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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Accessibility of the metropolitan bus transportation system in Belo Horizonte

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Abstract

As is the case in most Brazilian Metropolitan Regions, Belo Horizonte exhibits occupation patterns that require large population displacements to reach employment and consumption opportunities. The bus is the main mode of mass transportation in Metropolitan Region of Belo Horizonte (MRBH), which should guarantee the population's ability to come and go. In this context, the present article evaluates the accessibility of the metropolitan bus transportation system in Belo Horizonte. To this end, an index based on the total supply of metropolitan bus lines, bus trips offered and municipalities of MRBH reached is proposed. In general, the results indicate the predominance of low accessibility levels in most of the analyzed territorial units (*Campos*), with better values for those located in the central and peri-central region of the municipality (the Central Business District of Belo Horizonte) and bordering the main municipal and metropolitan road corridors in the western axis towards the main MRBH industrial pole, where important employment opportunities are located. In this sense, in addition to the possibilities of methodological improvement offered, the proposed index can serve as a subsidy to the formulation of constructive measures aimed at supporting the formation of public opinion and better decision-making to minimize possible distortions in the distribution and provide accessibility.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Accessibility, metropolitan region; metropolitan transportation system; bus transportation; index; Central Business District; Belo Horizonte.

1. Introduction

Brazilian cities, particularly in the second half of the twentieth century, have experienced one of the most rapid urban transitions in world history. Today, more than 84% of Brazil's population lives in urban areas. Rapid urbanization and the accelerated metropolization process were motivated by late industrialization and demographic growth, resulting from high birth rates and reduced mortality (Martine and McGranahan, 2010). According to Cunha

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Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY

(2010), in the same period, the growth of large urban areas was observed in the country, mainly in the Southeast, where the most important expansion cores are located, such as the capital cities of São Paulo, Rio de Janeiro and Belo Horizonte. The urban concentration has widened social distances, particularly in larger cities, which have become a great *lócus* of social inequality and concentration of poverty. The existence of shared problems between the urban nuclei and neighboring municipalities resulted, among other aspects, in the need to institutionalize the Metropolitan Regions (MR) in the 1970s. Among the objectives of RMs implementation is the unified management of public services of metropolitan interest, such as collective transportation (Brazil, 1988; Pedroso and Lima Neto, 2015).

The Metropolitan Region of Belo Horizonte (MRBH), with an estimated population of 5.9 million (Brasil, 2017), is the third largest in Brazil. MRBH is made up of 34 municipalities, and Belo Horizonte, the capital of the state of Minas Gerais, is the main centrality, where most of the commerce, services (public and private) and schools are located. According to the census data and analyses carried out by Lobo et al. (2013), the municipality receives daily large numbers of workers residing in the municipalities of the MRBH, given their degree of polarization of job opportunities and services. Consequently, both the public (inter and intra) municipal transport system (mostly carried out by bus) and the circulation system are even more burdened by the increasing demand for work-related displacements, a situation also observed in other large Brazilian cities. As is the case in most Brazilian metropolises, in Belo Horizonte, numerous precarious conditions are reproduced in the provision of urban accessibility, reflecting the (in)capacity of government intervention in the process of urbanization and social exclusion, especially in metropolitan suburbs, which contributes to the aggravation of situations of social vulnerability and environmental degradation. Thus, the distribution of spatial accessibility and mobility is characterized by a series of inequalities resulting from the structure of a circulation space in which the privileges of individual transport (motorized) are maintained and the concerns of the most vulnerable groups related to circulation (pedestrians, cyclists and public transport users) have been passed over (Lobo et al., 2013). In 2008, according to the Urban Mobility Plan of Belo Horizonte, 54.5% of the daily trips in the city were carried out by bus and 45.5% by automobile. The absence of new investments in public transport improvements will promote a reversal of this scenario by 2020, when 52% of trips will be carried out by automobiles and 48% by public transport. This advance of individual motorization has contributed to the loss of the efficiency of the entire system, as well as the prevalence of low average speeds of collective transportation by bus, especially in the central area of Belo Horizonte (Belo Horizonte, 2012; Lobo and Cardoso, 2018).

Given this scenario, the main objective of this study is to evaluate the level of accessibility of the metropolitan bus transportation system in Belo Horizonte, taking as a reference travel data between spatial units, called *Campos*. To estimate the travel matrix, databases extracted from the Origin and Destination Survey of 2012 (OD 2012) and a vectorized digital network of the metropolitan bus lines were used. Analysis of the conditions of spatial accessibility in Belo Horizonte, based on the specific indicators proposed, allowed the elaboration of a diagnosis that surpasses the simple (re)cognition of a given condition, even if it is highly relevant. The comparison of the levels of accessibility of the metropolitan bus transportation system in Belo Horizonte *Campos* allows the recognition of certain spatial patterns. Such information can be useful to public administrators and subsidize the formulation of policies and proposed measures aimed at supporting political decision-making to minimize possible distortions in the distribution and provide mobility and urban accessibility.

2. Metropolitan accessibility: concepts and measures

The academic literature recognizes that the transport system has a direct influence on production costs, trade flows, social welfare and the articulation of market areas and plays an essential role in the economic growth and development of cities (Mitra and Saphores, 2016). Since the last century, the term accessibility has been used in different fields of scientific research, notably in the areas of urban planning and transportation (Karou and Hull, 2014; Morris et. al., 1979; Vulevic, 2016); in the analysis of forms of land use (Cervero, 1989; Harris, 1954; Levinson, 1998); as an agent and measure of socio-spatial segregation (Bocarejo and Oviedo, 2012; Gomide, 2003; Pyrialakou et al., 2016; van Wee and Geurs, 2011); or as an indicator of pedestrian access to the circulation infrastructure (Ewing and Handy, 2009; Vale et al., 2016). As Gould (1969, p. 64) notes, in the late 1960s, "accessibility is a slippery notion (...) one of those common terms that everyone uses until faced with the problem of defining and measuring it!" Gould's observations are still valid, despite the subsequent theoretical and empirical investment.

