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Is the Location of Warehouses Changing in the Belo Horizonte Metropolitan Area (Brazil)? A Logistics Sprawl Analysis in a Latin American Context

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Abstract: The location of logistics facilities is important for urban freight transport. Several metropolitan regions have identified that logistics facilities are relocating to suburban areas outside city center boundaries. This phenomenon is known as logistics sprawl. In this paper, we present an analysis of the logistics sprawl phenomenon in the Belo Horizonte Metropolitan Area (Brazil) between 1995 and 2015, through spatial analysis. The results show a logistics sprawl indicator (average change in the standard distance to the center of gravity) of 1.2 km (17.8 km in 1995 and 19 km in 2015). In addition, we explored the spatial correlation between socioeconomic data and the location of warehouses. In 2015, 80% of warehouses were located in the high-income area. Additionally, most of the warehouses were located within a two-kilometer buffer from the axis of the road and in a five-kilometer buffer from the railroad. Finally, we defined the service areas of the warehouses considering a maximum distance through the network of 5, 10, and 15 km. In 2015, the 15-km service area had a coverage of 89% of the population in the study area.

Keywords: urban freight transport; logistics facilities; logistics sprawl; cluster analysis

1. Introduction and Background

The location of warehouses can generate a competitive advantage in urban goods distribution [1], since it directly impacts the flow of cargo in cities, and given that warehouses are the origin or destination of a great deal of logistics activities [2]. Metropolitan areas attract warehouses due to the presence of transport infrastructure, potential customers, logistics real estate, and labor [3].

An analysis of logistics sprawl was proposed by Dablanc and Rakotonarivo [4] to understand the impact of the location of warehouses on urban freight transport. Additionally, these authors defined the logistics sprawl phenomenon as the movement of warehousing sites from urban centers to peripheral areas of a metropolitan region. It is important to understand this process due to the negative externalities associated with urban freight transport and the spatial distribution of the facilities [1,5]. Moreover, understanding and measuring logistics sprawl is a key step in assessing the dimensions and impact of the phenomena on urban freight distribution, since increased congestion has an impact on travel time, which causes delays in scheduled deliveries and, consequently, reduces the service level of carriers [1]. Logistics sprawl occurs due to the low cost of land, as well as the availability of areas for new warehouses in peripheral areas rather than in saturated central urban areas [6]. In some cases,

the location of warehouses in peripheral metropolitan areas can be associated with urban expansion rather than with morphological changes in these areas.

As reported in the paper by Heitz and Dablanc [3], one of the main consequences of logistics sprawl is the increase in travel distances, which contributes to increases in fuel consumption, greenhouse gas emissions, and noise pollution, among other problems. The same authors also demonstrated the importance of investigating the spreading of warehouse locations towards metropolitan areas, stimulating the location of logistics areas in urban centers in order to reduce the distances traveled by freight vehicles. Even though the location of logistics facilities, including warehouses, in urban areas is an important factor to consider in the assessment of the externalities of urban freight distribution, it not the only issue to be considered and might not be the most important one when evaluating these impacts [3]. Along with other important spatial, commercial, and operational issues, it is essential to measure and assess the logistics sprawl phenomenon and to determine how the location of logistics facilities affects each urban area.

In this context, the location of warehouses becomes a relevant theme for urban transport planning and urban mobility. However, there are few studies focused on understanding the spatial distribution of warehouses in metropolitan regions [1,2,5–9]. The literature shows investigations that have been carried out in metropolitan areas in Europe [3,4,10–12], in North America [13–15], and for other metropolitan areas around the globe such as Tokyo [5,16]. In Table 1 we present the identified logistics sprawl case studies, indicating the database and the logistics sprawl indicator for each research project. The results indicated that, in most cases, the warehouses sprawled less than 5 km from the original spatial structure within the period analyzed. Additionally, in general, the methodological approach was based on a centrographic analysis [3,4,12–14]. As in the research by Sakai et al. [16], the shortest routes connecting incidents and facilities were computed. Furthermore, we used the dispersion ellipsis to assess the variability of the phenomenon [3], which indicated the direction of the sprawling as presented by Woudsma et al. [15].

Table 1. Databases and logistics sprawl indicators in the reviewed case studies.

Local	Database				Logistics Sprawl Indicator		
	Public	Private	Yellow Pages	OD Survey	<5 km	5–10 km	>10 km
Atlanta (US) [12]	●				●		
Brussels (Belgium) [10]				●	●		
Los Angeles (US) [13]	●						●
Paris [1] (France) [4]			●			●	
Paris [2] (France) [12]			●				●
Paris [3] (France) [3]	●				●		
Randstad (Netherlands) [11]	●				●		
Seattle (US) [14]	●				●		
Tokyo (Japan) [5]				●	●		●
Toronto (Canada) [15]	●						

[1.] Freight terminal. [2.] Express delivery. [3.] All warehouses.

As Table 1 shows, the logistics sprawl phenomenon in Latin American cities has not yet been investigated. In order to address this gap in the literature, this paper undertakes a geographic-based network analysis of the location of warehouses in the context of a Brazilian metropolitan region. In this paper we present an investigation conducted in the Belo Horizonte Metropolitan Area (BHMA) and Metropolitan Belt (BHMAMB). The BHMA has 34 municipalities, 5 million inhabitants, an area of 9460 km^2, and an annual gross domestic product of 228.1 million in Brazilian Real (1 US$ ≈ R$3.50 in April 2018). It is the third largest metropolitan region in Brazil and the seventh largest metropolitan region in Latin America.

