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Analysis of the Mesoacessibility of Bus Lines at UFPB: A Case Study in João Pessoa, PB

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Análise da Mesoacessibilidade das Linhas de Ônibus na UFPB: Um Estudo de Caso em João Pessoa, PB

RESUMO

Objetivo - Analisar a mesoacessibilidade das linhas de ônibus que atendem à Universidade Federal da Paraíba (UFPB) em João Pessoa, visando identificar padrões de distribuição da frota e qualidade do serviço, com foco na otimização do transporte público urbano.

Metodologia - Utilizou-se uma abordagem inovadora que integra dados geoespaciais e análise de Ordens de Serviço dos Ônibus (OSO), processados por meio de programação em Python e bibliotecas especializadas (geopandas, folium, branca, scikit-learn e shapely). Foram examinadas dez linhas de ônibus que conectam a UFPB ao centro da cidade e a áreas periféricas.

Originalidade/relevância - O estudo preenche uma lacuna teórica ao aplicar técnicas de análise espacial para avaliar a mesoacessibilidade no transporte urbano, oferecendo uma metodologia replicável para identificar ineficiências em sistemas de mobilidade. A temática é relevante academicamente devido à crescente urbanização e à necessidade de soluções sustentáveis para problemas como poluição e degradação ambiental.

Resultados - A pesquisa revelou uma distribuição desigual da frota de ônibus, com algumas linhas significativamente sobrecarregadas, impactando diretamente a acessibilidade e a qualidade do serviço.

Contribuições teóricas/metodológicas - O estudo contribui com uma abordagem metodológica inovadora, combinando análise geoespacial. estatística e processamento de dados em Python, permitindo a identificação de padrões de sobrecarga e a otimização de rotas.

Contribuições sociais e ambientais - Os achados podem subsidiar políticas públicas mais eficazes para melhorar o transporte urbano, reduzindo desigualdades na acessibilidade e promovendo mobilidade sustentável, com impactos positivos na qualidade de vida e no meio ambiente.

PALAVRAS-CHAVE: Transporte público. Mobilidade urbana. Análise geoespacial.

Analysis of the Mesoaccessibility of Bus Lines at UFPB: A Case Study in João Pessoa, PB

ABSTRACT

Objective – To analyze the meso-accessibility of bus lines serving the Federal University of Paraíba (UFPB) in João Pessoa, aiming to identify fleet distribution patterns and service quality, with a focus on optimizing urban public transport.

Methodology – An innovative approach was used, integrating geospatial data and Bus Service Orders (OSO) analysis, processed using Python programming and specialized libraries (geopandas, folium, branca, scikit-learn, and shapely). Ten bus lines connecting UFPB to the city center and peripheral areas were examined.

Originality/Relevance – The study addresses a theoretical gap by applying spatial analysis techniques to assess urban transport meso-accessibility, offers a replicable methodology to identify inefficiencies in mobility systems. The topic is academically relevant due to increasing urbanization and the need for sustainable solutions to problems such as pollution and environmental degradation.

Results – The research revealed an uneven distribution of the bus fleet, with some lines significantly overloaded, directly impacting accessibility and service quality.

Theoretical/Methodological Contributions – The study contributes an innovative methodological approach, combining geospatial and statistical analysis with Python data processing, allow for the identification of overload patterns and route optimization.

Social and Environmental Contributions – The findings can support more effective public policies to improve urban transport, reducing accessibility inequalities and promoting sustainable mobility, with positive impacts on quality of life and the environment.

KEYWORDS: Public transport. Urban mobility. Geospatial analysis.

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Análisis de la Mesoaccesibilidad de las Líneas de Autobuses en la UFPB: Un Estudio de Caso en João Pessoa, PB

RESUMEN

Objetivo – Analizar la mesoaccesibilidad de las líneas de autobuses que sirven a la Universidad Federal de Paraíba (UFPB) en João Pessoa, con el fin de identificar patrones de distribución de la flota y calidad del servicio, enfocándose en la optimización del transporte público urbano.

Metodología – Se utilizó un enfoque innovador que integra datos geoespaciales y análisis de Órdenes de Servicio de Autobuses (OSO), procesados mediante programación en Python y bibliotecas especializadas (geopandas, folium, branca, scikit-learn y shapely). Se examinaron diez líneas de autobuses que conectan la UFPB con el centro de la ciudad y áreas periféricas.

Originalidad/Relevancia – El estudio llena un vacío teórico al aplicar técnicas de análisis espacial para evaluar la mesoaccesibilidad en el transporte urbano, ofreciendo una metodología replicable para identificar ineficiencias en sistemas de movilidad. El tema es académicamente relevante debido a la creciente urbanización y la necesidad de soluciones sostenibles para problemas como la contaminación y la degradación ambiental.

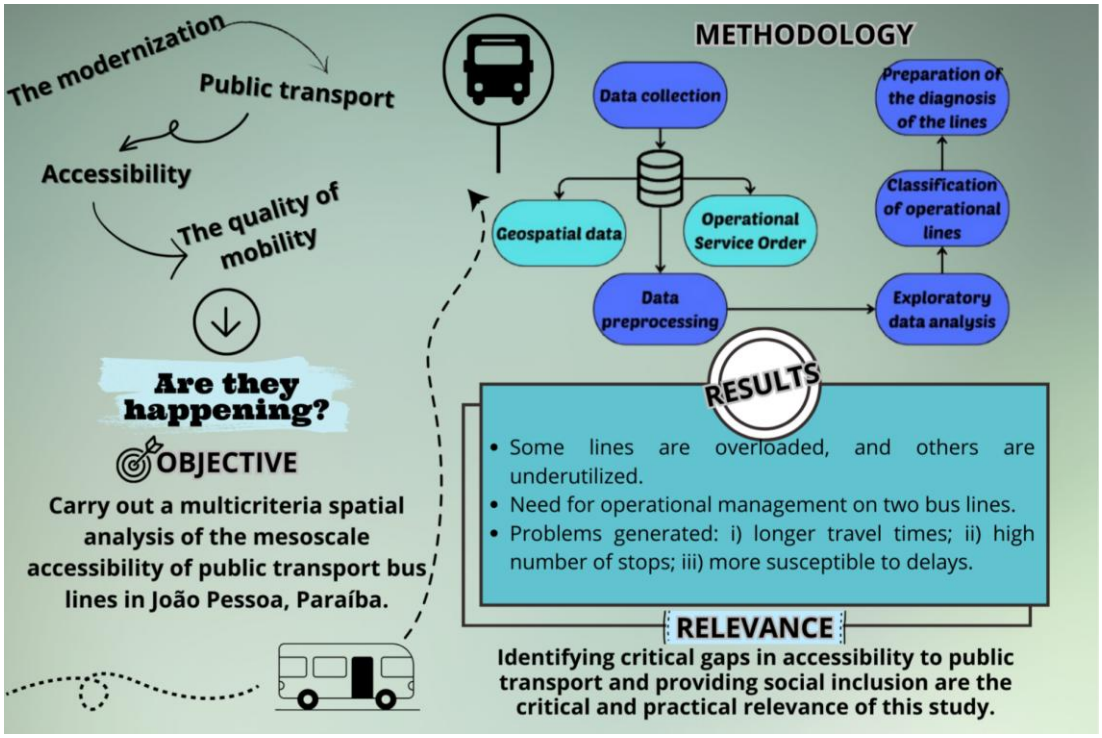
Resultados – La investigación reveló una distribución desigual de la flota de autobuses, con algunas líneas significativamente sobrecargadas, lo que afecta directamente la accesibilidad y la calidad del servicio.

