

Socio-spatial inequalities in accessibility to jobs in Fortaleza under distinct metrics

As desigualdades socioespaciais na acessibilidade ao trabalho em Fortaleza sob distintas métricas

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ABSTRACT

Representing socio-spatial inequalities in the access to jobs opportunities involves challenges in incorporating the complexity of the land-use and transport subsystems' elements related to this phenomenon. Therefore, the main objective of this paper is to compare representations of this problematic context in Fortaleza using different metrics of accessibility. Such a comparison considered four types of indicators: average travel time to opportunities, cumulative opportunities measure, balancing time and logsum. The four resulting representations were compared in respect to the spatial pattern of accessibility, to the distribution of accessibility levels among individuals, and the average values and their variability by region. The results indicated that three of the four indicators represented similar patterns regarding the analyzed aspects. The balancing time indicator, however, by incorporating competition in its formulation, represented distinct patterns, spatially as well as among individuals and regions.

RESUMO

Representar as desigualdades socioespaciais no acesso às oportunidades de trabalho envolve desafios em incorporar a complexidade dos elementos dos subsistemas de uso do solo e transportes envolvidos nesse fenômeno. Diante disso, o objetivo principal deste artigo é comparar representações dessa problemática em Fortaleza a partir da utilização de diferentes métricas de acessibilidade. Essa comparação foi feita considerando quatro tipos de indicadores: tempo médio de viagem às oportunidades, indicador de oportunidades cumulativas, tempo de equilíbrio emprego-população e logsum. As quatro representações obtidas foram comparadas quanto ao padrão espacial da acessibilidade, à distribuição dos níveis de acessibilidade entre os indivíduos, e aos valores de acessibilidade média e de sua variabilidade por região. Pelos resultados, três dos quatro indicadores apresentaram padrões semelhantes quanto aos aspectos analisados. Já o indicador de tempo de equilíbrio, ao incorporar a competitividade em sua formulação, representou distintos padrões, tanto espacialmente, quanto entre os indivíduos e entre as regiões.



1. INTRODUCTION

The occurrence of socio-spatial inequalities in accessibility to jobs is a phenomenon that strongly affects large Brazilian cities. In common, these cities are characterized by a high concentration of jobs opportunities in their central regions (Pereira *et al.*, 2019), along with a process of urban sprawl. In the case of Fortaleza, the 5th most populated Brazilian metropolis, it has been observed a process of peripheralization by segregation imposed on low-income

individuals, and of decentralization of the high-income population by self-segregation (Andrade *et al.*, 2020; Lima *et al.*, 2021), which contributes to the occurrence of the spatial mismatch phenomenon in the city. This problem has been worsening in the last two decades (Castro, 2019). Another relevant factor for the intensification of these inequalities in Fortaleza are the imbalances in the supply of transportation over the territory.

Because of the multiplicity of elements and relationships involved in this problem, it becomes a complex task to select a single indicator that could adequately characterize inequalities in access to job opportunities, incorporating both the spatial and social dimensions of this phenomenon. A thorough review of the most common accessibility indicators found in the literature (Baradaran and Ramjerdi, 2001; Geurs and van Wee, 2004; Curtis and Scheurer, 2010; Cheng *et al.*, 2013) indicates that each type of measure tends to incorporate only a portion of the elements involved in representing these inequalities, so that, depending on the metric used, different aspects of the same reality can be obtained.

In this context, the main objective of this paper is to compare the representation of socio-spatial inequalities in accessibility to jobs in Fortaleza using different metrics. The paper is structured as follows. Section 2 presents a synthesis of the problem characterization in Fortaleza. Section 3 brings a discussion of the main challenges in measuring such inequalities. The methodological approach for the comparison of the indicators is detailed in Section 4. Section 5 presents the analyses and discussion of the obtained results. Finally, Section 6 presents the main conclusions of the analyses and recommendations for future work.

2. SOCIO-SPATIAL INEQUALITIES IN ACCESSIBILITY TO JOBS IN FORTALEZA

Accessibility can be understood as the ease that individuals have to reach activities using a combination of transportation modes (Geurs and van Wee, 2004). According to these authors, accessibility levels are not the same for everyone, so that different groups of individuals have different restrictions and perceptions about access conditions, thus generating socio-spatial inequalities in accessibility levels. These inequalities are characterized as problems when the most vulnerable groups find themselves with the worst levels of access, being imposed, in an extreme situation, to a condition of social exclusion (van Wee and Geurs, 2011). Household income is one of the main attributes that end up limiting the population's access levels to urban activities (Pereira, 2019). It should be noted that it is not the fact that an individual has a higher income that instantly changes his or her accessibility conditions, but rather the set of opportunities that this condition provides, such as living closer to the activities they wish to perform or acquiring a motor vehicle to move more quickly, for example.

In Fortaleza, income is also a determinant of the levels of accessibility of the population. This is a result of the limitations imposed on locational and travel decisions arising from this attribute. The processes of peripheralization of the low-income population to the West side of the city (Figure 1a), of residential decentralization of the high-income population to the East side (Figure 1b), and of job concentration in the Central region (Figure 1c) reinforce spatial mismatch (Lima *et al.*, 2021), a term used to describe a broad set of geographic barriers that result from a disparity, or incompatibility, between where people live and where their respective employment opportunities are located (McLafferty, 2015).

The spatial mismatch problem, combined with the expansions of the road network on the East side of the city and of the public transportation network on its West side, has reinforced the socio-spatial inequalities in access to job opportunities in Fortaleza (Lima *et al.*, 2021).

These causal relationships are represented in Figure 2. The concentration of jobs in the Central region makes accessibility of those located in this region much higher than of those who live in any of the peripheral regions, regardless of the income group considered, which configures a situation of spatial inequality in access to job opportunities (Andrade *et al.*, 2020). This inequality is intensified by differences in the levels of accessibility among the peripheral regions of the Northern and Southern parts of the city. The Northwest and Northeast regions present a consolidated transportation infrastructure and are closer to the Central region, which provides its population with higher levels of accessibility than those in the Southern part of the city (Andrade *et al.*, 2020). In addition, the process of residential peripheralization, coupled with a strong dependence of the low-income population on the public transportation network, force the most vulnerable groups to reside in areas with the worst levels of accessibility, while the high-income segments are located in the most privileged regions, thus characterizing a situation of inequality between income groups (Lima *et al.*, 2021).