The BHMAMB, composed of 50 municipalities with 5.8 million inhabitants and an area of 14,978.9 km^2, encapsulates the BHMA and a municipality further north (Sete Lagoas) where new logistics facilities have been built in the last decade. We hypothesize the significance of the influence

of the new warehouses regarding the shape, the centrality, and the shifting in logistics sprawl in the BHMA. Thus, we computed the logistics sprawl indicator, as proposed by Dablanc and Rakotonarivo [4], and identified the dispersion and direction of the logistics sprawl, as suggested by Woudsma et al. [15]. Additionally, we used a cluster analysis to identify the concentration of warehouses along the railroad and road infrastructure, and to estimate the population served by the warehouses. Finally, we analyzed the impact of the freight villages proposed in the Master Plan of the Belo Horizonte Metropolitan Area on logistics sprawl. Although the previous studies were related to logistics sprawl in an urban sprawl context, the authors did not analyze the relationships among the location of warehouses confronted with road and railway infrastructure, and the population density. We have incorporated these elements into the current approach as one of the key contributions of this paper.

2. Method

In this section, we present the framework for the methodological approach regarding the analysis in Figure 1. We detail each step in the respective subsections.
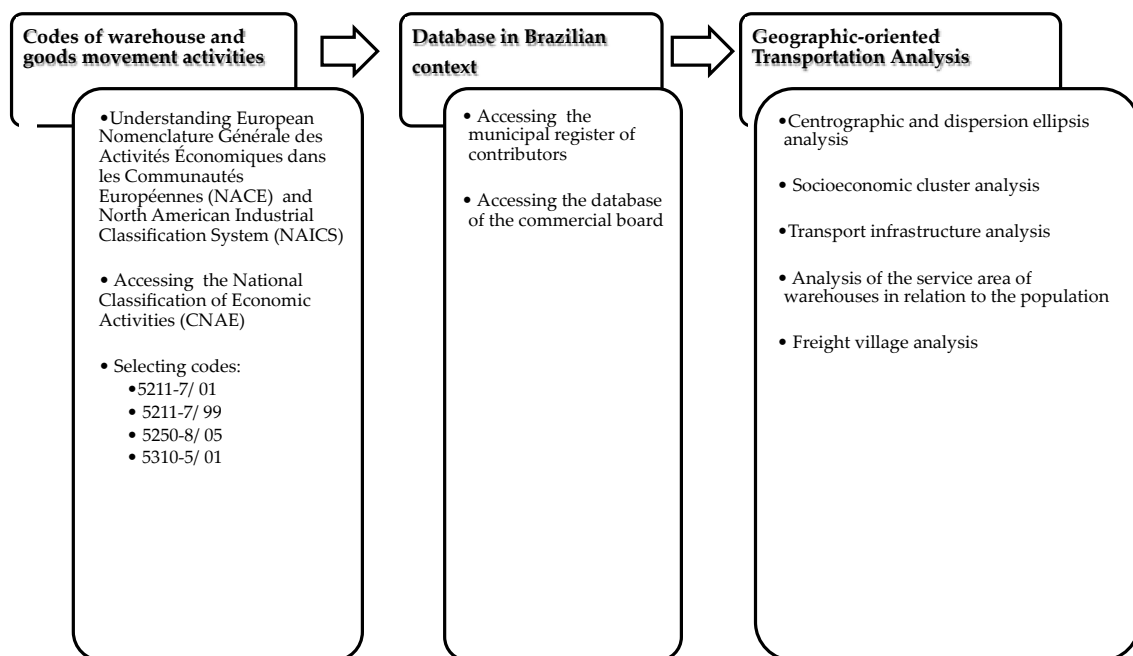
Codes of warehouse and goods movement activities

- Understanding European Nomenclature Générale des Activités Économiques dans les Communautés Européennes (NACE) and North American Industrial Classification System (NAICS)
- Accessing the National Classification of Economic Activities (CNAE)
- Selecting codes:
  - 5211-7/ 01
  - 5211-7/ 99
  - 5250-8/ 05
  - 5310-5/ 01

Database in Brazilian context

- Accessing the municipal register of contributors
- Accessing the database of the commercial board

Geographic-oriented Transportation Analysis

- Centrographic and dispersion ellipsis analysis
- Socioeconomic cluster analysis
- Transport infrastructure analysis
- Analysis of the service area of warehouses in relation to the population
- Freight village analysis

Figure 1. Framework for the proposed methodological approach.

2.1. Codes of the Warehouses and Goods Movements Activities

Firstly, it was necessary to identify the codification of storage and goods movement activities for the initial selection of logistics facilities. All relevant information was organized according certain characteristics in order to guarantee the compatibility of our approach with the European, North American, and Japanese studies previously discussed. We utilized the National Classification of Economic Activities (CNAE) as the main data source for the classification. The CNAE is a Brazilian classification system used to standardize the identification codes of the productive units of administration, contributing to the improvement of the quality of information systems. The CNAE is similar to the NACE (European Nomenclature Générale des Activités Économiques dans les Communautés Européennes) and NAICS (North American Industrial Classification System). We identified similar codes to the ones used by various authors in other related projects [3,11,13–15].