Other definitions include interpretations such as "the potential of opportunities for interaction" (Hansen, 1959, p. 4); the ease with which any land-use activity can be reached from a location using a particular transport system (Dalvi and Martin, 1976); the freedom of individuals to decide whether to participate in different activities (Burns, 1979); and the benefits provided by a transportation / land-use system (Ben-Akiva and Lerman, 1985). Accessibility can also be defined as the ability to reach activities, individuals or opportunities, if necessary, by moving to the locations where those needs are located (Geurs and Ritsema van Eck, 2001; Handy, 2005), which is understood to be a product of land use and the transport system (van Wee and Geurs, 2011; Vickerman, 1974). The concept of accessibility, as an indicator and socioeconomic value, also permits an approach that goes beyond access to transportation systems (Cardoso, 2007). There is also the distinction between the terms access and accessibility that are often used indiscriminately in the literature (Geurs and van Wee, 2004). Murray et al. (1998) and Geurs and van Wee (2004) suggest that access is the use opportunity based on the service proximity and its cost (individual perspective), whereas the “accessibility is the suitability of the network to get individuals from their system entry point to their system exit location in a reasonable amount of time” (location / network perspective).

When considering the social dimension of the term, in a context of poverty and non-development, the insufficient incidence of alternative modes of transportation, coupled with the problems related to the limited physical and tariff integration between the various collective modes that are components of transportation systems, results in and reflects a process of socio-spatial segregation since a significant portion of the population has fewer opportunities for work, study, consumption and leisure (Bocarejo and Oviedo, 2012). The literature recognizes that the proximity of transport services and their benefits is distributed unevenly in space. Therefore, accessibility levels are not the same for the entire population. This fact is related to the process of production and reproduction of urban space that reflects social inequities (Costa and Morais, 2014). According to Pyrialakou et al. (2016), space is only one dimension of the problem. In addition to the spatial distribution of social effects, the literature also focuses on the temporal, socioeconomic and demographic distribution of transport (Jones and Lucas, 2012).

In its broadest interpretation, accessibility provides measures of the degree to which people can access goods and services, emphasizing potential (capability) more than the actual behavior of users. In addition to the different approaches and concepts, the term can be grouped into three levels: micro (i.e., access to vehicles / the system), meso (i.e., connectivity and separation of networks) and strategic (i.e., regional access to employment) (Jones and Lucas, 2012). The micro level concerns the study of the design of the vehicle (i.e., adapted vehicles), the movement near the vehicle (i.e., elevators for rail platforms and high curbs at bus stops), and specific resources to aid movement (Burton and Mitchell, 2006; Cobb and Coughlin, 1999). The meso encompasses a range of issues, particularly the connectivity and permeability of the local street network when using different modes of transport, and the general ease of neighborhood access for disability groups (Jones and Lucas, 2012). Finally, at the last level, the strategic accessibility is concerned with the degree to which land use patterns and associated transport networks in a substantial area facilitate travel from one local area to another (Jones and Lucas, 2012). The focus of this paper is the last level, the strategic accessibility.

A growing body of literature has used accessibility indicators as tools to gain insight into policy and transport planning issues. An overview is provided by, among other authors, Handy and Niemeier (1997) and Geurs and Ritsema van Eck (2001). Geurs and van Wee (2004) distinguish four types of components that are important in accessibility calculation: transportation, land use, temporal and individual. The transportation component describes the transport system, expressed as the impedance for an individual to cover the distance between an origin and a destination using a specific mode of transport. Time (travel, waiting and parking), costs (fixed and variable) and effort (i.e., reliability, comfort level, risk of accident) are included. The provision of infrastructure includes its location and characteristics (maximum travel speed, number of lanes, public transport schedules and travel costs). Land-use consists of the distribution, supply and demand of various land-use types in space, defined in terms of quantity (i.e., residential and employment density) and quality (i.e., employment level, housing values, importance of services such as large hospitals and educational institutions) (Geurs and van Wee, 2004, Handy, 2005, Koenig 1980, Kwan 1998, Vale et al., 2016). The temporal component reflects time constraints, such as the availability of opportunities at different times of the day, and the time it takes for individuals to perform their activities (i.e., work, education, recreation) (Geers and van Wee, 2004; Hägerstraand, 1970). Finally, the individual component reflects the needs (depending on age, income, educational level, home situation), skills (depending on the physical condition of the person, availability of travel modes) and individuals opportunities (depending on income, travel budget, educational level).

Geurs and van Wee (2004) distinguish four types of accessibility measures: 1) infrastructure-based, which analyze the performance or service level of the transport infrastructure (i.e., congestion level and average speed of travel in the road network). This type of measure is typically used in transportation planning (Geurs and van Wee, 2004; Vale et al., 2016); 2) location-based, which analyze accessibility at locations, generally at the macro level (i.e., the number of jobs within 30 minutes of travel from the places of origin). These measures are typically used in urban planning and geographic studies (Geurs and van Wee, 2004); 3) person-based, which analyze accessibility at the individual level, considering the possibilities and constraints "on an individual's freedom of action in the environment" (Geurs and van Wee, 2004) (the number of activities in which an individual can participate in a given period of time). This type of measure is based on Hägererstrand's spatial / temporal theory (1970), which measures impedances in the individual's displacement (location, duration, cost and speed of movement); and 4) utility-based, which analyze the economic benefits derived from access to spatially distributed activities (Geurs and van Wee, 2004).