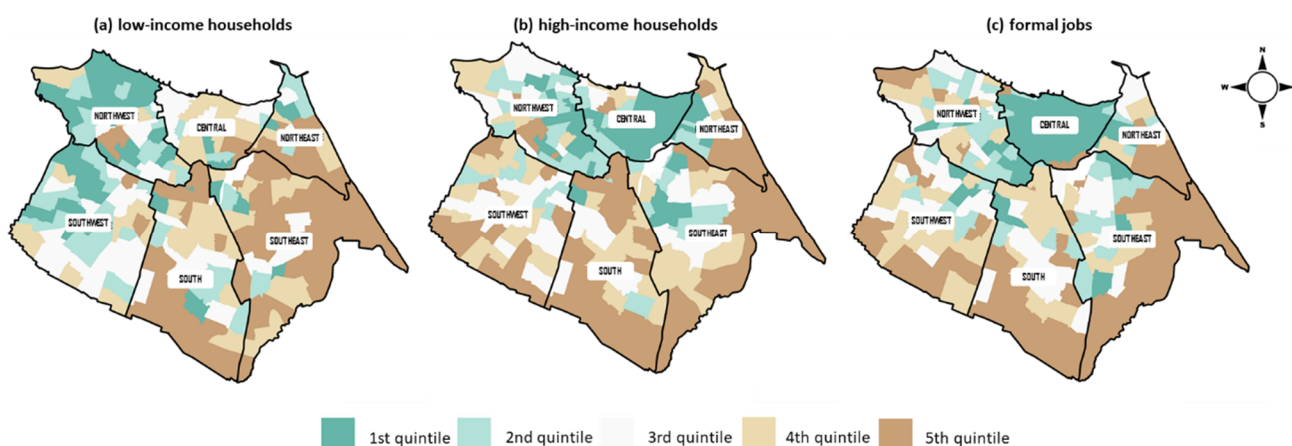


Figure 1. Density of low-income households (a), high-income households (b) and formal jobs (c)

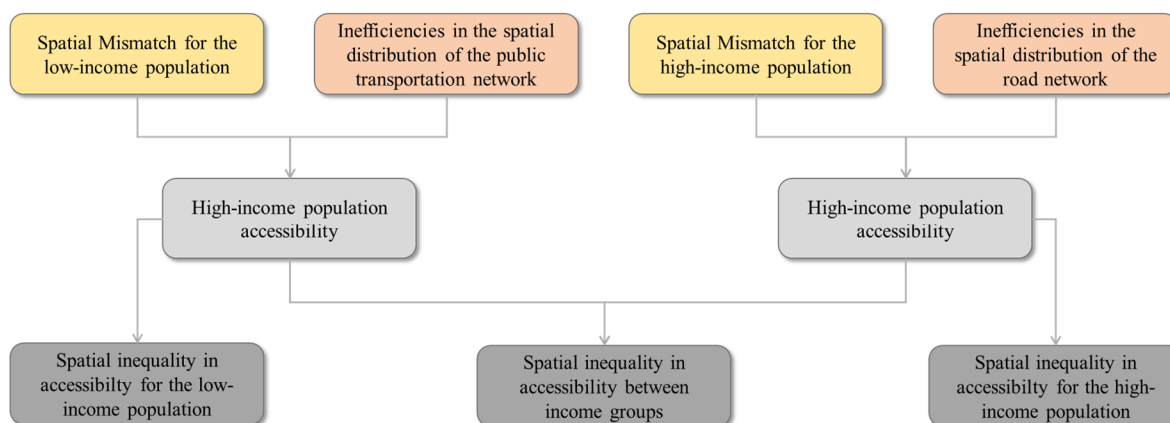


Figure 2. Representation of the causal relationships related to the socio-spatial inequalities in accessibility to jobs

3. CHALLENGES IN MEASURING SOCIO-SPATIAL INEQUALITIES IN ACCESSIBILITY TO JOBS

Geurs and van Wee (2004) classify accessibility indicators according to the part of the phenomenon they represent: infrastructure-based measures, location-based measures, and measures based on the individuals and their perception of utility. However, representing the various components of accessibility (transportation, land use, individual, and temporal)

through a single indicator is a complex task, making it challenging to characterize inequalities in access to job opportunities, which are expected to vary over space and across groups of individuals (Geurs, 2020).

Such challenge is reflected in the variety of measures used to assess inequalities in access to activities in the context of different Brazilian metropolises. Lima *et al.* (2021) used a measure based on travel times, modeled for the road and the public transportation networks of Fortaleza, to measure inequalities in access to jobs for different income groups. Location-based measures have also been widely used in analyses of socio-spatial inequalities of accessibility in Rio de Janeiro, São Paulo, Curitiba, and Recife, through the use of cumulative opportunity indicators (Pereira *et al.*, 2019; Pritchard *et al.*, 2019; Slovic *et al.*, 2019), gravity-based indicators (Boisjoly *et al.*, 2020; Giannotti *et al.*, 2021), or even measures that incorporate competitiveness for opportunities (Barboza *et al.*, 2021; Bittencourt *et al.*, 2021). Other research works seek to improve this representation by incorporating individual preferences in the measurement of accessibility using logsum-based measures (Freire *et al.*, 2020; de Souza *et al.*, 2020).

Given the variety of accessibility indicators, and considering the different aspects of the phenomenon incorporated by each one, as well as their applicability for the analysis of characterization of socio-spatial inequalities in access to job opportunities (Sousa, 2019), we conducted a literature review to comprehend the main characteristics, advantages, and limitations of the different types of metrics of accessibility, according to the classification proposed by Geurs and van Wee (2004).