Considering the compatibility of the classification codes of Brazilian, European, and North American economic activities, the codes related to the activities of storage and support for freight transport were identified:

- 5211-7/01: warehouses;
- 5211-7/99: warehouse of goods for third parties, except general warehouses and furniture warehouses;
- 5250-8/05: intermodal transport operator;
- 5310-5/01: post office warehouses.

It is important to highlight the inclusion of the postal service, specifically the Brazilian Post Office (code 5310-5/01), which is not included in the European and North American studies, but is of significant importance to this study as a major public logistics operator in Brazil.

2.2. Databases

Two public databases available for academic research were used to obtain the data regarding the establishments that carry out the activities outlined above and their respective locations:

- The Municipal Register of Contributors (MRC), with information on the legal companies that carry out activities in the municipality. The MRC activities were described considering the CNAE codes. Based on the degree of organization of the municipal administration, this database was generally consistent, complete, and up-to-date.
- The Database of the Commercial Board, which is responsible for executing and administering the services of the public registry of trading companies and related activities in the Brazilian states. In general, these data can be obtained through public consultation (as in the case of São Paulo State) or by the acquisition of the database (as in the case of Minas Gerais State).

2.3. Geographic-Oriented Transportation Analysis

The geographic-oriented transportation analysis of this investigation relied on five complementary analytical approaches detailed in the subsections below.

2.3.1. Spatial Statistics

We measured the spatial–temporal changes in the locations of warehouses in the BHMAMB using centrographic analysis and dispersion ellipsis. Thus, we calculated three parameters that were compared spatially and temporally: (i) mean center of the geocoded points that represented each warehouse in the study area; (ii) standard distance; and (iii) directional distribution, calculated considering the standard deviational ellipse. These three indicators were compared in order to determine the temporal changes from 1995 and 2015 in the spatial structure of the warehouses. The standard deviation ellipses were determined to indicate the direction of the shift considering the gravity center.

2.3.2. Socioeconomic Cluster Analysis

Considering the importance of socioeconomic factors in determining the spatial location of the warehouses, we organized data from the current Brazilian national census on a municipal basis. Thus, the maps that represent the areas of the BHMAMB were overlaid with the highest concentration of the potential market. Given these data, we calculated an index composed of the product between the average household monthly income and the population (InPop) for each spatial unit. The goal of this index is to determine the areas with a high concentration of potential consumers of goods that will demand home delivery.

In order to identify whether there is a statistically valid spatial concentration for the InPop index, we conducted a Getis Ord Gi* cluster analysis considering the municipalities in the study

area. This approach was developed using the spatial analyst tools and spatial statistics tools available through the ESRI ArcGIS 10.3 software. The cluster analysis is a measure of spatial association based on a hot spot analysis tool that considers the calculation of the Getis Ord Gi* statistic [17]. The Z-scores and *p*-values were calculated and then assessed in order to determine whether the data was clustered spatially regarding high and low values. A fixed distance band was considered for the conceptualization of the spatial relationships among units (municipalities), and no distance cutoff value was appropriated for the threshold distance of the hot spot analysis (Getis-Ord Gi*). Only the clustered data with statistical significance was considered in this analysis. For this, we selected only the municipalities with a Z-score higher than 2.0 (showing a clustered pattern of high values of the InPop index) and a *p*-value lower than 0.05 (for 95% significance, indicating strong evidence in support of rejecting the null hypothesis). We identified the number of warehouses located in this area, the spatial relations among the locations of the warehouses, and the potential market after identifying the clustered municipalities based on the InPop index.

2.3.3. Transport Infrastructure Analysis

The objective of the third analysis was to identify the linear locations of the warehouses with respect to the transport infrastructure—roads and railroads. We defined a two-kilometer buffer (Euclidean distance) from the axis of the roads and a five kilometer buffer from the axis of the railroad. Next, we calculated the number of warehouses located in the area of direct influence of the transport infrastructure to identify the concentration of logistics facilities located near the transport infrastructure (road or railroads).

2.3.4. Service Area of Warehouses and Respective Population Served

We calculated the service area analyses determined by the distances in the network of roads located in the area of study. A network service area is derived from a location that considers all the roads available within the specified impedance (time or distance). We used the Network Analyst toolbox from the ESRI ArcGIS 10.3 software (ESRI, Redlands, Canada) to compute the service areas. The solver is based on Dijkstra's algorithm [18,19], and the primary goal is to determine a subset of roads within the network distance. After that, the service area polygons were generated for each location through a triangulated irregular network. We calculated the population served by the warehouses in each range and focused on the years 1995 and 2015 when considering the service areas (5, 10, and 15 km) that were generated.

2.3.5. Analysis of the Freight Village Proposed in the Master Plan of the BHMA

The Master Plan of the BHMA proposed the location of three freight villages within the study area, and therefore the analysis of these facilities was necessary to assess the practical implications of the BHMAMB Master Plan directives in a logistics sprawl context. The logistics sprawl indicators were used to assess the impact. Metrics such as the mean center, the standard distance, and the directional distribution regarding the location of the warehouses and the freight villages were computed. We defined the closest freight village for each warehouse in order to analyze the concurrency among the freight villages and the current warehouses. The Closest Facilities tool of ESRI ArcGIS Network Analyst toolbox was used to compute the closest freight village. The solver of this function measures the distance between incidents and facilities and proposes the shortest route between them. This routing solver is also based on Dijkstra's algorithm.