The level of accessibility offered by public transportation is an important factor for proper system operation. To better recognize and understand the spatial patterns distributed at the local and regional level, it is necessary to measure and map them, which is the objective of this document. It also enables the formulation of policies and proposed measures aimed at supporting political decision-making to minimize possible distortions in the distribution and provision of urban accessibility. Accessibility therefore involves the combination of the destinations locations to be reached and the characteristics of the transportation system, considering the geographical distribution of population and economic activities, as well as the respective characteristics. Therefore, the idea of accessibility is related to the ability to reach desired and / or necessary destinations rather than the movement *stricto sensu* (Tagore and Sikdar, 1995). In this sense, Levine (1998) observes that the accessibility is higher among closer destinations, even if the trip speed is reduced, which results in a process that Hanson (1995) defines as "place accessibility," referring to a facility with certain places that can be reached. Considering that the propensity for interaction between two points is higher, as long as the cost of movement between them decreases (Raia Júnior, 1997), the urban equipment and services will be more accessible if they are close to the residential areas. The accessibility is also enhanced using non-motorized transportation modes, including walking (Lobo and Cardoso, 2018).

3. Database, space units and research methodology

The data used to estimate the metropolitan bus travel matrix in MRBH were extracted from the Origin and Destination Survey of 2012 (OD 2012), a periodical sample survey, the last version of which was conducted by the Agência de Desenvolvimento da Região Metropolitana de Belo Horizonte (Agência RMBH). The digital metropolitan bus lines network and the cartographic bases of Belo Horizonte and MRBH (Fig. 1) were ceded by the Secretaria de Estado de Transportes e Obras Públicas do Estado de Minas Gerais (SETOP) and Empresa de Informática e Informação do Município de Belo Horizonte (PRODABEL), respectively. The data referring to the resident population stock were obtained from Demographic Census 2010 (IBGE), originally aggregated by census tracts, and the specific data of each line (schedules and total of lines of each municipality) were obtained from SETOP. For the purposes of processing and analysis, the municipal boundaries were used for the Metropolitan Periphery of Belo Horizonte (MPBH), here identified as the municipalities of the MR (except Belo Horizonte). Currently, the MPBH comprises 33 municipalities. Moreover, spatial units named *Campos* (Fig. 1) were used, which comprise aggregations of *Áreas Homogêneas* (lower level of spatial disaggregation spatially compatible with the census tracts). The *Campos* are considered key units in the analysis of urban space. They often coincide with neighborhoods or small groups of neighborhoods, which makes information more accessible to the public and the public authorities (Appendix A). In Belo Horizonte, according to the space cut established in the Origin and Destination Survey of 2012, 120 *Campos* were determined, divided into nine administrative regions: Barreiro, Oeste, Centro-Sul, Noroeste, Leste; Pampulha, Nordeste; Norte and Venda Nova (Fig. 1).

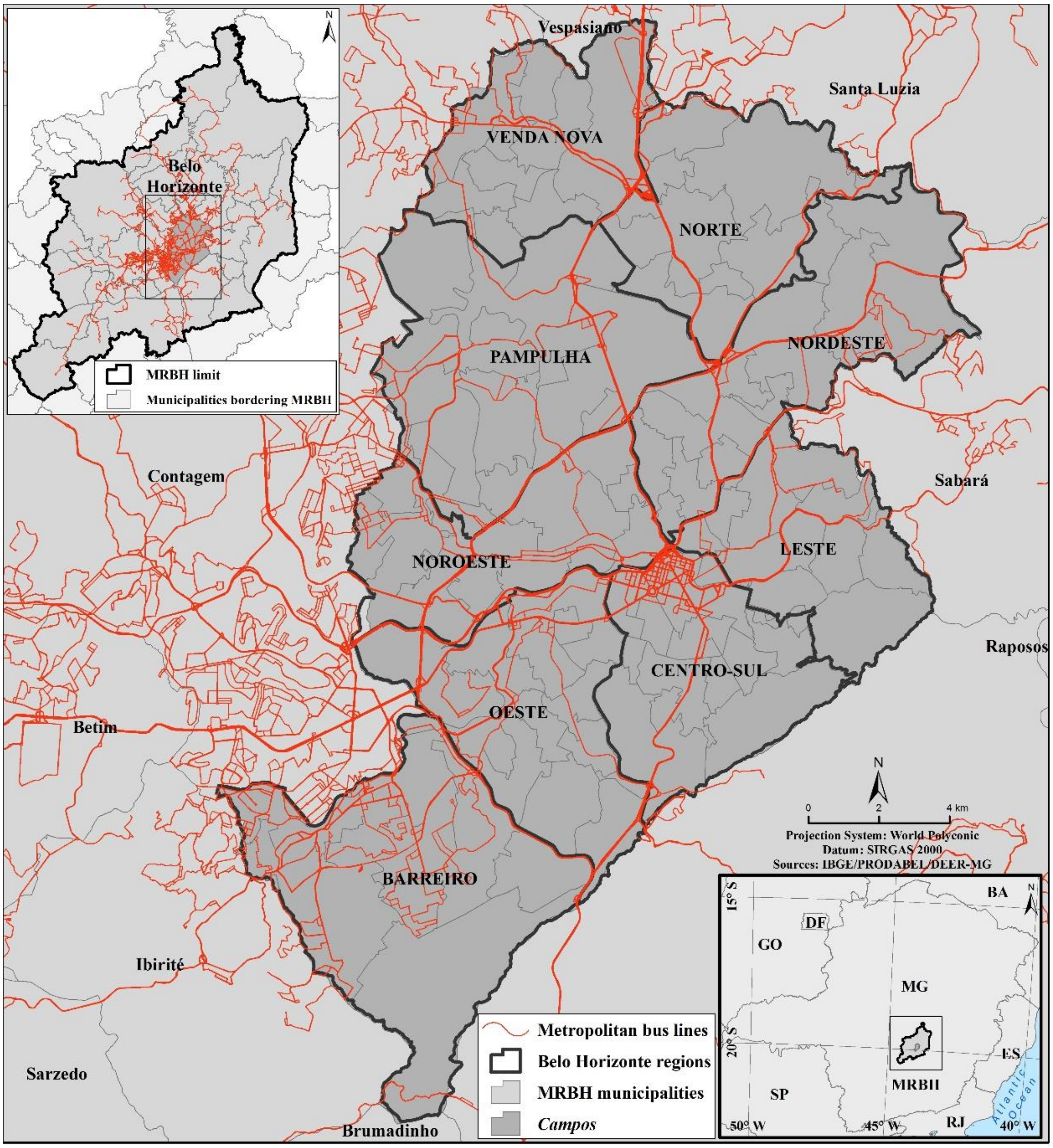


Fig. 1. Metropolitan bus lines network. Source of data: Digital base of SETOP e PRODABEL.