3.1. Infrastructure-based measures

Infrastructure-based measures, such as travel time or travel speed, quantify accessibility levels through the performance of road and public transport networks (Geurs and van Eck, 2001). This type of measurement makes it possible to understand the impact of each mode of transportation on spatial inequalities in accessibility. Nevertheless, in order to evaluate the effects of the network on the levels of access to activities of different groups of individuals, it is necessary to assume that the accessibility provided by a given mode represents the access conditions of a certain population segment. When comparing different socioeconomic groups in large Brazilian cities, it can be assumed that the accessibility provided by public transportation best represents the conditions of the low-income group, while the high-income group is assumed to travel mostly by car. However, comparisons of other personal characteristics, such as gender or age, for example, may be compromised when using this type of indicator.

3.2. Location-based measures

Location-based indicators incorporate the performance of transportation and land-use subsystems, the latter here understood as the spatial distribution of households and activities. This feature makes it possible to understand how processes related to the concentration of jobs or the peripheralization of the population can cause inequalities in urban accessibility. Travel time weighted by the number job opportunities is one of the simplest examples of this type of indicator. However, one of the most used metrics to represent the accessibility of a locality is the cumulative opportunities measure, which accounts for the amount of accessible activities within an impedance radius (El-Geneidy *et al.*, 2016; Boisjoly *et al.*, 2017; Pereira *et al.*, 2017; Pereira, 2019).

These two indicators, though, do not consider the spatial distribution of the population in their formulation, such that the representation of socio-spatial inequalities in access to work would not be able to incorporate the phenomenon of spatial mismatch. Moreover, when there is a strong spatial concentration of job opportunities, they end up becoming a proxy of the distance to the region in which the concentration of activities occurs (Carneiro *et al.*, 2019). To incorporate the socio-spatial distribution of households and promote a deeper analysis of spatial mismatch on inequalities in accessibility, an option would be the use of the balancing time indicator (Barboza *et al.*, 2021), which measures the travel time required to access a number of job opportunities equal to the population of a given region.

Location-based measures share in common the possibility of incorporating decay functions to reduce the attractiveness of more distant employment areas. They can also be formulated to measure only the specific opportunities of each population group, thus creating an indicator that is more representative of their particular conditions of accessibility. In this effort, the difficulty lies in collecting this information, since the microdata from RAIS and CAGED, the most disaggregated sources of information on formal jobs in Brazil (made available annually by the Ministry of Labor and Employment) are spatialized only at the household level. In addition, these official databases do not incorporate informal jobs, which represent about 50% of job occupations in Brazilian metropolises.

3.3. Individual-based measures

Despite the progress made in incorporating the spatial distribution of activities, the use of location-based metrics to characterize inequalities in accessibility among socioeconomic groups still requires the association of a group with a particular mode of transportation. This limitation could be overcome by considering metrics based on individual perceptions of accessibility conditions, particularly those formulated based on the concept of utility, as they incorporate differences in perceptions about the attributes of commuting alternatives among individuals belonging to different socioeconomic groups (Geurs, 2018). The logsum (Geurs *et al.*, 2010) is the most widely used metric of this type, whose formulation is grounded in economic utility theory (Miller, 2018).

Logsum is an aggregate subjective measure of the satisfaction or well-being of a social group in a given system, where multiple choices are possible. It is commonly applied to measure consumer surplus or the difference in benefits provided by an intervention or public policy. It is based on random utility theory which provides a direct link to traditional microeconomic theory (Cascetta *et al.*, 2013). Nonetheless, as a measure of accessibility, the logsum is applied to estimate the perceived accessibility of users when subjected to a set of mode/route choices, rather than the difference in welfare provided by an intervention or policy (Bhat *et al.*, 2000; Börjesson *et al.*, 2014; Geurs *et al.*, 2010; van Wee, 2016). When this is the case, the utility function usually has parameters related to attributes as the travel cost and the opportunity to perform activities (de Jong *et al.*, 2007; Handy and Niemeier, 1997).

Van Wee (2016) and Miller (2020) highlight some limitations of the logsum as a measure of accessibility. In its original formulation, the logsum does not make possible measuring accessibility across social groups, as it represents a relative measure of well-being within a homogeneous segment of individuals in a given period. In transport project evaluation, the logsum is converted into a monetary value to compute the change in welfare (monetary gain or loss) due to an intervention in the transportation network (de Jong *et al.*, 2007; Geurs *et al.*,

2010). However, the comparison between the accessibility levels of different population groups is limited, since utility has no scale (Geurs, 2020). Miller (2020) reinforces that without further manipulation, the units of accessibility have no particular physical or intuitive meaning, that is, if one area has an accessibility of 200 and another area has an accessibility of 400, one can conclude that the accessibility of the latter is relatively greater than that of the former, but it is not possible to account for the practical meaning of this difference of 200, nor that the accessibility of the former is twice as small. This is because the absolute value of utility is dependent on an integration constant and a scale parameter of unknown values, which vary arbitrarily from one application to another (Miller, 2020).

Given this variety of indicators, as well as the different aspects related to socio-spatial inequalities in accessibility to jobs incorporated by them, the comparative analysis of inequality patterns characterized by different metrics is relevant. As reinforced by Curtis and Scheurer (2010), there is no perfect measure of accessibility, so it is necessary to combine several indicators to obtain substantial information about the analyzed phenomenon.

4. DESCRIPTION OF THE PROPOSED METHOD

Considering the conceptual differences of distinct types of accessibility indicators, as well as the different aspects of the accessibility phenomenon incorporated by them, the selection of an appropriate indicator for the representation of socio-spatial inequalities in accessibility to job opportunities is a complex task and can affect the conclusions of the analysis depending on the indicator used. Therefore, the method proposed in this work consists in characterizing the inequality problem, for the context of Fortaleza, using different types of indicators according to the classification presented in Section 3. The objective is to compare the respective representations obtained and analyze the sensitivity of the conclusions about socio-spatial inequalities when using distinct accessibility metrics.