3. Results

The results are organized and presented in five sections according to the geographic-oriented transportation analysis section, as follows.

3.1. Centrographic and Dispersion Ellipsis Analysis

In 1995, there were 95 logistics facilities classified as warehouses, located in 16 cities of the BHMAMB (with a population of 3.8 million in those municipalities). In 2015, the same area registered 401 warehouses located in 24 cities (with a population of 5.5 million). The main descriptive indicators for the time changes from 1995–2015 of the warehouses' locations are presented in Table 2. The indicators show a growth of 322% in the number of warehouses in the analyzed period (20 years). Annually, the growth was 15.3 warehouses per year. In the study area, the concentrations of warehouses occurred mostly in three cities: in 1995, the cities of Belo Horizonte, Contagem, and Betim registered 82% of the warehouses (46%, 26% and 9%, respectively), while in 2015, this percentage was 79% (39%, 32% and 8%, respectively).

Table 2. Descriptive indicators for the changes of warehouse location in the BHMAMB.

Indicator	1995	2015	Variation (%)
Number of warehouses	95	401	322%
Warehouses/millions of inhabitants	22.69	68.99	204%
Warehouse/1000 km^2	6.34	26.77	172%
Total area of the warehouses (m^2)	364,988	993,296	172%

In Figure 2, the spatial descriptive statistics (mean center, standard distance, and directional distribution) are presented in order to identify the changes in warehouse location in the BHMAC from 1995–2015. In 1995, the standard distance was 17.8 km from the mean center. In 2015, the standard distance was 19 km. These results indicate that the BHMAC did not experience a significant logistics sprawl during the 20 year period (with an overall increase of 1.2 km). In other words, warehouses have sprawled an average distance of 0.06 km per year. Given these results, it is likely that locational studies were carried out to identify the best location near the consumer potential market (which is consistent with our hypothesis).
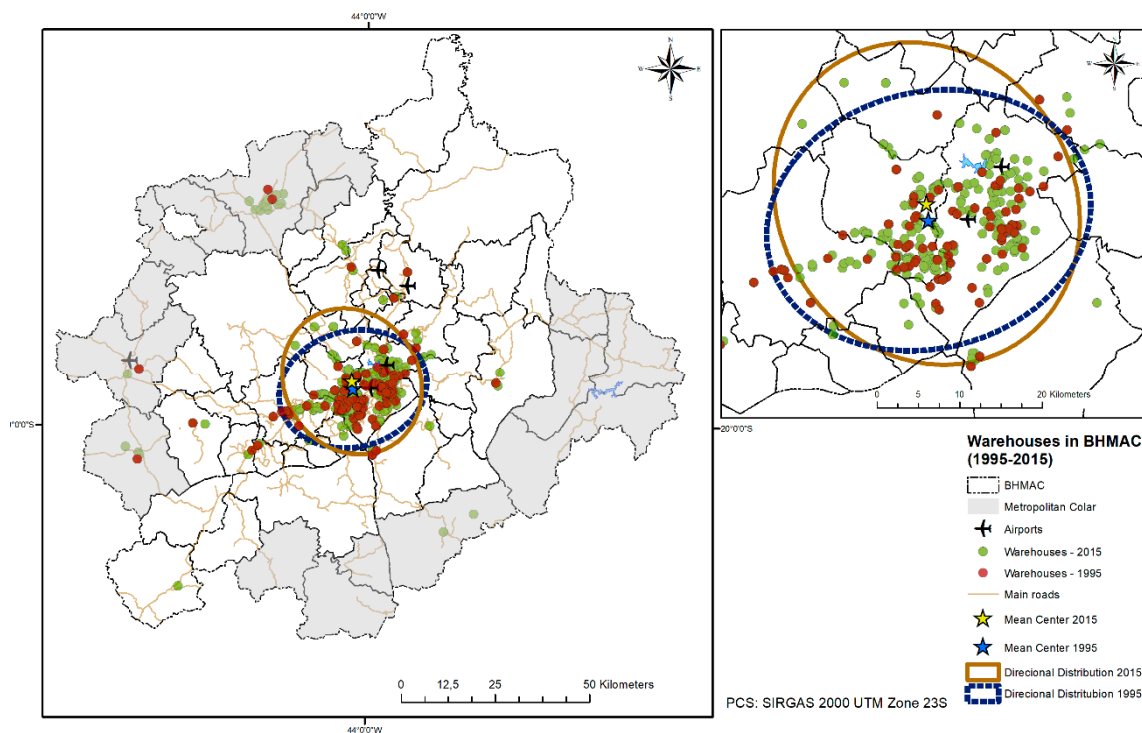

Figure 2. Logistics sprawl analysis in the BHMAMB.

In addition, in 1995, the directional distribution for the warehouses was in the east–west direction (dotted blue ellipse in Figure 2). In 2015, there was a change in the spatial dispersion regarding the location of warehouses, with the main axis from the southeast to the northwest (continuous brown ellipse in Figure 2). The change in the main direction of the directional distribution indicates that there is a new spatial conformation of the warehouses in the BHMAC, consistent with public policies that seek the territorial occupation of the north vector of this metropolitan area. Further, the economic development of Sete Lagoas, as an important city for the BHMAMB, was enhanced. These results corroborate the hypothesis that, in all likelihood, business owners utilized locational studies before the implementation of warehouses.