Contribuciones Teóricas/Metodológicas – El estudio aporta un enfoque metodológico innovador, combinando análisis geoespacial, estadístico y procesamiento de datos en Python, permitiendo la identificación de patrones de sobrecarga y la optimización de rutas.

Contribuciones Sociales y Ambientales – Los hallazgos pueden respaldar políticas públicas más efectivas para mejorar el transporte urbano, reduciendo desigualdades en la accesibilidad y promoviendo una movilidad sostenible, con impactos positivos en la calidad de vida y el medio ambiente.

PALABRAS CLAVE: Transporte público. Movilidad urbana. Análisis geoespacial.

GRAPHIC SUMMARY



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1 INTRODUCTION

In the 21st century, cities have been constantly modernizing and facing various challenges, whether due to the demand for services or the impacts resulting from climate change (Javed et al., 2022). Regarding service demand, the pursuit of innovative and sustainable operations for urban development has become increasingly urgent, reorganizing spaces to promote accessibility (Gelpi & Kalil, 2018). Sustainable urban mobility, with a focus on walking, cycling, and public transportation, presents itself as a promising strategy to make—maintain—cities healthier, more livable, and resilient (Gaglione, Zucaro & Cottrill, 2021; Rybarczyk & Shaker, 2021).

Urban mobility plays a crucial role in daily life, especially in Brazilian cities where buses stand out as a fundamental means of transportation (Dos Santos & Lima, 2021). This mode of transport facilitates movement across vast areas, promoting equitable access to various locations within the urban perimeter (Fochesatto, Polli & De Carvalho, 2023). Investing in adequate and safe infrastructure for passengers is essential, as such investments are directly influenced by governmental actions and policies (Dell'Olio, Ibeas & Cecin, 2011; Jane Gibson & Marshall, 2022). The creation of green areas, accessible public spaces, and points of interest also contributes to making the public transport experience more pleasant and enjoyable (Caselli et al., 2021; Jaber, Abu Baker & Csonka, 2022).

When portraying Brazilian urban mobility, it is evident that it heavily relies on the use of private automobiles, creating a vicious cycle perpetuated by the construction of highways and neighborhoods that depend directly on car mobility due to the distance from commercial centers and essential services (Rodríguez & Martinez, 2024; Oestreich, 2023). This scenario leads to various problems, such as increased noise and air pollution, urban warming, environmental degradation, and reduced attractiveness of urban centers for residents and visitors, negatively impacting local commerce and social interactions (Singh, Meena & Agarwal, 2021; Panchal et al., 2022; Leroutier & Quirion, 2022). Due to investments in individual transport, hostile environments for pedestrians and cyclists are also created, making the public necessarily dependent on motorized modes (Nakamura, 2020; Brand et al., 2014; Fitch, Thigpen & Handy, 2016).

The quality of urban mobility in João Pessoa, Paraíba, Brazil, is frequently questioned and is often considered unsatisfactory and unsustainable. Excessive dependence on private automobiles and the lack of adequate planning exacerbates issues related to traffic, pollution, and environmental degradation (De Andrade et al., 2022; Carvalho, 2011). Public transportation, in turn, faces criticism for poor accessibility, primarily serving main streets while leaving neighborhood streets underserved (Acheampong & Asabere, 2022). This situation negatively impacts residents' mobility, as many often lack easy access to nearby bus stops.

The surroundings of the Federal University of Paraíba (UFPB) is a region of great importance and high passenger demand, necessitating a detailed study. The UFPB attracts a significant number of students, employees, and visitors daily, increasing the need for an efficient and accessible public transportation system. Failure to adequately serve this area can result in

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greater mobility difficulties, hindering access to education and work for many (De Farias, 2021; Acheampong; Asabere, 2022). Therefore, the analysis and improvement of public transportation in the regions near UFPB are essential to meet the growing demand and promote more sustainable and inclusive mobility.

Thus, innovative methodologies based on the Python programming language and its libraries were used, enabling efficient data extraction, transformation, and loading. This process ensured a detailed and accurate analysis, expanding the possibilities for applying the results.

Additionally, this study explores mesoscale accessibility, a rarely addressed but essential perspective for integrating mobility and urban planning. By adopting this approach, the aim is to generate insights that contribute to the improvement of public transportation infrastructure, thereby promoting better mobility conditions and quality of life for citizens.

2 OBJECTIVES

This work aims to conduct a multicriteria spatial analysis of mesoscale accessibility in public transportation bus lines serving UFPB and the surrounding regions in João Pessoa, Paraíba. To achieve this goal, the study will: i) analyze the coverage area of public transportation in the surroundings of Campus I of UFPB; ii) identify bus lines with weak mesoscale accessibility based on the intersection criterion; iii) conduct a diagnosis of spatial conditions using statistical methods.

3 BIBLIOGRAPHICAL REVIEWS

When using public transportation, users face challenges such as accessibility, service reliability, travel time, and increased operational costs, which require strategic government planning and investment (Da Silva et al., 2020; Li & Bertini, 2009). To understand and address these problems, spatial analysis emerges as an essential tool to identify regions that need better service and changes in public transportation routes (Liu et al., 2022).