As the problem of interest involves comparing accessibility levels between socioeconomic groups, it was necessary to classify individuals based on their household income. They were classified as low- or high-income, according to the method proposed by Sousa (2019). By this approach, individuals with household income equal to or below 3.1 minimum wages (60th percentile of household income) were classified as low-income (LI). Whereas high-income group (HI) was composed of individuals with household income equal to or above 10.1 minimum wages (90th percentile of household income). The spatial distributions of these two groups were based on data from the 2017 PNAD-C (Continuous National Household Sample Survey) for Fortaleza.

4.1. Selection of the accessibility indicators

Based on the classification presented in section 3, we selected indicators that incorporate different aspects of the accessibility phenomenon, presenting different levels of complexity in their formulation and operationalization. Infrastructure-based measures were not included in the analyses due to the fact that they do not consider the spatial distribution of activities in their formulation. Based on these criteria, three location-based and one utility-based accessibility measures were selected: (1) average travel time to job opportunities (TT), an indicator that, in addition to considering the infrastructural component of the transportation network, incorporates the distribution of activities in its formulation; (2) cumulative opportunities measure (CO), which also incorporates the performance of the transportation network and the

distribution of activities, with the advantage of being easily operationalizable and communicable with the stakeholders; (3) balancing time (*BT*), which advances in methodological terms by incorporating the competition for opportunities among individuals; and (4) logsum (*LOG*), which represents the state of the art in terms of measuring accessibility, by incorporating different individual perceptions, but with the disadvantage of being difficult to communicate to stakeholders. Table 1 presents the mathematical formulation of the selected metrics.

Table 1 – Mathematical formulation of the selected accessibility indicators

| | |
|---|---|
| <i>TT</i> | TT_i^k , average travel time to job opportunities through mode <i>k</i> from zone <i>i</i> t_{ij}^k , travel time using mode <i>k</i> between a zone of origin <i>i</i> and a zone of destination <i>j</i> Job_j^n , job opportunities of type <i>n</i> in zone <i>j</i> |
| $ACS_1 = \frac{1}{TT_i^k}; TT_i^k = \frac{t_{ij}^k * Job_j^n}{\sum_j Job_j^n}$ | |
| <i>CO</i> | CO_i^k , proportion of job opportunities accessible through mode <i>k</i> from zone <i>i</i> Job_j^n , job opportunities of type <i>n</i> in zone <i>j</i> t_{ij}^k , travel time using mode <i>k</i> between a zone of origin <i>i</i> and a zone of destination <i>j</i> t_{max} , maximum acceptable travel time to reach job opportunities |
| $ACS_2 = CO_i^k = \frac{\sum_j Job_j^n * a_j}{\sum_j Job_j^n}$ if $t_{ij}^k \leq t_{max}$, $a_j = 1$ if $t_{ij}^k > t_{max}$, $a_j = 0$ | |
| <i>BT</i> | BT_i^k , balancing time jobs – population through mode <i>k</i> from zone <i>i</i> t_{ij}^k , travel time using mode <i>k</i> between a zone of origin <i>i</i> and a zone of destination <i>j</i> $Pop_{n,i}$, population of grupo <i>n</i> in zone of origin <i>i</i> $f(t)$, decay function |
| $ACS_3 = \frac{1}{BT_i^k} = \frac{1}{t_{ij}^{k_{min}}}$ $t_{ij}^{k_{min}}$ so that $\sum_{j=1}^n Job_j * f(t) \geq Pop_{n,i}$ | |
| <i>LOG</i> | LOG_i , average logsum to job opportunities from zone <i>i</i> LOG_{ij} , logsum of travel utilities between zone <i>i</i> and <i>j</i> Job_j^n , job opportunities of type <i>n</i> in zone <i>j</i> $U_{ij}^{m,k}$, travel utility for group of individuals <i>m</i> using mode <i>k</i> from zone <i>i</i> to zone <i>j</i> $a^{m,k}$, alternative specific constant for group of individuals <i>m</i> using mode <i>k</i> $b_1^{m,k}$, utility elasticity as a function of travel time for group of individuals <i>m</i> $b_2^{m,k}$, utility elasticity as a function of travel cost for group of individuals <i>m</i> c_{ij}^k , travel cost using mode <i>k</i> between a zone of origin <i>i</i> and a zone of destination <i>j</i> t_{ij}^k , travel time using mode <i>k</i> between a zone of origin <i>i</i> and a zone of destination <i>j</i> |
| $LOG_{ij} = \sum_k e^{U_{ij}^{m,k}}$ $ACS_4 = LOG_i = \frac{LOG_{ij} * Job_j^n}{\sum_j Job_j^n}$ $U_{ij}^{m,k} = a^{m,k} - b_1^m * t_{ij}^k - b_2^m * c_{ij}^k$ | |

The four indicators were calculated at the level of the 241 zones, with an average radius of 500m, according to the zoning scheme proposed by Lima (2017) for Fortaleza’s territory. This zoning scheme aggregates the city’s census tracts maximizing homogeneity in income conditions. Demographic data were obtained from PNAD-C (2017) and formal jobs information from the Annual Report of Social Information (RAIS); the number of informal jobs was obtained through PNAD-C and spatialized with the use of both RAIS data and the spatial distribution of land use in Fortaleza. All jobs were classified according to the socioeconomic group to which it was designated (Pinto, 2020). Travel times between zones were collected for the morning

peak hour, using Google's Distance Matrix API, considering the programmed GTFS (General Transit Feed Specification) table for public transport trips and Google Maps data for car trips.