3.2. Socioeconomic Cluster Analysis

The socioeconomic cluster analysis aimed to integrate the spatial characteristics of the population and the potential market of the area. Therefore, we present the spatial concentration of warehouses in the clustered municipalities with strong potential markets (areas with a high income and population index). The results for the year 2015 showed that 321 of 401 warehouses (80%) are located within the area with a high Getis-Ord index (Z-score values higher than 2.0 represented in red in Figure 3a and p-values lower than 0.05 represented in blue in Figure 3b), which represents 75% of the available area for warehousing. Additionally, the clustered area with a large potential market represents 73% of the BHMAMB population (4.3 million inhabitants). This analysis shows a strong concentration of warehouses overlaying the concentration of a potential market for last mile deliveries (high InPop values). Thus, we can conclude that the majority of warehouses located in the BHMAMB are destined to be logistics facilities for handling goods in order to ship to final consumers and retailers.
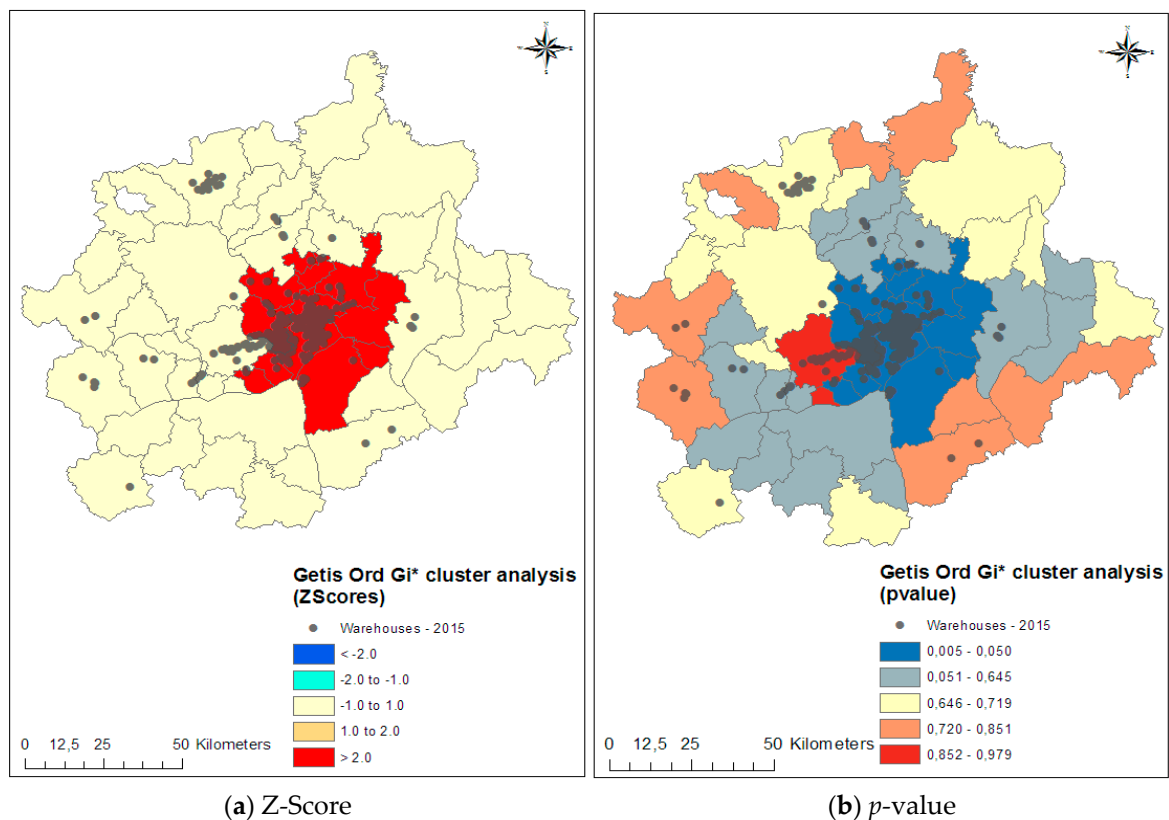

(**a**) Z-Score   (**b**) p-value

Figure 3. Spatial concentration of warehouses in the clustered municipalities: Z-Score (**a**) and p-value (**b**).