The Accessibility Index of Belo Horizonte (AI_{BH}) was proposed as part of the methodological procedure. This is an aggregate index that represents the accessibility of the metropolitan bus transportation system in each *Campo* of Belo Horizonte, based on three dimensions: the metropolitan bus lines supply, bus trips offered and MP municipalities reached. According to the OD 2012, 32 of the 120 *Campos* of the capital did not register trips by bus to MP, and therefore they were excluded from the analysis. To produce the three dimensions, the geo-referenced vectors of the 639 metropolitan bus lines were converted from keyhole markup language (kmz) to shape file (shp) format, with the aid of the ArcGis 10.1® SIG and some additional scripts. Only the lines that intersected the feature representing the municipality of Belo Horizonte were selected. Therefore, the lines that do not access the metropolitan core were excluded from analysis. To calculate the total daily trips for each bus line, only the business-day schedule was considered. Thus, the lines that operate only on Saturdays, Sundays and holidays were excluded from analysis. All metropolitan lines that met the established criteria were compacted in a single layer (Merge tool) and intersected

(Intersect tool) with the *Campos*, resulting in a file with the information of each space unit and its respective attendances of metropolitan bus lines. Finally, after the elimination of duplicate data, the daily trips offered by the system and the total metropolitan lines that connect *Campos* to the MPBH municipalities were obtained. The total number of municipalities that can be reached by direct trips was obtained based on the interrelation of the metropolitan bus lines data and the MP municipalities (*Spatial Join tool*). AI_{BH} was derived from three indicators, given below:

1. Line Ratio (LR_i): daily metropolitan bus lines available in each *Campo*, which allow direct access to MP (Equation 1).

$$LR_i = \frac{\sum_i^n L_i}{T_i} \times P_i \quad (1)$$

where:

- L_i = total number of metropolitan bus lines originated in *Campo* i and destined to the MP;
- T_i = total number of effective daily metropolitan bus trips originated in *Campo* i and destined to the MP; and
- P_i = population of *Campo* i.

2. Trips Ratio (TR_i): daily metropolitan bus trips offered by the system originated in *Campo* i and destined to the MP (Equation 2).

$$TR_i = \frac{\sum_i^n T_{o_i}}{T_i} \times P_i \quad (2)$$

where:

- T_{o_i} = total number of daily metropolitan bus trips offered by the system originated in *Campo* i and destined to MP;
- T_i = total number of effective daily metropolitan bus trips originated from *Campo* i and destined to MP; and
- P_i = population of *Campo* i.

3. Municipalities Ratio (MR_i): MP municipalities that can be reached by direct trips (Equation 3).

$$MR_i = \frac{\sum_i^n M_i}{V_{r_i}} \times P_i \quad (3)$$

where:

- M_i = total of MP municipalities that can be reached by direct trips originated in the *Campo* i;
- T_i = total of effective daily metropolitan bus trips originated from *Campo* i and destined to MP; and
- P_i = population of *Campo* i.

The values of LR_i, TR_i and MR_i were standardized (R_p), converted to a 0 to 1 range, which correspond to the observed minimum and maximum values, respectively, as described in Equation 4:

$$R_p = \frac{R_i - R_{min}}{R_{max} - R_{min}} \quad (4)$$

The Accessibility Index of Belo Horizonte (AI_{BH}) was obtained by the arithmetic mean of the three standardized indicators (LR_p, TR_p and MR_p).

To classify the data related to the cartograms presented herein, (Figs. 2 and 3) the Natural Breaks method was selected. Also known as natural break (Jenks, 1967), this model aims to find the class intervals in order to minimize the internal variance, identifying the largest differences between the limits of each interval. Thus, this classification method seeks clusters that occur "naturally" in the data set, to obtain a greater internal homogeneity for each class and the lowest between classes.

4. Analysis and interpretation of the results: the index for the *Campos* of Belo Horizonte

As expected, the *Campos* located along the important road corridors (Via Expressa located to the west and the Avenidas Antônio Carlos and Cristiano Machado located to the north) have a higher concentration of bus trips to MP municipalities located in the immediate peripheries of the west and to the north. It is evident that the main municipality trip destinations are Contagem, Betim and Ibirité (8%, 5% and 5%, respectively), located to the west of Belo Horizonte; and Santa Luzia, Ribeirão das Neves and Vespasiano (7%, 6% and 5%, respectively), located to the north of Belo Horizonte. ~~According to data from OD 2012, the higher trip percentages originate in the *Campos* named Lindéia (13.56%), Glória (4.35%), Maria Emília (3.64%), Santa Helena (3.56%), Gameleira (3.42%), Pindorama (3.13%) and Lagoinha (3.00%), located in the Noroeste and Barreiro regions, bordering the municipalities Contagem and Betim, corroborating the data presented previously. Alternately, the lowest percentages correspond to Isodoro (0.15%), Santa Lucia - São Bento (0.18%), Jaraguá - Aeroporto (0.26%), Nordeste - Agglomerado (0.32%) and Gutierrez - Grajaú (0.34%), which suggests, in those cases, a lower degree of interaction with MP.~~ According to data from OD 2012, the higher trip percentages originate in the *Campos* located in the Noroeste and Barreiro regions, bordering the municipalities Contagem and Betim (Tab. 1), corroborating the data presented previously. Alternately, the lowest percentages (Tab. 1) suggests, in those cases, a lower degree of interaction with MP.