To conduct spatial analysis, it is crucial to integrate different scales to best detail the approach to be achieved. In the context of urban mobility in Brazil, Kneib and Portugal (2017) propose an accessibility analysis at different scales—micro, meso, and macro—allowing for a comprehensive assessment that considers various types of urban transport and promotes sustainable mobility. Accessibility is a key factor in ensuring that public bus transportation is easily reachable. According to Litman (2008), the definition of accessibility has become broader and now refers to the ease with which all individuals can access goods, services, and activities.

Combining scales with accessibility, three modes of analyzing mobility are formed: micro-accessibility, meso-accessibility, and macro-accessibility. Micro-accessibility focuses on the most restricted scale, related to access to activities around the residence by non-motorized modes, such as walking and cycling (Grieco, Portugal & Alves, 2015; Li et al., 2024). Factors such as urban density, land use diversity, urban design, public transportation availability, and proximity to accessible destinations are determinants for the quality of micro-accessibility, impacting habitability, health, and local sustainability (Zegras, 2005).

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On the other hand, meso-accessibility focuses on an intermediate scale, covering areas such as neighborhoods, administrative regions, or municipalities on the metropolitan periphery. At this scale, the focus is on local autonomy, i.e., the capacity of each locality to offer the necessary activities and services for the daily lives of its inhabitants, reducing the need for long and frequent trips (Mello, 2015). Meso-accessibility depends on the integration between public transportation, such as buses, and the structural network, as well as the diversified offer of activities, such as commerce, services, and employment, near residences. The emphasis is on creating local centralities that meet the population's needs, promoting quality of life and urban sustainability (Kneib & Portugal, 2017).

When referring to macro-accessibility, it unfolds into access to the entire territory equitably, usually covering extensive areas such as a metropolitan region. It depends on a high-capacity and qualified public transportation network, such as metro and train, which enables efficient and integrated movement between different localities, promoting connectivity on a broader scale (Kneib, Mello & Gonzaga, 2017; James, Marian & Tukuta, 2022).

The bus lines in João Pessoa are divided into three types of service: i) radial axis, which connect peripheral areas directly to the city center; ii) transversal, which connect different neighborhoods without the need to pass through the center; iii) circular, which perform a closed circuit within the urban perimeter. The municipality has integration terminals and temporal integration, which facilitate the connection between the lines and different modes of transportation, designed to improve system connectivity and efficiency (Ferraz & Torres, 2004).

The analysis of the bus lines' itinerary is an important initial phase for strategic planning development by transportation agencies, aiming to improve the operational scheme of buses (Sahu et. al., 2021; Corazza & Favaretto, 2019).

4 METHODOLOGIES

The method used in this exploratory qualitative-quantitative research adopted five main stages, with the first stage being data collection, which took place in two ways: i) obtaining geospatial data; and ii) obtaining service orders, both of which were obtained through protocols addressed to the City Hall of João Pessoa and the Executive Superintendence of Urban Mobility (SEMOB). The obtained data were pre-processed, analyzed, operational lines were classified, and finally, a diagnosis of the lines was prepared.

4.1 Data collection

To achieve the objectives of this study, the study area was determined, and relevant data on the bus lines operating in the region were selected. As support, the pre-determined areas by the City Hall of João Pessoa (2023) were used, highlighting the regions surrounding UFPB. These regions can be observed through Figure 1.

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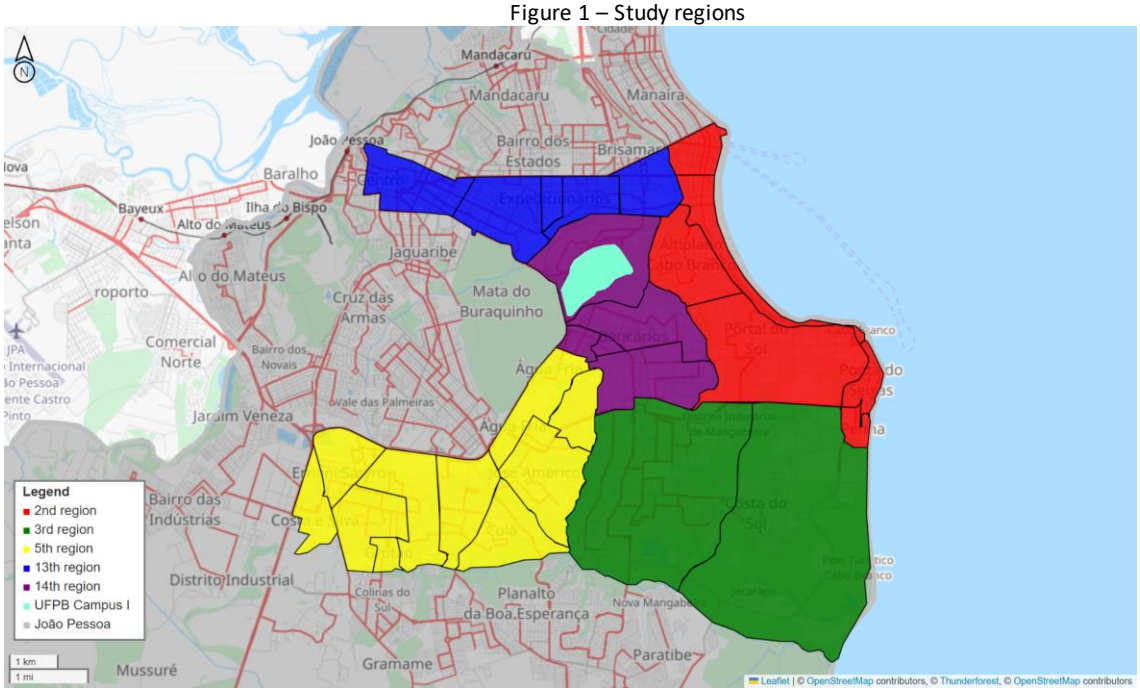
Figure 1 – Study regions



Source: Authors (2024).

With the delimitation of these regions, geospatial data and Bus Service Orders (OSO) were requested from SEMOB. The extraction of this data allowed for the verification of all active bus lines in João Pessoa in the year 2024, comprising radial axis, transversal, integration, and circular lines, making it possible to initially identify the areas being served and detail the routes traveled on the map.

4.2 Data preprocessing

After the extraction of data provided via protocols, the geospatial data and OSO obtained were manipulated so they could be consulted, making it possible to proceed with their processing and analyzing the information provided and those corresponding to the study area.

Upon processing and analyzing the OSO and geospatial information, 10 bus lines operating on the radial axis and accessing the regions around UFPB were identified. The geospatial data, obtained in shapefile format, was allocated to create support environments for the study (ESRI, 1998; GSDI, 2008).