The calibration of the utility functions for the calculation of the *LOG* indicator was performed using the method of log-likelihood maximization, with the Biogeme 2.2 software (Bierlaire, 2016). The parameters were calibrated using a stated preference survey of modal choice, applied in 2015 in Fortaleza, with 3198 valid observations. The experiment design considered a multinomial logit model with three mode choice alternatives: non-motorized (walking/cycling), public transport, or private mode (car/motorcycle), represented by the attributes of waiting time, in-vehicle time, and commuting cost. The design was reduced into an orthogonal factorial of 3^3 scenarios, in order to keep separate the main effect of the attributes. In this work, we considered only the 1556 observations referring to individuals who commuted to work and who did not choose the non-motorized mode. This is because the estimation of the levels of accessibility to jobs in Fortaleza contemplates predominantly inter-zonal trips made by motorized modes. Among the calibration attempts, one proved satisfactory for this application (Table 2) generating a single model with mode/group-specific ASC constants, but generic commuting time and cost parameters for both modes and income groups. Based on this function, therefore, it is not possible to capture the specific value of time to low- and high-income groups. This limits somehow the ability of such an indicator to capture distinct perceptions, being able to model only each group's preference for the private motorized mode rather than public transport.

Table 2 – Parameters of the utility function

| Coefficient | Estimate | p-Value |
|---|-----------|---------|
| ASC – Private Motorized – Low-Income ($a^{m,k}$) | 0.031 (*) | 0.820 |
| ASC – Private Motorized – High-Income ($a^{m,k}$) | 2.513 | < 0.001 |
| Travel Time (b_1^m) | -0.005 | < 0.100 |
| Travel Cost (b_1^m) | -0.044 | < 0.001 |

(*) Coefficient not significantly different from zero

Some assumptions were also considered to make it feasible to calculate the *TT*, *CO*, and *BT* in a consistently manner for each income group: it was assumed that the LI group was best represented by accessibility calculated for bus trips; and the HI group was best represented by travel times by car. This is expected to represent the extreme situation of these inequalities with respect to differences in the performance of the respective modes. This assumption was not necessary for the calculation of the *LOG*, since it incorporates the perceptions of groups of individuals about the alternatives. In addition to that, for the *CO* indicator, it was used time thresholds of 30 and 45 minutes for the trips made by car and public transportation, respectively. These limits were based on the average travel times observed for each mode in Fortaleza, recognizing the differences in access for each population group. We recognize some limitations regarding the arbitrary determination of this time threshold and the impact of this choice on the results (Pereira, 2019). However, for the purposes of the analysis performed in this research, which is to compare how the indicators differently represent the conditions of accessibility for distinct socioeconomic groups, we believe that the criteria established for the choice of these time thresholds are coherent and sufficient.

4.2. Comparative analysis of the different representations

As highlighted in Section 3, depending on the type of indicator used, different components are incorporated in the representation of the socio-spatial inequalities in accessibility to job opportunities. By characterizing the levels of accessibility to job opportunities in Fortaleza based on the four different metrics selected, we seek to verify the degree of sensitivity of the conclusions about the distribution of these inequalities over the city's territory, especially in those regions where low- and high-income groups predominantly live.

This analysis was based on the comparison of the representation obtained by the four selected indicators, considering the following criteria: (1) the spatial pattern observed from the distribution of accessibility quintiles of each indicator, identifying possible differences in the distribution of accessibility over the territory; (2) differences in this spatial pattern observed for each socioeconomic group, through bivariate global (Moran's I) and local (BiLisa Maps) spatial correlation analysis; (3) differences in the mean values of accessibility and its variation by region, through the analysis of boxplot diagrams, looking for possible differences in the more aggregate behavior (by regions), and considering its inter-zonal variability; and (4) the distribution of the accessibility levels among individuals of each socioeconomic group, based on the analysis of histograms, depicting possible differences among the indicators regarding the distribution of accessibility in an individual level, considering their income differences. For comparison purposes, the values of the indicators were standardized by their Z-score.

5. RESULTS AND DISCUSSION

Figure 3 presents the spatial distribution of accessibility quintiles for the four metrics analyzed. The best accessibility levels are highlighted with the strongest shades of each color. The results of global and local spatial correlation between the accessibility values of low- and high-income groups are also presented.

The accessibility measured by *TT*, *CO*, and *LOG* show a strong similarity in the spatial patterns for both population groups. In all three cases, it can be observed the occurrence of spatial inequalities, configured by the concentration of the best levels of accessibility in the Central region and the worst levels in the peripheral areas of the city. The spatial correlations quantified by the Moran's I reinforce this similarity, as also does the existence of clusters of high accessibility levels occupying the entire Central region and clusters of low accessibility in the outskirts of the city.

As for the *BT* indicator, it provides a concentric spatial pattern in the distribution of accessibility of the low-income population, but somewhat more disperse than that verified with the other three metrics. Conversely, the pattern of accessibility for the high-income group presents a much more disperse spatial distribution. The low value of Moran's I (0.041) when comparing the accessibility provided by *BT* for low- and high-income groups reinforces the distinction in the pattern observed for the two socioeconomic segments by this indicator. Although more disperse, *BT* shows some clusters of high accessibility to the West side of the Central region, as well as clusters of low accessibility in areas of the Southwest and Southeast regions.

By incorporating the competition for the job opportunities, *BT* characterizes some zones of the Central region with low levels of accessibility, whereas some zones of the peripheral regions present high levels of accessibility for the high-income group. This is probably because *BT* only

considers the ratio between demand and supply of these opportunities, disregarding their absolute values. Thus, a supply of 8,000 jobs for a demand of 4,000 individuals, as observed in the Central region, results in the same level of accessibility as 800 jobs for 400 individuals, as can be seen in zones of peripheral areas.