3.3. Transport Infrastructure Analysis

We analyzed the location of the warehouses within a maximum Euclidean distance from the road infrastructure, shown in Figure 4. The warehouses are mainly installed close to the transport infrastructure with a strong concentration between Belo Horizonte and the municipalities located along the west direction of the highways BR-381, BR-040, and BR-262. Considering the railroad infrastructure, in 1995 100% of warehouses were located within a 5-km buffer from the railroad axis (95 out of 95). In 2015, 83% of these facilities were located within the same range (332 out of 401). Considering the road infrastructure, 91% of the warehouses are located within a 2-km buffer of the road axis (66 out of 95), and in 2015, 93% were located within the same range (371 out of 401).
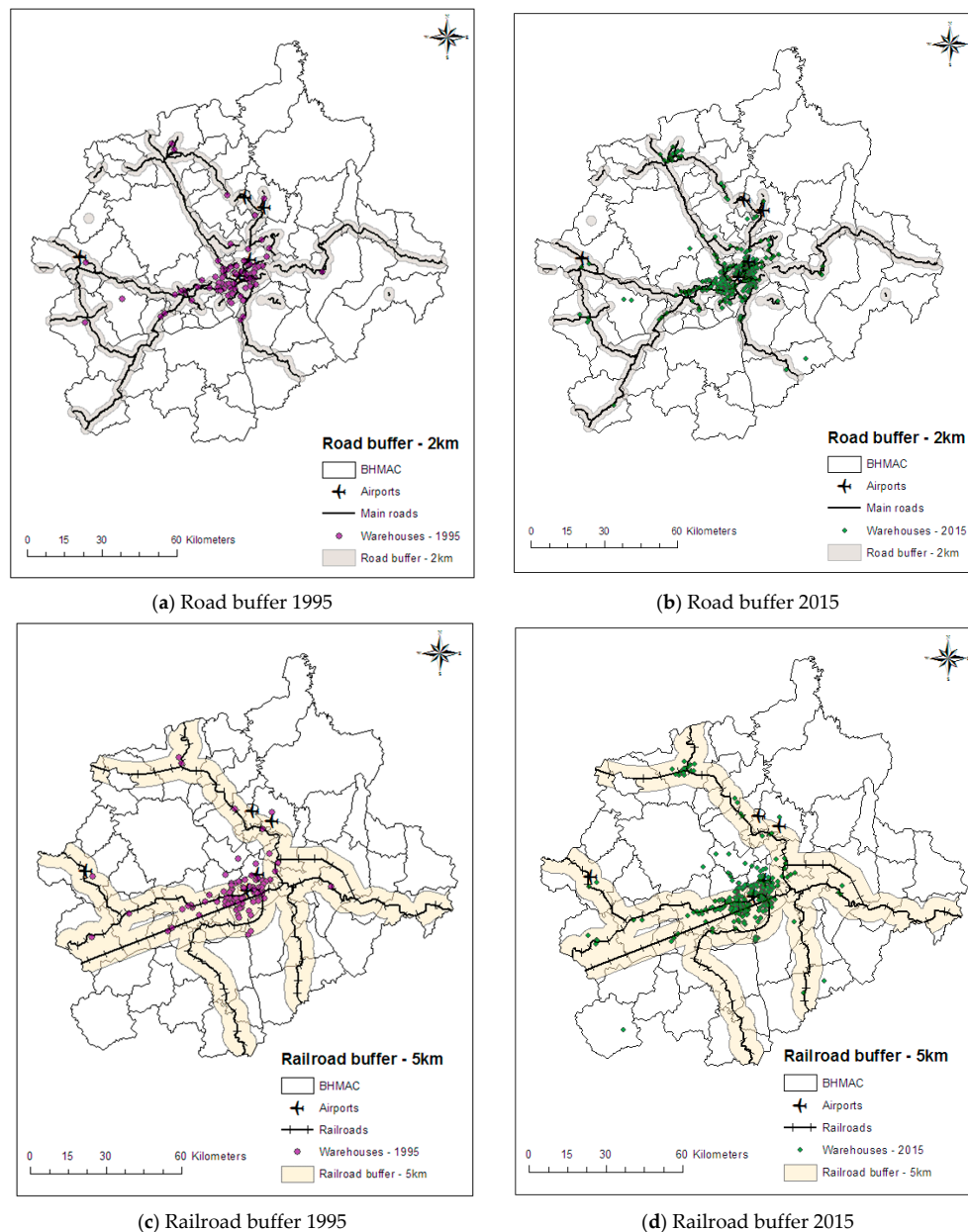

(**a**) Road buffer 1995   (**b**) Road buffer 2015

(**c**) Railroad buffer 1995   (**d**) Railroad buffer 2015

Figure 4. Concentration of warehouses in relation to: (**a**) the road infrastructure in 1995; (**b**) the road infrastructure in 2015; (**c**) railroad infrastructure in 1995; (**d**) railroad infrastructure in 2015.

These results indicate that the proximity to road infrastructure strongly influences the decision of where a new warehouse should be located. As a result, the warehouses are located close to

the clustered municipalities with the highest InPop concentrations (which may be understood as a higher concentration of potential consumption). Still, the concentration of logistics facilities near the intersections of highways is a factor that needs attention from policy-makers and transportation authorities. This concentration and, consequently, the volume of freight vehicles generated by the warehouses have the potential to contribute to the generation of congestion, resulting in negative impacts for the region.