Table 1. Trip percentages.

The higher trip percentages		The lowest trip percentages	
Origin's *Campos*	Trip (%)	Origin's *Campos*	Trip (%)
Lindéia	13.56	Isodoro	0.15
Glória	4.35	Santa Lucia - São Bento	0.18
Maria Emília	3.64	Jaraguá - Aeroporto	0.26
Santa Helena	3.56	Nordeste - Agglomerado	0.32
Gameleira	3.42	Gutierrez - Grajaú	0.34
Pindorama	3.13	Baleia	0,38

According to the analysis of Fig. 2, the three accessibility dimensions in each *Campo* indicate a heterogeneous spatial distribution. The *Campo* with the highest concentration of the three dimensions (daily metropolitan bus lines, total of daily trips offered by the system, and total number of reached municipalities) was Centro (Tab. 2)~~ (251, 6,483 and 32, as shown in Fig. 2a, 2b and 2c, respectively)~~. This feature was expected, considering the monocentric structure of Belo Horizonte verified by Lessa et al. (2018). Additionally, the *Campo* named Centro represents the capital Central Business District (CBD). Concerning the total number of daily metropolitan bus lines (Fig. 2a), the highest values are concentrated in *Campos* of Centro-Sul, Noroeste and Oeste regions (Tab. 2), along the main road corridors (Via Expressa and Avenida Amazonas) that link the CBD to the main destinations already highlighted: the municipalities of Contagem, Betim and Ibirité. ~~The *Campos* with the highest values were Centro (251), Lagoinha (232), Padre Eustáquio (180), Dom Cabral (178), Prado - Calafate (170), Floresta (158), Alto dos Pinheiros (158), Santa Maria (156), Gameleira (148) and Hospital - Quartel (147).~~ Additionally, located to the north of Belo Horizonte, the regions where the highest values are concentrated were Pampulha, Norte and Venda Nova, bordering the main road corridors (Avenida Antônio Carlos and Avenida Cristiano Machado) that link the CBD to the main municipalities located in the "northern vector," such as Santa Luzia, Ribeirão das Neves and Vespasiano.

Table 2. The highest values of accessibility dimensions

Campos	Bus Lines	*Campos*	Trip Offer	*Campos*	Reached Municip.
Centro	251	Centro	6,483	Centro	32
Lagoinha	232	Floresta	4,497	Lagoinha	32
Padre Eustáquio	180	Padre Eustáquio	4,252	Floresta	31
Dom Cabral	178	Dom Cabral	4,217	Padre Eustaquio	26

Prado – Calafate	170	Prado – Calafate	4,032	Dom Cabral	26
Floresta	158	Santa Maria	4,001	Alto dos Pinheiros	26
Alto dos Pinheiros	158	Lourdes	3.666	Santa Maria	23
Santa Maria	156	Alto dos Pinheiros	3.483	Cabana	23
Gameleira	148	Gameleira	3.346	Prado - Calafate	22
Hospital - Quartel	147	Hospital - Quartel	3.337	Gameleira	21
Lourdes	135	Serra Verde	3.251	Hospital - Quartel	21

In the opposite sense, the *Campos* with the lowest concentration of daily metropolitan bus lines (Tab. 3) were Baleia (1), Leblon (3), Céu Azul (4), Braúnas (5), Barreiro de Cima (6), Vera Cruz (8), Nova Barroca 8), Salgado Filho (8) and Serrano (8). Some of these *Campos* coincide with areas that have the lowest access to the municipal bus system (Lessa et al., 2017), indicating the areas in which the accessibility to the transportation bus system as a whole is precarious, and more expressive investments are necessary to extend the access to collective mode in the municipality.

Table 3. The lowest values of accessibility dimensions

Campos	Bus Lines	*Campos*	Trip Offer	*Campos*	Reached Municip.
Baleia	1	Baleia	6	Baleia	1
Leblon	3	Leblon	45	Vera Cruz	1
Ceu Azul	4	Ceu Azul	82	Leblon	2
Braunas	5	Braunas	101	Ceu Azul	2
Barreiro de Cima	6	Serrano	116	Braunas	2
Vera Cruz	8	Vera Cruz	164	Santo Andre	2
Serrano	8	Ouro Preto - Eng Nogueira	191	Ressaca Velha	2
Salgado Filho	8	Nova Barroca	214	Alipio de Melo	2
Nova Barroca	8	Salgado Filho	235	Maria Emilia	2

The total number of daily bus trips offered by the system originating in Belo Horizonte (Fig. 2b) has a very strong relationship with the number of available bus lines (Fig. 2a). Regarding this dimension, the *Campos* with the highest values were Centro (6,483), Floresta (4,497), Padre Eustáquio (4,252), Dom Cabral (4,217) and Prado – Calafate (4,032), are located in the Centro-Sul, Noroeste and Oeste regions (Tab. 2). Moreover, located to the north of Belo Horizonte, the regions where the highest values are concentrated are Pampulha, Norte and Venda Nova, along the main road corridors that link the CBD to the main municipalities located in the "northern vector." In the north of Belo Horizonte, the *Campo* with the highest value was Serra Verde, located between Belo Horizonte and Vespasiano, where the Administrative Center of Minas Gerais is placed. Considered a metropolitan travel generator pole, the Administrative Center attracts more than 6,443 bus trips from all MR municipalities (Belo Horizonte, 2012). Alternately, the *Campos* with the lowest daily bus trips offered from Belo Horizonte to MP (Tab. 3) were Baleia (6), Leblon (45), Céu Azul (82), Braunas (101), Serrano (116), and Vera Cruz Nogueira (191), all of which are located in peripheral areas of the municipality.