For map insertion, the shapefile was loaded, and the latitude and longitude of the geospatial data were extracted using the geopandas library in Python. After importing the geopandas library and extracting the latitude and longitude data, the folium library in Python was used. The folium library, developed by MIT laboratories, is used for visualizing data in Geographic Information Systems (GIS) maps and is part of the Python ecosystem for manipulating and generating geospatial data visualizations (Ozmen, 2021). The folium interface is well-designed and implemented with Hypertext Markup Language (HTML), suitable for conducting scientific studies and preparing studies by automating tasks in programming.

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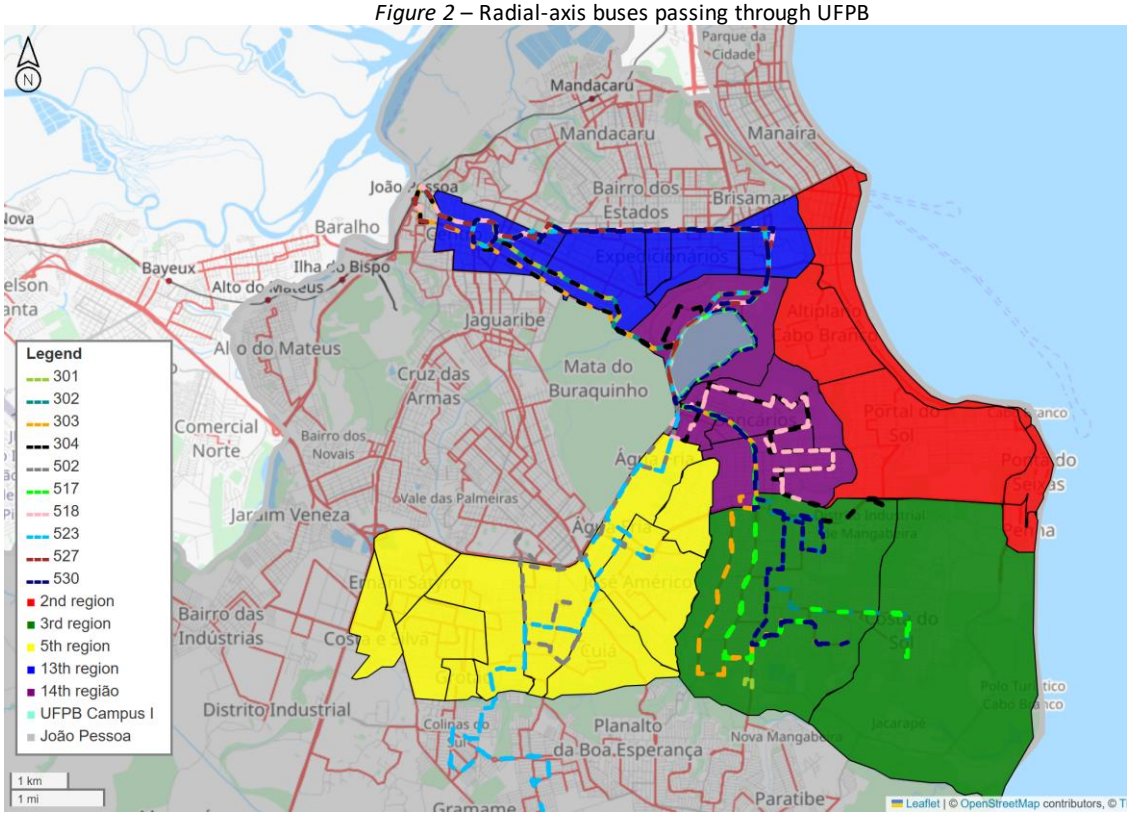
After transforming the map into HTML format, the branca library was integrated, expanding the functionality and data analysis capacity. This library is a derivative of the folium library and allows generating HTML based on Jinja2 (PyPI, 2024), which enabled the creation of the legend and its import into the map. By combining geopandas, folium, and branca with geospatial data, a map presenting the itineraries of the bus lines selected for this study was created, as shown in Figure 2.

Figure 2 – Radial-axis buses passing through UFPB



Source: Authors (2024).

Through this map, it is possible to observe the distribution of radial bus lines that serve UFPB, Campus I, belonging to the 14th region. The buses included in this study, being classified as radial, pass through the 13th region, where the center of João Pessoa city is located, and are distributed to peripheral areas of the city.

4.3 Exploratory data analysis

This analysis included the import of the shapely library in Python to extract data from the itineraries presented in topic 3.2, allowing the evaluation of the efficiency of the public transportation service in terms of coverage and spatial distribution, identifying areas with specific deficiencies that require operational improvements (Gillies, Bierbaum & Lautaportti, 2024). A 400-meter buffer was applied around the bus lines, a distance that represents an ideal limit for better accessibility to public transportation (Furth & Rahbee, 2000; Phuong et al., 2024; Noh, Mohamad & Hamid, 2021). This buffer operation is presented in Figure 3.

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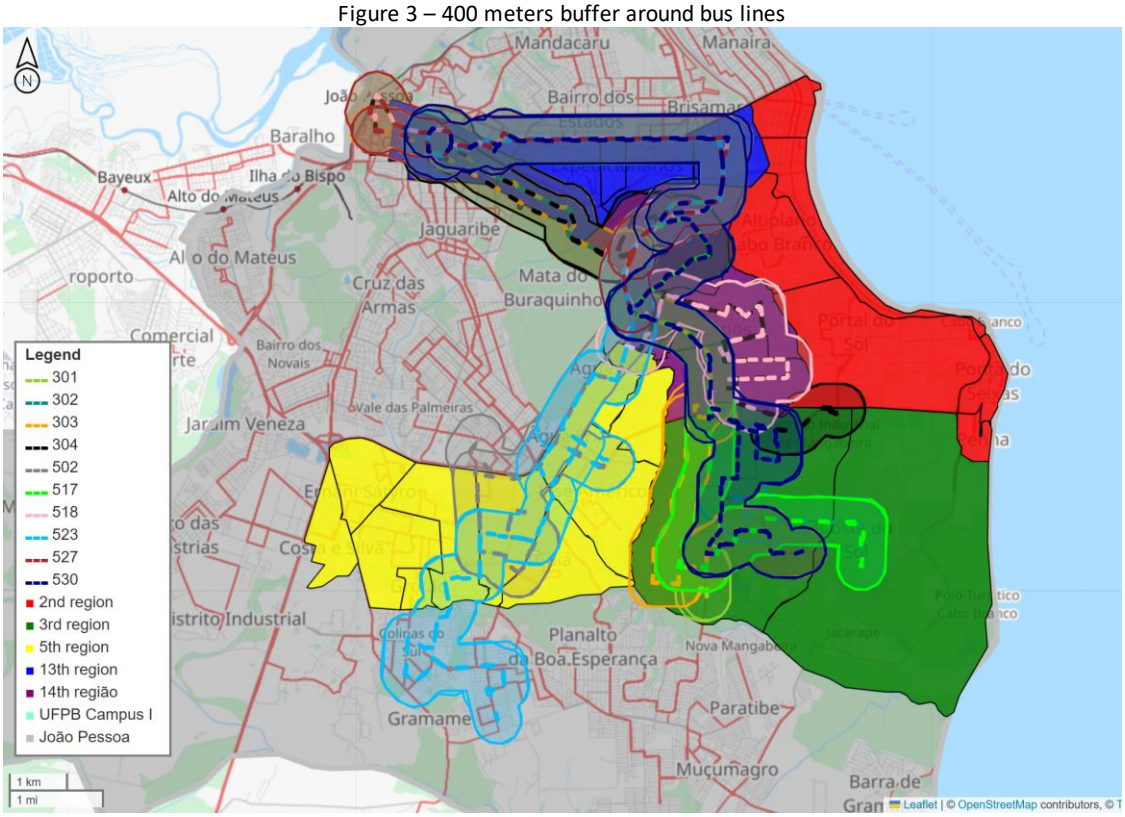
Figure 3 – 400 meters buffer around bus lines