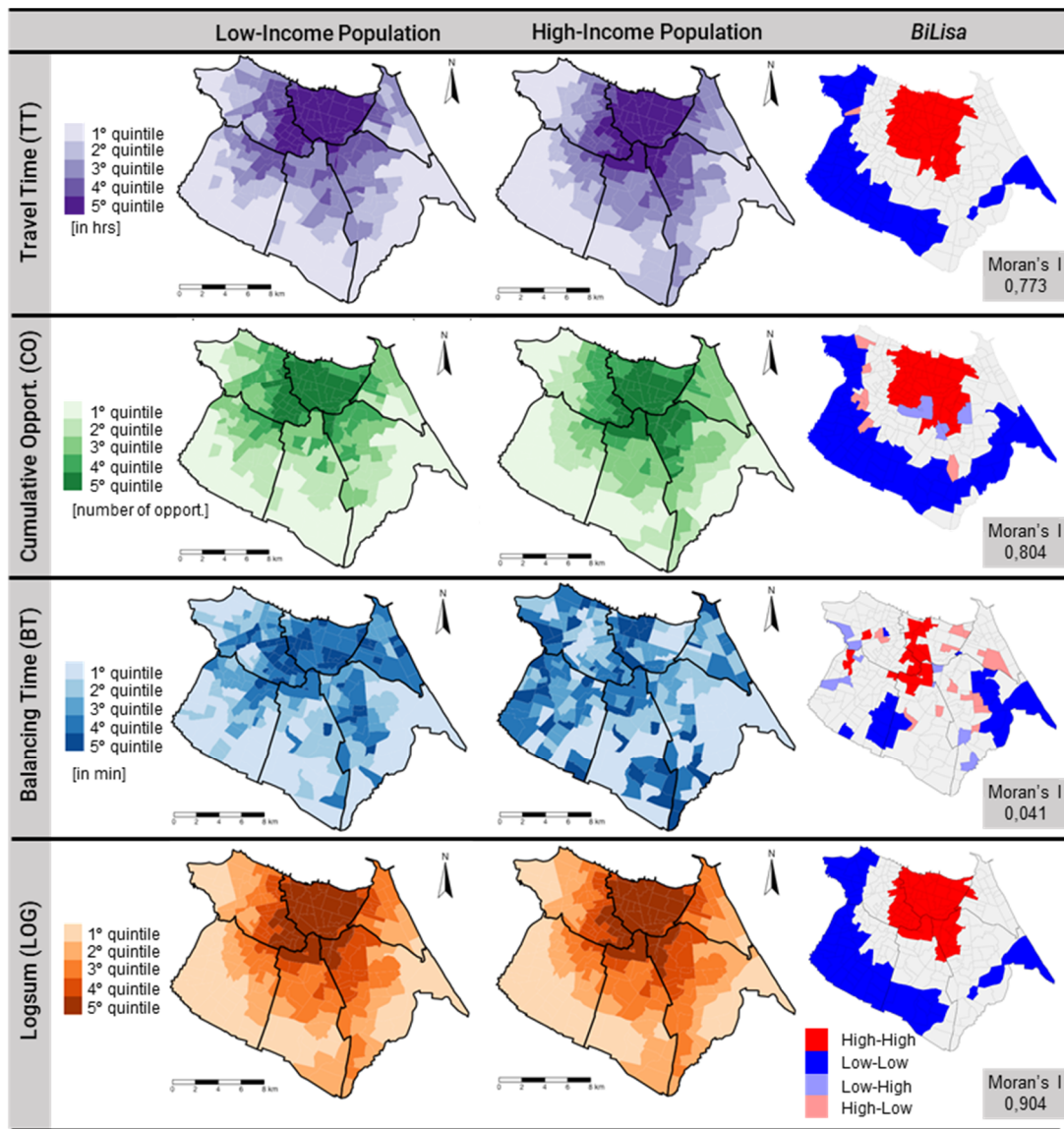


Figure 3. Spatial distribution of accessibility quintiles

If the aggregate and more qualitative spatial patterns point to similarities between the representation of accessibility by *TT*, *CO*, and *LOG* indicators, a more disaggregated and quantitative analysis of the boxplot diagrams of Figure 4 facilitates the identification of possible differences between them in the representation of the mean accessibility by region. For the low-income group, both *TT* and *CO* represented the same hierarchy of average accessibility by region, where the Central region presents the best condition, as well as the least dispersion pattern of values among zones, while the Southwest region is that with the lowest value of average accessibility. These two indicators show that the better levels of average accessibility are in the Northern regions of the city, in detriment of the Southern regions, which present a greater variability among zones.