Regarding the third dimension, the total number of MP municipalities that can be reached by direct trips originating in Belo Horizonte (Fig. 2c), the *Campos* with the highest values were Lagoinha and Centro, which had the absolute highest values (both with 32 reached municipalities), Floresta (31), Alto dos Pinheiros (26), Dom Cabral (26) and Padre Eustáquio (26), all of them are located in the Centro-Sul, Noroeste and Oeste regions (Tab. 2), bordering the main road corridors that link the CBD of the Capital to the municipalities of Contagem, Betim and Ibirité. The same was not verified for the "northern vector." The *Campos* with the least reached MP municipalities were Vera Cruz and Beleia (both with 1) and Santo André, Maria Emilia, Alípio de Melo, Ressaca Velha, Braúnas, Leblon and Céu Azul (each with 2), all of which are located in peripheral areas of the municipality (Tab. 3).

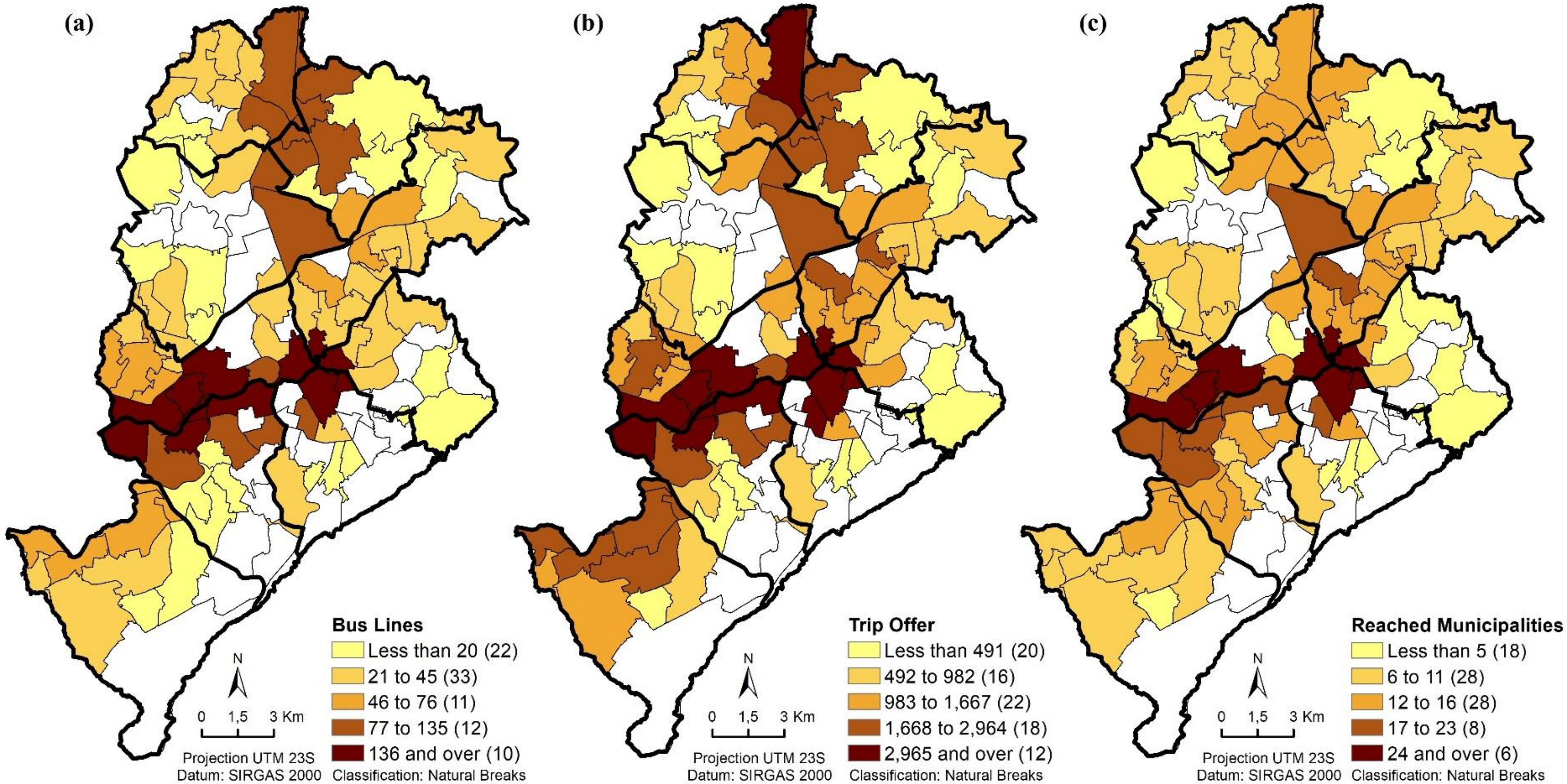


Fig. 2. Total number of metropolitan bus lines (a), metropolitan bus trips offered (b) and MP municipalities reached (c) per *Campo* of Belo Horizonte / MG. Source of data: Digital base SETOP and PRODABEL, OD Survey 2012; Demographic Census 2010.