Source: Authors (2024).

With the application of buffers around the public transportation lines, as illustrated in Figure 3, it is observed that in several regions, the service area is partial, such as in the 5th, 3rd, and 2nd regions. On the other hand, regions like the 14th and 13th show a broader and more efficient coverage. Through these operations, it was possible to obtain the areas of each region and the intersection areas, which are presented in Table 1.

Table 1 - Areas of regions and areas of intersection of regions

Region	Area of region (km²)	Total area of intersections (km²)	Percentage (%)
2nd region	10,73	0,67	6,24
3rd region	23,65	10,17	43,00
5th region	15,63	6,65	42,55
13th region	6,79	5,33	78,50
14th region	8,81	8,46	96,03

Source: Authors, 2024.

Only the 13th and 14th regions cover more than 70% of the area. The intersections between the five analyzed regions and the buffer of the bus lines individually were also obtained in this methodology with the application of the previously described libraries and were used to evaluate the accessibility by bus line.

4.4 Classification and Diagnosis of Operational Lines

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The classification and diagnosis of operational lines are based on obtaining intersections between the five analyzed regions and the individual buffers. With this geospatial data, the identification of patterns and outliers—values of intersection that are very far from the majority of values—allows for the easy identification of positions within data analysis (Ghosh & Vogt, 2012). The identification of outliers helps to observe indicators whose values stand out significantly from others, whether extremely high, associated with a high level of accessibility, or extremely low, related to a low level of accessibility.

To analyze and understand data from the intersection set, statistical techniques such as Principal Component Analysis (PCA) can be used. This technique is used to reduce the dimensionality of data, transforming a large number of variables into a smaller set of uncorrelated variables, simplifying data analysis, identifying patterns, and reducing redundancy (Singh & Kathuria, 2023).

The application of PCA allows focusing on the most relevant aspects of the data, identifying the main factors driving a specific phenomenon, facilitating the interpretation of results and strategic decision-making. When used to evaluate public bus transportation, Peng et al., 2018, use it to improve the accuracy of bus arrival time prediction with a support vector machine (SVM) model. To identify the main factors affecting customer satisfaction with public transportation services, Deveci et al., 2019, reduce the number of customer satisfaction criteria to a smaller number of factors, used as input for a quality function deployment (QFD) analysis. Nwachukwu, 2014, groups transportation service quality attributes, collapsing 17 service quality attributes into orthogonal factors, identifying broad areas for stakeholder planning and decision-making.

To evaluate the accessibility of the obtained data fairly, given that the regions have distinct areas ranging from 6.79 to 23.65 km², data normalization was performed using the scikit-learn library in Python. Normalization ensured that all intersection variables in relation to the region's area had the same scale, contributing equally to the PCA result, preventing variables with different scales from disproportionately influencing the analysis results.

Thus, the normalization process allowed PCA to reduce data dimensionality, highlighting the main components that most influence public transportation performance, providing a clearer and more focused view of the most impactful factors.

5 RESULTS

With the application of the PCA method to the data obtained from geospatial analysis, it was possible to identify five main dimensions, each representing a specific set of correlated variables. These dimensions reflect the patterns of variation in the analyzed data. The analysis allowed for determining the percentage of variance explained by each dimension, indicating its contribution to the explanation of the total data variability. To facilitate interpretation, the explained variance accumulated by the principal components was calculated and presented in Figure 4. It is observed that the principal components Dim 1 and Dim 2, which capture the most relevant aspects of the data, together explain 77.69% of the total variance, providing a simplified and easy-to-understand visualization of the information.

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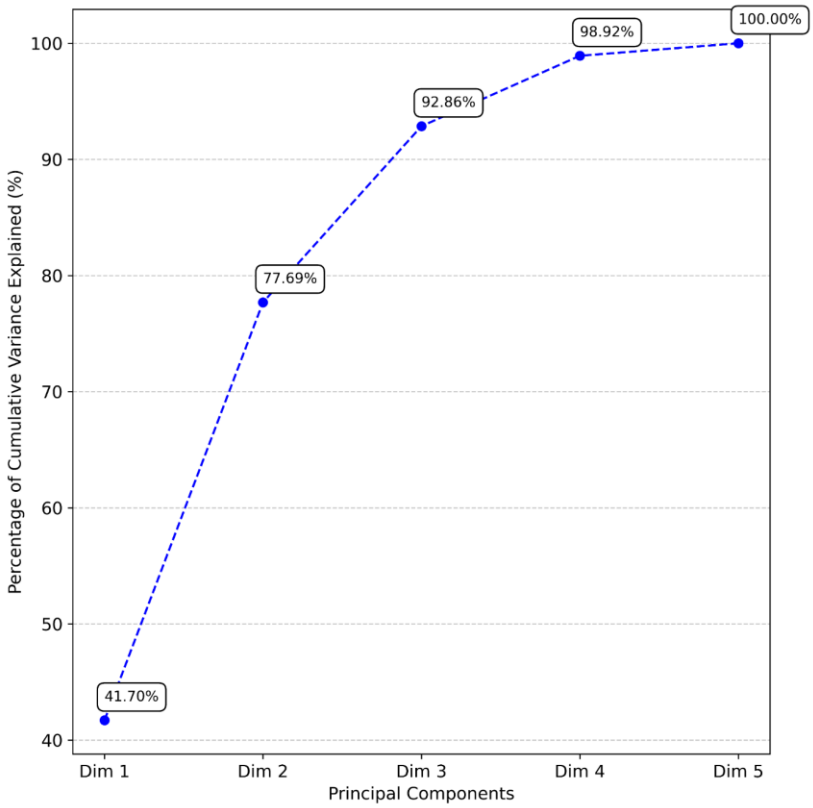
Figure 4 – Cumulative variance explained by principal components



Source: Authors (2024).

