulty in accessing RAIS (Annual Social Information Report) data, using the CNPJ was the viable alternative for this work. Similarly, relying on 2010 Census data may not reflect the most recent transformations of the Carioca population, particularly following the COVID-19 pandemic. Furthermore, the analysis focused exclusively on the BRT mode without considering integration with the subway, VLT (light rail), conventional buses, or active modes, which may overestimate the relative importance of the BRT and underestimate other travel alternatives.

Finally, it is worth emphasizing that accessibility must be understood as a tool for promoting equity among diverse population groups. The mere physical expansion of transport systems does not guarantee equity if it does not consider how opportunities are distributed and which users benefit from them. In a city marked by deep socio-spatial asymmetries, transport policies must systematically integrate the spatial and temporal dimensions of inequality, promoting planning that is truly oriented toward social justice.

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Author’s Contributions

Antunes, F.S. - The author contributed to the elaboration, realization and manipulation of the data and writing.

Cardoso, C.F. - The author contributed to the realization and manipulation of the data and writing.

Mizuno, S.C.G. - The author contributed to the realization and manipulation of the data and writing.

Fernandes, M.C. - The author contributed to the writing.

Conflict of Interest

The authors declare that there is no conflict of interest.

Research Data Availability

All the data supporting the results of this study were published in the article itself.

Use of AI

No Artificial Intelligence tools were used.

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