AI_{BH}, shown in Fig. 3, evidenced patterns and differences in the spatial distribution of accessibility to the metropolitan bus transportation system in the *Campos* of Belo Horizonte. The Centro-Sul and Noroeste regions concentrated the *Campos* with the highest AI_{BH}, for example, Centro (0.79), Lagoinha (0.72), Dom Cabral (0.69), Floresta (0.66), Padre Eustáquio (0.61) and Alto dos Pinheiros (0.58). Moreover, located to the north of Belo Horizonte, the regions where the highest values are concentrated are Pampulha, Norte and Venda Nova. The *Campos* with the highest values were Jaraguá (0.66), Planalto (0.40), Serra Verde (0.39), Vilarinho (0.38) and São Benedito (0.35), all bordering border the Belo Horizonte main road corridors. Additionally, the metropolitan traffic corridors (BR 381 and BR 262) facilitate the bus lines passing through the MP territories, allowing a better offer of bus lines and trips to the other MRBH municipalities. Therefore, it was verified that the proximity to the important road corridors is a decisive factor for the three dimensions analyzed and, consequently, for AI_{BH}. Furthermore, the Centro-Sul region has low AI_{BH} values since demand for metropolitan buses in their *Campos* (Savassi, Carmo – Sion, Cruzeiro – Anchieta) is very low and, in some cases, null (*Campos* in white: Belvedere, Mangabeiras, Santo Antônio – São Pedro, Santo Agostinho, Serra, Funcionários), according to OD Survey 2012. Thereby, the low AI_{BH} values of the Centro-Sul region do not necessarily indicate the limited accessibility of the metropolitan bus system but may suggest its low attractiveness since the region concentrates the higher-income population of the municipality that tends to prioritize (and even expand) the individual motorized modes, as verified by Miranda et al. (2018). In the opposite sense, the low AI_{BH} values of the peripheries of the Leste, Norte, Venda Nova, Pampulha and Barreiro regions indicate unfavorable conditions of the metropolitan bus system accessibility. Similar results were also observed in the municipal bus system (Lessa et al., 2017). The *Campos* with the lowest AI_{BH} values were Baleia (0.001), Vera Cruz (0.011), Leblon (0.013), Céu Azul (0.018), Braúnas (0.019), Barreiro de Cima (0.043), Ribeiro de Abreu Tupi (0.057) and Santo André (0.059).

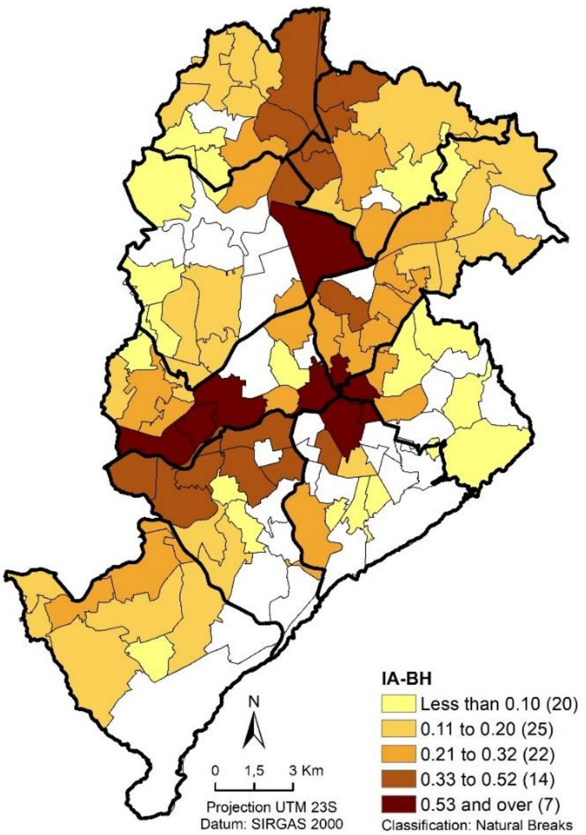


Fig. 3. Accessibility Index of Belo Horizonte (AI_{BH}). Source of data: Digital base SETOP and PRODABEL, OD Survey 2012; Demographic Census 2010.

The fact that there are some *Campos* with high IA_{BH} values does not necessarily indicate greater efficiency in accessibility to the metropolitan bus transportation system. It is important to emphasize that, although there are high IA_{BH} values, the precariousness of the MRBH public transportation services is latent. The inequality of access to the metropolitan bus system also results in the inequity of access opportunities to private and public services, jobs and education offered outside the MRBH center. In addition, 32 of the 120 *Campos* do not have direct access to the MP, reinforcing the lack of accessibility to the metropolitan bus transportation system in Belo Horizonte. The average IA_{BH} is 0.244, suggesting that most of the studied *Campos* have serious accessibility problems

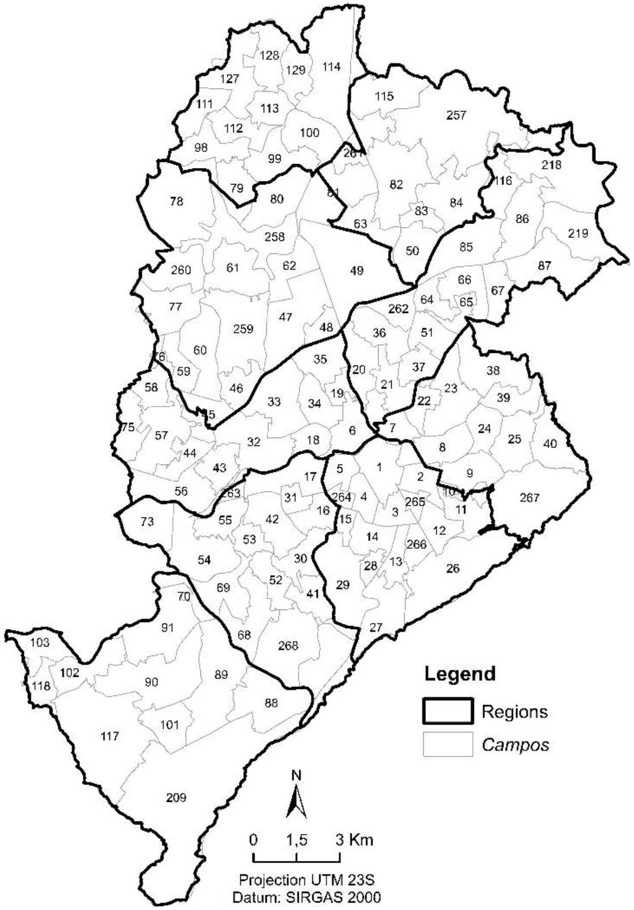
5. Conclusions

Accessibility, considered as the ability to reach desired or necessary destinations, has a considerable dependence on transportation modes (public or private). As is the case in most Brazilian metropolises, Belo Horizonte is characterized by a peripheral urbanization pattern with the reproduction of numerous precarious conditions in the provision of urban accessibility, which contributes to the aggravation of situations of social and economic vulnerability and environmental degradation. The MRBH has the bus as the main mode of mass transportation, which is considered inadequate, especially when considering the level of centrality, the extension of the metropolitan area and the other modes of better capacity and efficiency, such as rapid transit. Among the effects of road transportation as a modal choice, the increase of travel time and congestion due the increase of motorized individual transport draw attention. In this sense, the structuring of a circulation space maintains the privileges of individual transport, and the concerns of the most economically, socially and physically vulnerable groups have been passed over.