With the collected intersection areas and the explained variance analyzed, the linear combination between the values and their relationships was observed, obtaining the correlation circle, presented in Figure 5. The correlation circle allows visualizing the relationship between the original variables and the principal components. The linear combination represented by the vectors is explained as the weighted sum of the original variables, corresponding to the intersections between the analyzed bus line buffers and the defined regions, to form the principal components.

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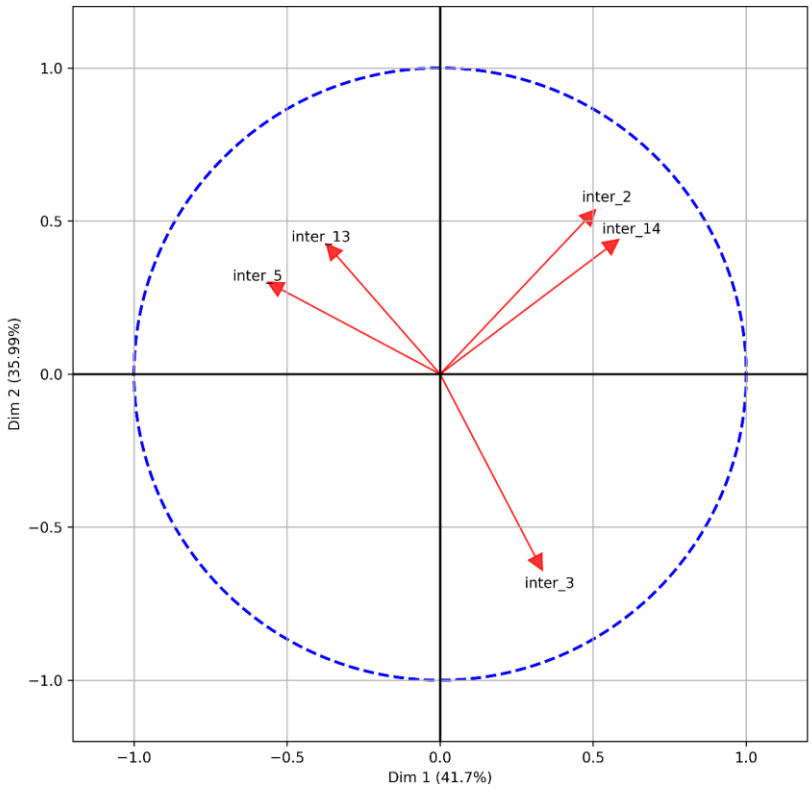
Figure 5 – Linear combination of PCA variables



Source: Authors (2024).

Each vector in Figure 5 shows the contribution of a variable to the principal components. The position of the vectors helps to understand how the original variables relate to each other and to the principal components. By analyzing the intersection data, it is possible to identify criteria that maintain a relationship with each other. The intersection between regions 5 and 13 reveals a positive correlation, indicating a direct relationship between them. On the other hand, the relationship with regions 2 and 14 is characterized by independence, as they approach perpendicularity. Finally, the intersection in region 3 presents a negative correlation when compared to the intersections of regions 5 and 13.

Given a total of 5 dimensions in the applied PCA method, the loads of intersection variables in the five dimensions are presented in Figure 6, where the bars show the loads of the variables used in this work for the respective dimensions. High positive or negative loads indicate a strong influence of a variable in the corresponding dimension. Conversely, loads close to zero indicate a minor or insignificant influence of the variable, helping to understand how the original variables contribute to the dimensions formed by the PCA, providing insight into the data structure obtained and the importance of each variable in different dimensions.

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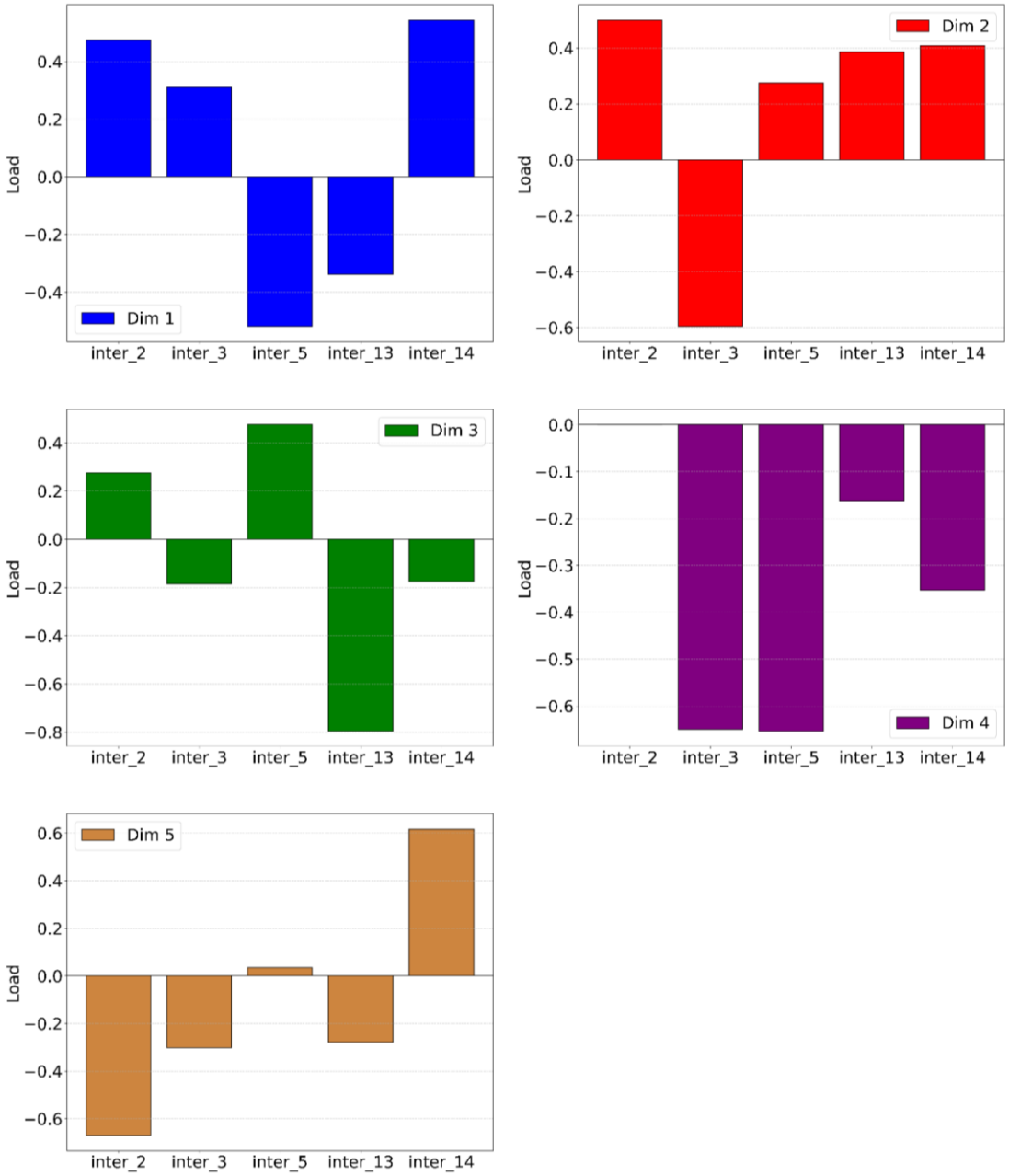
Figure 6 – Load by dimension