3.4. Service Area of Warehouses and Respective Population Served

The service area of warehouses and the respective population served is important if we consider home deliveries. We analyzed three ranges (5 km, 10 km, and 15 km) to evaluate the number of inhabitants that could be served by the warehouses located in the BHMAC (Figure 5). In Table 3, we detailed the service areas and the percentage of inhabitants served by the warehouses. The results show a wider coverage in the 15-km range. The results also indicated these warehouses have the potential to provide home deliveries, and we may conclude that the warehouses are concentrated in the same areas where the population to be served is located. Additionally, the concentration of people implies a concentration of commercial establishments. Therefore, we can surmise that the warehouses are located near those facilities where there may be a concentration of retail deliveries.
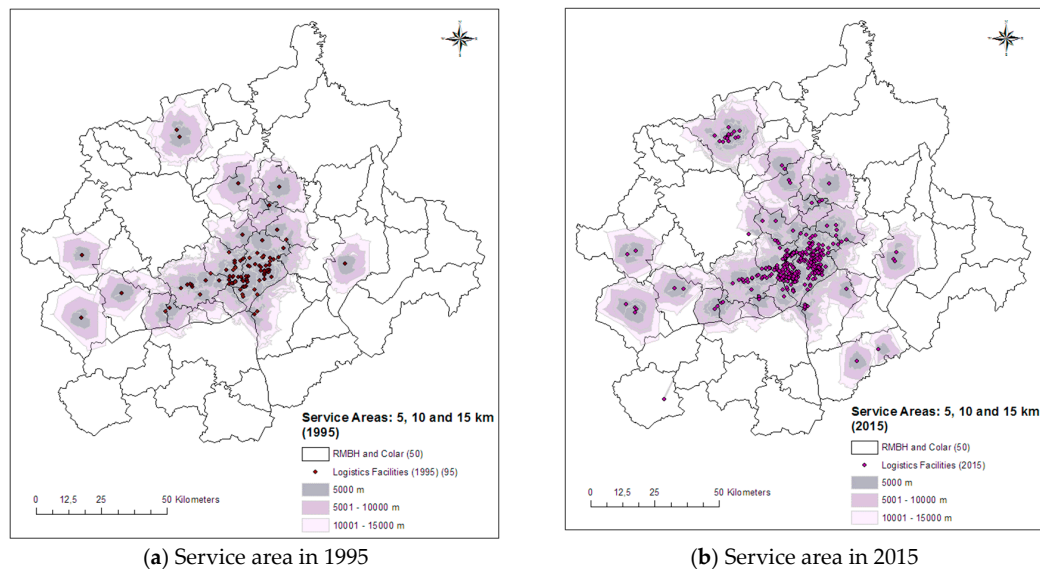

(**a**) Service area in 1995   (**b**) Service area in 2015

Figure 5. Service area of warehouses in relation to the population in 1995 (**a**) and 2015 (**b**).

Table 3. Service area of warehouses.

Indicator	5000 m	10,000 m	15,000 m
Population served in 1995	54.6%	76.6%	86.3%
Population served in 2015	63.7%	81.8%	89.3%

In addition, another analysis considered the spatial structure of the warehouses in 1995 and 2015, with regards to large segments of the population within the study area. The findings showed that the structure of the warehouses for 2015 demonstrated a good spatial distribution for urban deliveries (strong adherence among the cluster of the warehouses and the needs of the local population (market)).

3.5. Analysis of the Freight Village Proposed in the Master Plan of the BHMA

In the final analysis, we considered the BHMA's Master Plan, developed in 2011. This Master Plan predicts the installation of freight villages (short-term for 2015) and public spaces for storage for the

purpose of urban goods distribution in Belo Horizonte, without estimating the flow of vehicles or goods and the market served. Data from CeasaMinas, which is the largest trade center for agricultural and food products in the state of Minas Gerais, showed that in 2015 CeaseMinas attracted 24,170 freight vehicles each month—moving, on average, 1,949,000 tons in that year. Thus, if these logistics platforms had similar flows to CeasaMinas, a new transport infrastructure would be required to ensure freight mobility.