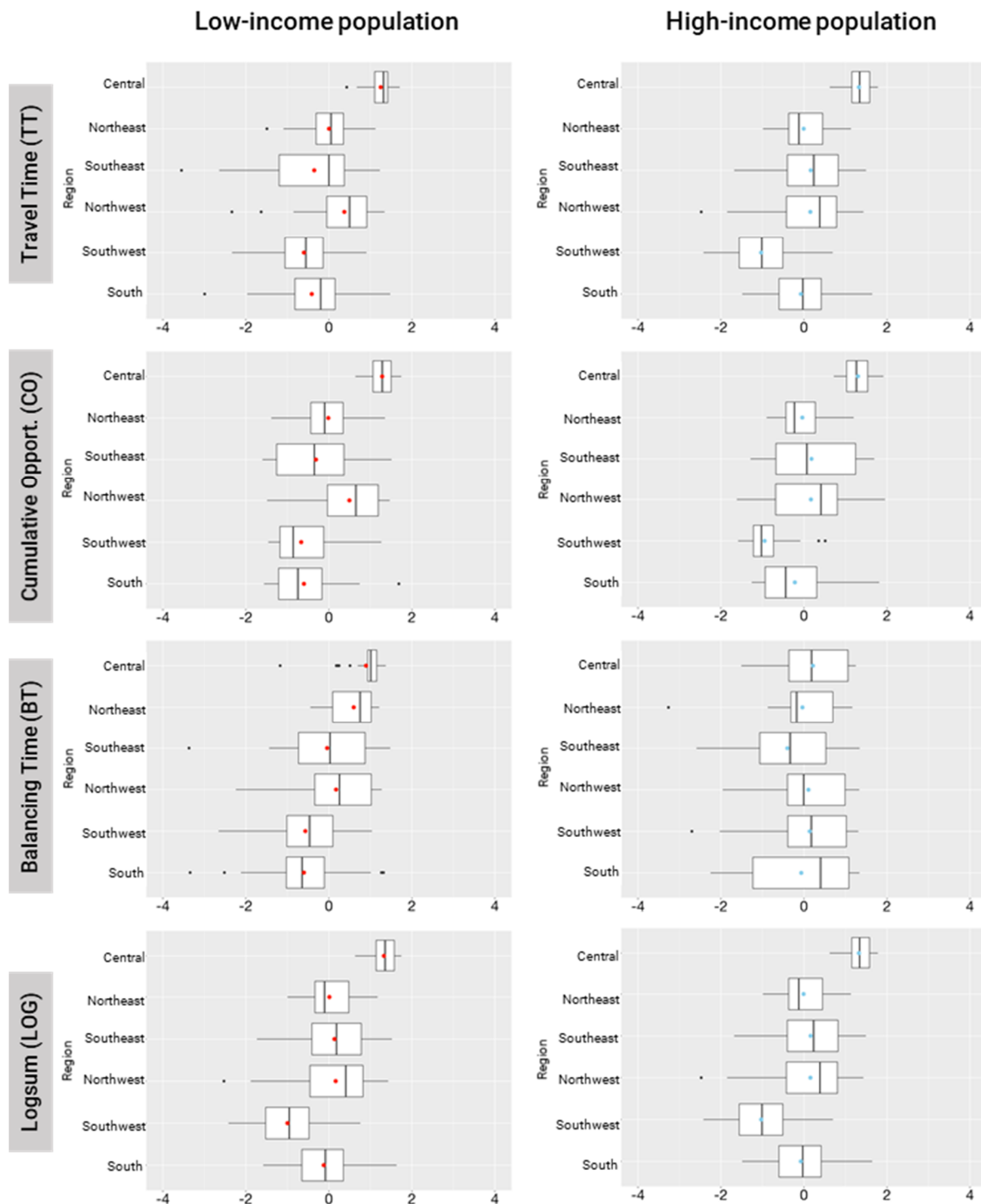


Figure 4. Boxplot diagrams by region

The boxplot diagrams of the *LOG* indicator for the low-income group also indicates a greater inequality between the Central and Southwest regions, as the one with the best and worst average accessibility, respectively. This inequality is reflected in an even more intense way, if compared to *CO* and *BT* indicators. This is evidenced by a greater difference observed between the averages for the two regions. With respect to the other regions, it is not possible to note, using *LOG*, major differences in average accessibility among the Northeast, Southeast, Northwest, and South regions, with all presenting similar patterns related to its average and variability.

In a similar way, *BT* indicates that the region with the best accessibility levels and the least variability is also the Central region. However, differently from the other three indicators, by this measure the South region is the one with the worst accessibility levels for the low-income group. Similar to the patterns represented by *TT* and *CO*, *BT* suggests better levels of average accessibility in the Northern regions in comparison to the Southern ones. It is also noticeable, by *BT*, a predominance of better levels of average accessibility in the East side of the city, where there is a low concentration of low-income individuals.

With respect to the accessibility values for the high-income group, the boxplot diagrams (Figure 4) of *TT*, *CO*, and *LOG* indicators highlight the same hierarchy of average accessibility among the regions. Similar to what was observed for the low-income group, the Central region has the best average accessibility and less variability among zones, while the Southwest region has the worst situation, with less variability by *CO*. For these three metrics, the Southeast region has the second-best average accessibility. This region is characterized by being the main destination of the self-segregated high-income population (Lima *et al.*, 2021), reinforcing the concentration of this group in areas of better conditions of access. In contrast, the boxplot diagram of *BT* highlights the Southeast region as having the worst average accessibility and the Central region with the best results. However, the difference between these two regions, 0.6 standard deviation from the average, is not as large as that observed by the other three indicators, which presented values of approximately 2 standard deviations. This may be due to the effect of competition in reducing the levels of accessibility in regions with a high concentration of high-income individuals. It is also worth mentioning that, in general, zones in the East side of the city had better values of average accessibility than those in the West, probably as an effect of the low densification of the high-income population in the Southwest and Northwest regions.

The histograms in Figure 5 show the percentage of individuals in each socioeconomic group subject to different levels of accessibility. It was possible to identify differences in the non-spatial distribution of accessibility among individuals from the two groups. The rightward asymmetry in the distributions of low-income accessibility observed using the *TT*, *CO*, and *LOG* indicators reflects a larger share of these individuals subjected to the worst levels of accessibility. Comparatively, there is a greater concentration of high-income individuals in areas of better accessibility, since their distributions are asymmetric to the left. This pattern is probably a result of the concentration of the low-income population on the West side of Fortaleza, with its Central region being mainly occupied by the high-income group (Lima *et al.*, 2021), suggesting the existence of inequalities in accessibility to jobs between different socioeconomic groups, once the most vulnerable group resides in the least accessible regions.

In contrast, *BT* once again presented a distinct configuration from the other three indicators, as it does not represent differences in the distribution of accessibility levels between low- and high-income individuals. This suggests a situation of equity in the distribution of accessibility between the two groups. Compared to the other indicators, we notice a translation of the curve of accessibility of high-income individuals towards the lowest levels of accessibility, resulting mainly from the low values observed in part of the Central region, where these individuals are more concentrated. In both cases, a certain symmetry of the distributions is observed, indicating that there are similar percentages of individuals living in areas with high and low levels of accessibility.