Source: Authors (2024).

After verifying the relationship between the variables and the components, the classification of the operational lines was carried out using Equation 1, making it possible to observe the level of meso-accessibility in the regions where the research was conducted, summarizing the information obtained from all the principal components into a single value.

$$PCA_{Index} = \sum_{i=1}^{5} (PC_i \times VE_i) \quad (1)$$

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Where PCA_{Index} is the Principal Component Analysis Index, PC_i are the Principal Components according to Dimension i, and VE_i are the values associated with each component.

Using Equation 1, based on the loads attributed to each principal component and the normalized intersection values over the regions, it was possible to construct Table 2, which indicates the corresponding value by Principal Component PC_i for the bus lines.

Table 2: Values corresponding to the mesoaccessibility of bus lines

Bus line	PC_1	PC_2	PC_3	PC_4	PC_5	PC_{Index}
301	0,114817	-1,37158	0,607539	0,613964	0,248267	-0,31365
302	0,455674	-1,81295	0,472672	0,045853	0,021922	-0,3877
303	0,40867	-1,83047	0,457413	-0,02174	0,051165	-0,41971
304	2,824442	1,995991	1,214926	0,090171	-0,22843	2,083408
502	-2,22457	0,88947	0,69443	-0,38643	-0,00742	-0,52576
517	0,630298	-0,63891	-1,11738	-0,76676	-0,20587	-0,18529
518	0,631649	1,796698	-1,00864	0,161204	0,513254	0,772313
523	-2,23627	0,899841	0,707064	-0,40729	-0,00274	-0,52621
527	-1,18455	0,390396	-0,98604	1,198858	-0,3372	-0,43396
530	0,579838	-0,31848	-1,04199	-0,52783	-0,05296	-0,06345

Source: Authors, 2024.

From Table 2, it is possible to verify that the values indicate the contribution of each component to the total variance of the data. In this analysis, with a total of 10 buses, eight have negative scores, while only two have positive scores. This demonstrates a discrepancy in accessibility among these buses, indicating that most lines have similarly accessible fleets when compared to the two positive lines, which are lines 304 and 518. Therefore, there is a need to operationally manage the bus lines and their respective routes, allowing them to pass through paths that serve a larger portion of the population, facilitating accessibility, serving passengers more closely, and improving the dynamics of bus routes. A boxplot graph was created to identify outliers, clearly showing the difference in values, presented in Figure 7.

Considering meso-accessibility, bus lines 304 and 518 serve four of the five analyzed regions (see Figure 2 and Figure 3), presenting high accessibility scores compared to the other lines in this study, as shown in Figure 7. However, the extensive routes required for high geographical coverage and increased accessibility result in lower service quality for several reasons. Among them are: i) longer travel times; ii) a high number of stops; and iii) more susceptibility to delays caused by traffic, traffic lights, and other factors.

The efficiency of lines 304 and 518, although covering longer routes, does not necessarily imply better service for a larger number of people. Efficiency is better evaluated by considering the population density of the areas served. Lines that cover high-density population areas can provide more effective service, even with shorter routes, as they serve more passengers in less time and with greater reliability.

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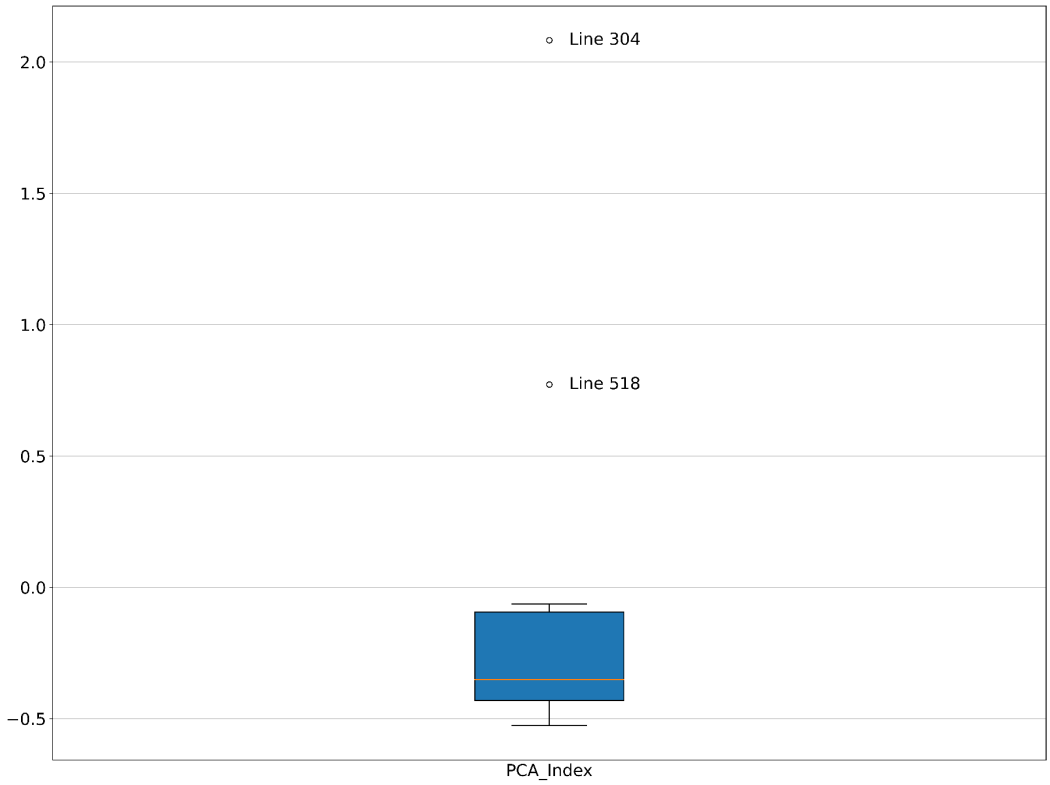
Figure 7 – PCA_{Index} boxplot