Regarding the Master Plan of the BHMA, we presented the location of the three freight villages (FV) suggested in 2011 (but not yet implemented) in Figure 6. The FV-South is located near the intersection of highways BR-356 and BR-040, in Nova Lima—a place with a high concentration of mining activities and low real estate exploration. The FV-North needs to be prioritized because it is located in a region of accelerated growth, and due to the investments and needs that may arise through the deployment of this infrastructure. In addition, the proximity of the international airport and the railway infrastructure can enable the multimodality of the FV, contributing to the attraction (inbound) of products of small dimensions and high added value, as well as low added value products for the industry. The FV-Northeast is closer to other warehouses already installed. Due the time elapsed since the planning and until possible implementation, these FVs will find a saturated market regarding handling and warehouse capacity, or there may be no land available for FVs. If this is the case, studies are needed to avoid the imbalance and inactivity of the existing logistics infrastructure in the region. We ran a simulation to analyze the LS indicators, including the three FVs in the dataset in 2015, and the results indicate that these installations do not interfere with the dispersion of the direction of the ellipse and do not contribute to the LS indicators.
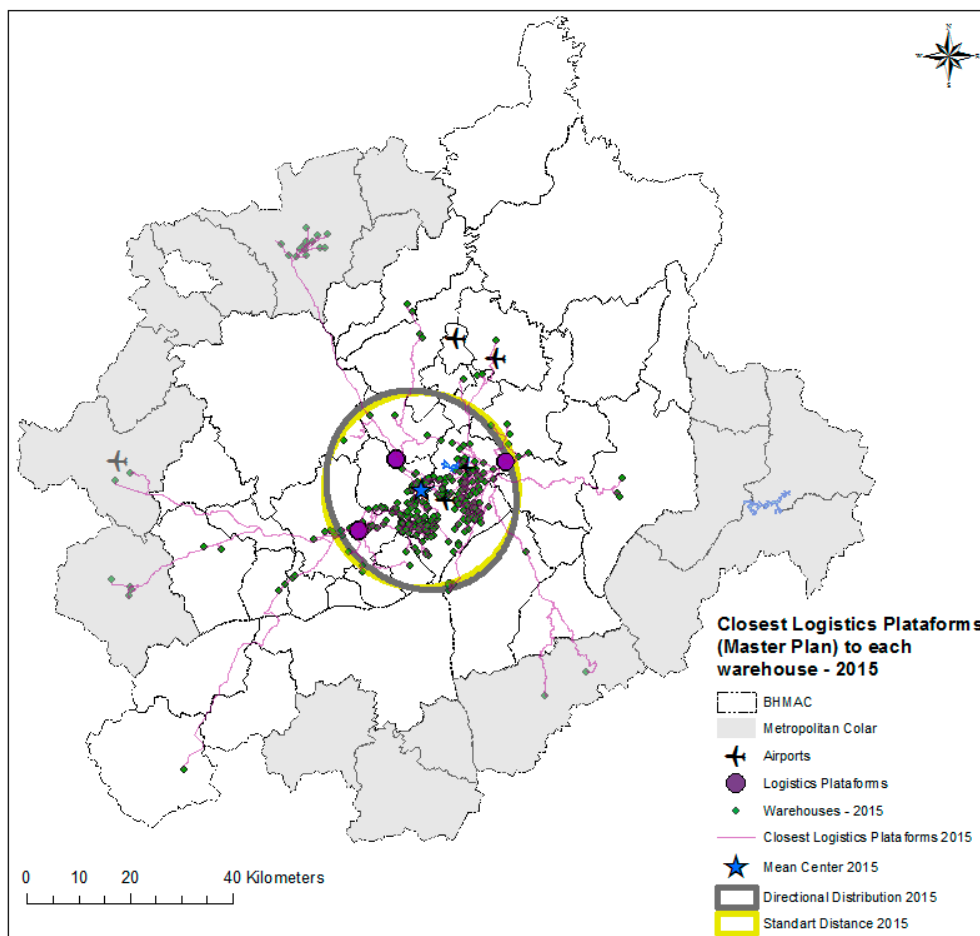

Figure 6. Freight villages proposed in the Master Plan of the BHMA and impacts on logistics sprawl.

These results indicate that there are uncertainties about where and how FVs should be implemented. Thus, the effective insertion of urban freight transport into metropolitan and municipal mobility plans becomes imperative. Attention should primarily be paid to the possibility of creating a logistics sprawl phenomenon with new infrastructure projects if they are undertaken without impact analysis. In addition, these new infrastructure projects need to be supported by green strategies in order to obtain positive results. Furthermore, the implantation of the FVs must be planned together with a strategy of land use and occupation that is well-structured and discussed with the municipalities of the region.

4. Discussion

The results converge with the statement of Dablanc et al. [14], whereby the concentration of warehouses is partially a result of the accessibility to road infrastructure, and may also be a result of public policies that encourage the concentration of certain types of land use. In this sense, we acknowledged that the warehouses have sprawled mainly from the southeast to the northwest, allowing the identification of the strong influence of the Betim and Contagem municipalities in the region as well as the influence of the Centre of Supply of Minas Gerais (CeasaMinas) located in Contagem on highway BR-040—an important highway in the region that causes the concentration of a large number of warehouses. Added to this, the increase in the number of warehouses could be explained by the incentive of the development of the northern region of the BHMA (established in the metropolitan Master Plan). The spatial network analysis offered strategic capabilities to analyze the complexity of the metropolitan environment regarding the dynamics of population and economic activities, and consequently the demand dynamics.

5. Conclusions

The adaptation of the methodology to analyze logistics sprawl in the Brazilian context encourages the development of new studies on the subject in Brazil, making possible future comparisons and the joint discussion of solutions for the distribution of urban goods in a regional context. This is important because of the impact of urban freight transport on road infrastructure; understanding the phenomenon involved allows for the identification of problems and the development of solutions that reduce the use of road infrastructure and, consequently, reduce congestion—one of the main impacts of urban freight transport.

Our findings indicate a significant increase in the number of logistics facilities and minor logistics sprawl in the BHMA. Among the possible causes for the minor logistics sprawl is the investment in the northern region of the BHMA and the public policies adopted by the cities neighboring Belo Horizonte, mainly Contagem and Betim. The current challenge for the metropolitan region of Belo Horizonte is the implementation of integrated municipal and metropolitan strategies to reduce the effects of urban freight transport and, consequently, improve the quality of life of the population. It is fundamental to understand the relationship between transport infrastructure and land policies, location, and freight trip generation in order to define effective public policies. Limitations of this research include the availability of secondary databases which, despite not presenting direct data on urban freight transportation, allowed us to proceed with the proposed analysis. Still, the availability of data could be a challenge for such analyses in other Brazilian metropolitan regions. However, other databases can be used, such as electronic invoice data and freight surveys.

Finally, the data did not reveal the factors of logistics sprawl. Thus, the investigation of the factors that influence the location of logistics facilities and understanding these factors could be useful in improving urban freight planning at the metropolitan level, through informing more efficient public policies.

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