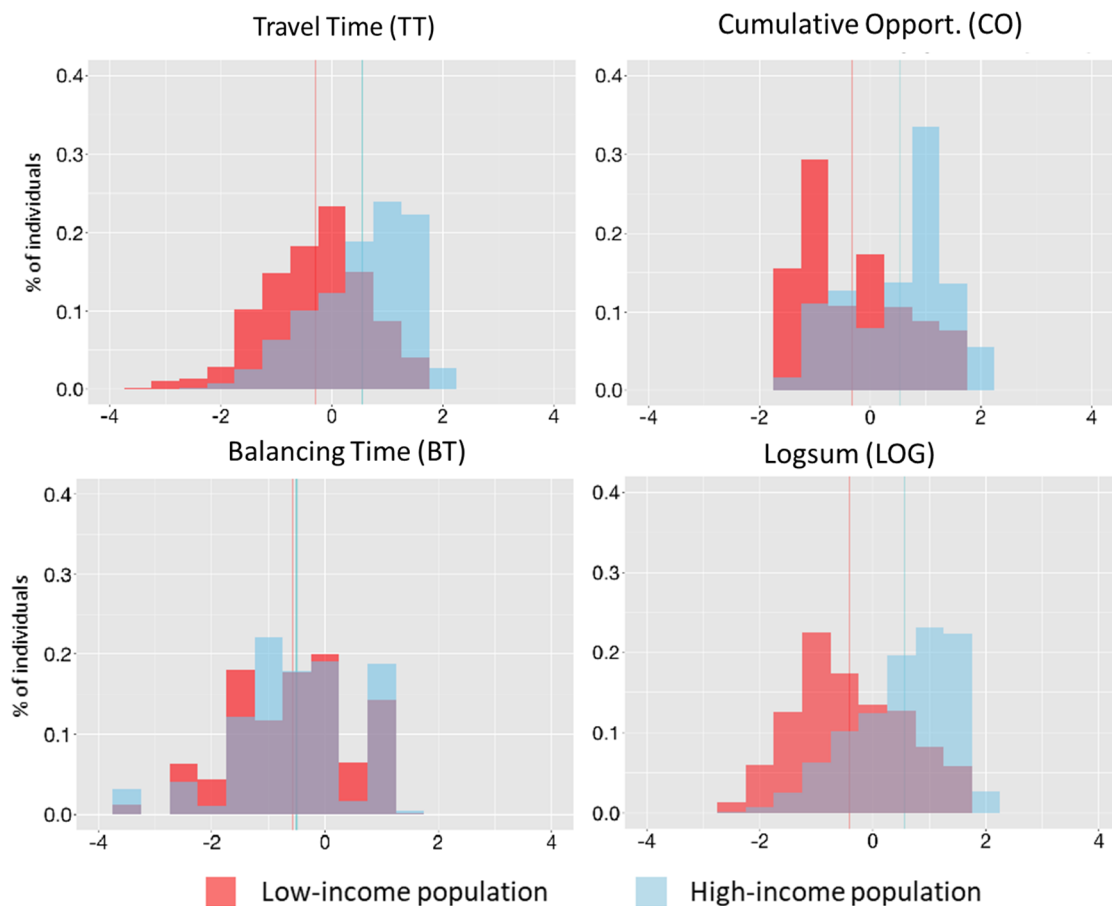


Figure 5. Histograms of the normalized values of the indicators

6. CONCLUSIONS AND RECOMMENDATIONS

The main purpose of this research was to compare the different representations of socio-spatial inequalities in the accessibility to jobs in Fortaleza using different metrics. The problem under investigation was characterized by four different accessibility indicators (*TT*, *CO*, *BT*, and *LOG*), whose representations for low- and high-income groups were compared regarding the spatial distribution of accessibility, the non-spatial frequency distribution among individuals, and the average accessibility values and its variability among the regions.

Regarding the spatial distribution of accessibility in each group, *TT*, *CO*, and *LOG* indicators showed similar patterns. From the spatial correlation analyses it was possible to note that this similarity held for the distributions of the two socioeconomic groups based on all three indicators. It was expected that *TT* and *CO*, given their formulation, would present the same pattern observed for the two groups, since the distribution of jobs opportunities in Fortaleza present a monocentric pattern. The incorporation of the individual preferences of the two groups by *LOG* did not produce differences in the representation of the spatial pattern of accessibility when comparing to the first two indicators. Alternatively, *BT* depicted distinct spatial patterns for low and high-income groups. While for the low-income group, it presents a concentric spatial pattern, for the high-income group the observed pattern is much more dispersed, reflecting the incorporation of the characteristic of competition for employment. Even so, *BT* does not reflect possible differences in the way competition is represented, so

that regions with high supply and high demand for opportunities present the same levels of accessibility as areas with low supply and demand values.

When analyzing the differences in the levels of average accessibility by region, the four indicators highlighted the best accessibility condition of the Central region, reflecting the high concentration of jobs in that area. Conversely, differences were found in the representation of the region with the worst accessibility both for low- and high-income groups. In the first case, the four metrics denoted a greater North-South dichotomy. In the second, *TT*, *CO* and *LOG* implied better conditions to the East side of the city, as well as in the Central region, reflecting the greater share of high-income individuals subject to better accessibility conditions, since they are more strongly concentrated in these regions. In contrast, *BT* did not depict a large variation in average accessibility levels by region, thus not reflecting spatial inequalities within the high-income group.

Finally, about the distribution of accessibility levels among individuals, *TT*, *CO*, and *LOG* indicators reflect a higher concentration of low-income individuals in areas of less accessibility, thus showing a higher proportion of people in the vulnerable group subject to the worse levels, if compared to high-income individuals. From *TT* and *CO*, this conclusion was direct, since it was possible to numerically compare accessibility levels between the two groups. For *LOG*, however, the impossibility of directly comparing the numerical values obtained for the two groups only allowed a relative comparison, hindering a deeper analysis from a social equity perspective. *BT*, in contrast, once again presented a distinct pattern from the others, presenting no significant differences between socioeconomic groups. As already highlighted, this pattern probably reflects the way competition is incorporated by this indicator, disregarding possible differences in the way it manifests among these socioeconomic groups.

Based on these conclusions, it is recommended for future work to analyze differences in the representation of accessibility inequalities using indicators that incorporate other aspects related to the phenomenon, such as calibrating a decay function to represent the attractiveness of opportunities by distance, or through a generalized cost function, and considering indicators that incorporate the competition for job opportunities in a more complex way than the *BT* does, for example. It is also suggested to perform the same analysis in contexts in which the phenomenon behaves differently from Fortaleza, such as in large cities of the Global South with polycentric morphological structures.

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