Source: Authors (2024).

Therefore, when analyzing accessibility in relation to efficiency, it is seen that there is a need to review the service between lines 304 and 518, improving the route itineraries so that the service is sufficient and better distributed. Lines with extensive lengths to generate greater accessibility may require more frequent vehicle maintenance and renovations due to the increased effort in serving different areas and the increased distance traveled within the service zones. This unequal distribution suggests that some lines are overburdened, creating challenges in terms of frequency and travel time, while other lines may be underutilized in the analyzed regions.

6 CONCLUSIONS

This research analyzed the meso-accessibility of public bus transportation in João Pessoa, focusing on the Federal University of Paraíba (UFPB), using Python programming language libraries for geospatial data analysis. The use of innovative computational tools allowed for the identification of accessibility patterns in a more precise and replicable manner, providing relevant contributions to both the field of urban mobility and the application of analytical methods in medium-sized cities in Brazil.

The results highlighted significant inequalities in the coverage of the public transportation system. Some regions were identified as underserved, facing difficulties in accessing bus lines, while others showed an overload of demand. The application of a 400-meter buffer along the bus lines allowed for a clear visualization of these gaps and the proposal of data-

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based solutions. The analyses suggest that this unequal distribution not only impacts travel time but also affects user satisfaction and well-being, reinforcing the need for structural interventions in system planning.

This study also stands out for proposing a restructuring plan based on geospatial data, with the strategic redistribution of bus lines to serve underserved areas and reduce travel time by up to 20%. Additionally, it suggests the implementation of a pilot plan in critical areas, allowing for the evaluation of the impacts of reconfiguration before its expansion to the entire city.

Despite its contributions, this research has limitations. The focus on a single area of the city may not fully reflect the reality of the public transportation system in João Pessoa. Additionally, aspects such as bus frequency, waiting time, and the density of the regions were not addressed in depth. To overcome these limitations, future studies could include real-time data analyses, travel time estimates, and the expansion of the focus to other areas of great relevance, such as tourist spots and high-density population regions.

The scientific and practical relevance of this study is evidenced by the identification of critical gaps in public transportation accessibility and the potential to directly influence public policy formulation intended for social inclusion. In addition to promoting greater social inclusion, the proposed solutions contribute to the reduction of pollutant emissions and the improvement of urban quality of life, aligning with the Sustainable Development Goals (SDGs). Finally, this work reinforces the importance of integrating urban planning and data analysis as essential tools for sustainable urban development.

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CONTRIBUIÇÃO DE CADA AUTOR

Nós, Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima, utilizamos os seguintes critérios para a participação de cada autor:

- **Concepção e Design do Estudo**: Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima tiveram a ideia central do estudo e ajudaram a definir os objetivos e a metodologia.
- **Curadoria de Dados**: Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima organizaram e verificaram os dados para garantir sua qualidade.
- **Análise Formal**: Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima realizaram as análises dos dados, aplicando métodos específicos.
- **Aquisição de Financiamento**: Os recursos financeiros necessários para o estudo foram obtidos pelo Programa de Pós-Graduação em Engenharia Civil e Ambiental da Universidade Federal da Paraíba (PPGECAM), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Prefeitura municipal de João Pessoa, Superintendência Executiva de Mobilidade Urbana (SEMOB), Sindicato das Empresas de Transporte Coletivo Urbano de Passageiros no Município de João Pessoa (SINTUR) e Laboratório de Análise do Trabalho (LAT) da Universidade Federal da Paraíba.
- **Investigação**: Marcelo Chalub Llanco quem conduziu a coleta de dados ou experimentos práticos.
- **Metodologia**: Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima desenvolveram e ajustaram as metodologias aplicadas no estudo.
- **Redação - Rascunho Inicial**: Marcelo Chalub Llanco e Luiz Bueno da Silva escreveram a primeira versão do manuscrito.
- **Redação - Revisão Crítica**: Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima revisaram o texto, melhorando a clareza e a coerência.
- **Revisão e Edição Final**: Marcelo Chalub Llanco, Luiz Bueno da Silva e Jessica Helena de Lima revisaram e ajustaram o manuscrito para garantir que atende às normas da revista.
- **Supervisão**: Luiz Bueno da Silva e Jessica Helena de Lima coordenaram o trabalho e garantiram a qualidade geral do estudo.

DECLARAÇÃO DE CONFLITOS DE INTERESSE

Nós, **Marcelo Chalub Llanco, Luiz Bueno da Silva** e **Jessica Helena de Lima**, declaramos que o manuscrito intitulado "**Análise da Mesoacessibilidade das Linhas de Ônibus na UFPB: Um Estudo de Caso em João Pessoal PB**":

1. **Vínculos Financeiros**: Não possui vínculos financeiros que possam influenciar os resultados ou interpretação do trabalho. Nenhuma instituição ou entidade financiadora esteve envolvida no desenvolvimento deste estudo.
2. **Relações Profissionais**: Não possui relações profissionais que possam impactar na análise, interpretação ou apresentação dos resultados. Nenhuma relação profissional relevante ao conteúdo deste manuscrito foi estabelecida.
3. **Conflitos Pessoais**: Não possui conflitos de interesse pessoais relacionados ao conteúdo do manuscrito. Nenhum conflito pessoal relacionado ao conteúdo foi identificado.