The accessibility of the metropolitan bus transportation system in Belo Horizonte is spatially heterogeneous and strongly related to the proximity to the main municipal and metropolitan road corridors (Via Expressa, Avenida Amazonas, BR381 and BR262). Although more detailed analyses are required, the results suggest that the population’s "travel desires" are actually conditioned by the transport infrastructure, which was assessed as inadequate in this work. This argument can be reinforced by the average IA_{BH}, 0.244 in a 0-to-0.798 range, suggesting that most of the studied *Campos* have serious accessibility problems. In addition, the IA_{BH} of Centro-Sul regional *Campos* showed low values. However, these reduced IA_{BH} values do not necessarily indicate the limited accessibility of the metropolitan bus system but may suggest its low attractiveness in these areas, where the individual motorized modes are prioritized and tend to expand. Alternately, the low AI_{BH} values observed at the peripheries of the Leste, Norte, Venda Nova, Pampulha and Barreiro regions indicate unfavorable conditions of the metropolitan bus system accessibility, considering the high metropolitan bus demand in these areas. Ultimately, the analysis showed that six of the seven *Campos* with the best AI_{BH} values are on the western axis towards the main MRBH industrial pole, where important employment opportunities are located.

In general, the results converge on at least two main strands: a) the need for government intervention to reduce the discrepancies in the distribution of the accessibility of the metropolitan bus transportation system in some areas of Belo Horizonte. This need for intervention is especially important in less favored areas since they exert greater demands on transportation by bus given the low level of use of individual means; b) the potential offered by indexes capable of assessing the accessibility conditions in urban areas. In addition to the possibilities of the methodological improvement offered, the proposed index can serve as a subsidy to the formulation of constructive measures aimed at supporting the formation of public opinion and better decision-making to minimize possible distortions in the distribution and provide accessibility.

Appendix A. *Campos* of Belo Horizonte



CAMPOS NUMBER	*CAMPOS* NAME	*CAMPOS* NUMBER	*CAMPOS* NAME	*CAMPOS* NUMBER	*CAMPOS* NAME
1	Centro	41	Mansoes	84	Tupi
2	Sao Lucas	42	Jardim America	85	Sao Gabriel
3	Savassi	43	Dom Cabral	86	Vila Sao Gabriel
4	Lourdes	44	California	87	Gorduras
5	Barro Preto	45	Ipanema	88	Olhos Dagua
6	Lagoinha	46	Jardim Alvorada	89	Bonsucesso
7	Floresta	47	Cid Universitaria	90	Santa Helena
8	Santa Tereza	48	Sao Francisco	91	Barreiro de Baixo
9	Santa Efigenia - Paraiso	49	Jaragua - Aeroporto	98	Ceu Azul
10	Novo Sao Lucas	50	Aarao Reis - 1o Maio	99	Santa Monica
11	Favela da Serra	51	Vilas Reunidas	100	Venda Nova
12	Serra	52	Nova Barroca	101	Barreiro de Cima
13	Carmo - Sion	53	Salgado Filho	102	Tirol
14	Santo Antonio - Sao Pedro	54	Cabana	103	Lindeia
15	Cidade Jardim	55	Hospital - Quartel	111	Lagoa
16	Gutierrez - Grajau	56	Alto dos Pinheiros	112	Rio Branco
17	Prado - Calafate	57	Gloria	113	Leticia
18	Carlos Prates	58	Maria Emilia	114	Serra Verde
19	Sr Bom Jesus	59	Alipio de Melo	115	Sao Benedito
20	Cachoeirinha	60	Castelo	116	Ribeiro de Abreu
21	Renascenca	61	Bandeirantes	117	Vale do Jatoba
22	Sagrada Familia	62	Sao Luiz	118	Jatoba
23	Horto	63	Sao Bernardo	127	Nova America
24	Pompeia	64	Sao Paulo	128	SESC
25	Vera Cruz	65	Sao Marcos	129	Jardim Europa
26	Mangabeiras	66	Maria Goretti	209	Sul do Barreiro
27	Belvedere	67	Vila Brasilia	218	Nordeste Aglomerado
28	Favela Santa Lucia	68	Palmeiras	219	Leste Aglomerado
29	Santa Lucia - Sao Bento	69	Betania	257	Isidoro
30	Favela da Barroca - Querosene	70	Bairro das Industrias	258	Lagoa da Pampulha
31	Barroca	73	Santa Maria	259	Ouro Preto - Eng Nogueira
32	Padre Eustaquio	75	Pindorama	260	Jardim Zoologico
33	Caicara	76	Ressaca Velha	261	Vilarinho
34	Santo Andre	77	Serrano	262	Palmares
35	Aparecida	78	Braunas	263	Gameleira
36	Ipiranga - Santa Cruz	79	Leblon	264	Santo Augustinho
37	Cidade Nova	80	Jardim Atlantico	265	Funcionarios
38	Santa Ines	81	Planalto	266	Cruzeiro - Anchieta
39	Sao Geraldo	82	Floramar	267	Baleia
40	Flamengo - Taquaril	83	Guarani	268	Buritis

Fig. A.1. Identification of Belo Horizonte *Campos*. Source of data: OD Survey 2012.

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