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RESEARCH PAPER

Methodology Proposal for Accessibility Analysis of a Road Corridor for Freight Transport

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ABSTRACT
In recent years changes in freight transport demand, both locally and internationally, have significantly increased cargo flows to and from logistics centers. As a result, it is essential to develop effective methods for assessing freight accessibility to road corridors designated for land cargo transportation. This paper proposes a methodology that facilitates the freight accessibility analysis to a road corridor for land cargo transportation. The accessibility analysis considers several key variables such as the mobilized tons, the overall conditions of the roads, the route lengths connected to the corridor, and origin-destination nodes associated with the productive chains mobilized by this transportation mode. We validate the methodology through a comprehensive case study conducted in Colombia. The results reveal road corridors such as Llanos de Cuivá (Yarumal) -La Apartada (Córdoba), and Soledad- Barranquilla present the lowest accessibility measure and require infrastructure investments to enhance road corridor accessibility and promote the efficient transportation of goods. Furthermore, it offers valuable insights into characterizing areas with significant cargo generation and reception, enabling targeted improvements in transportation industry responsiveness.

KEYWORDS: *Freight accessibility; Freight transport; Logistics corridor; Land cargo transportation; Origin-destination nodes; Productive chains.*

1. Introduction

Changes in freight transport demand for local and international trade in recent years have led to an increase in cargo flows mobilized from countries towards logistics centers for import and export. Analyzing the accessibility of the origin and destination points to the routes generated by road freight transport allows the identification of opportunities for economic and infrastructure development [1], [2]. It has also shown a direct relationship between the accessibility degree on commercial terms with the growth of a region's economy [3].
Analyzing the accessibility of the goods to road infrastructure for freight transportation allows for identifying the geographical areas that must be concentrated efforts to improve response time, transportation costs, and competitiveness for goods mobilization [4], [5].
Démare et al., [6] define a road corridor for freight transport as the set of routes through which goods are mobilized in order to bring them up to customers. A road corridor for freight transport is created by a road network that allows goods transport to and from origin-destination nodes. As [6], [7] stated, information tools are used to visualize the amount of freight mobilized, the routes connected to the road corridor, and even the performance indicators for the corridor as the mobility, accessibility, travel time, road infrastructure quality, etc.
Owen and Levinson [8] defined mobility as the ease of moving through the road corridor regardless of the destination. [1] established accessibility as the difficulty level of individuals, communities, or other entities to access a place, measuring the ease with which it manages to transport goods from the origin to the desired destinations. Accessibility and mobility are metrics considered in some transport systems studies [9–11], to analyze road corridor performance.
Freight transportation is essential for any country's economy [12]. It is used to transport goods and raw materials to and from production and consumption centers. Different reports presented by international entities such as the World Economic Forum (WEF) and the World Bank have pointed out the need to generate tools to analyze countries' road networks.

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According to the Global Competitiveness Index generated by the WEF, in Colombia, the infrastructure item presents a score of 64.3 out of 100 [13], positioning the country at the 81st spot among 141 nations [14]. Arvis et al., [15] ranked Colombia at 71 of 167 countries evaluated in terms of logistics efficiency with a Logistics Performance Index of 2.81 over 5. This study highlights infrastructure as the factor with the lowest score for Colombia, followed by transport time. For logistics costs, it is evident that Colombia bears higher transport expenses in comparison to its regional counterparts, with land transport standing out as the most expensive, reaching a value of USD 1,535 per container in 2015. This exceeds Brazil's cost of USD 990 per container for the same mode of transport [16].
Efficient freight transport is crucial for the economic growth and competitiveness of Colombia. However, according to the National Logistics Survey 2020 by the National Planning Department [17], the sector is facing major challenges. These challenges include poor road infrastructure, which was cited as the biggest problem by 22% of logistics services providers [18], high travel time and freight cost, inadequate planning, and lack of investment [19]. It translates to increased costs, decreased supply chain efficiency, and environmental damage.
Recognizing these critical issues, this research aims to address the following research questions:
RQ1: How can we effectively assess the accessibility of Colombian road corridors for freight transport, considering the specific challenges of poor infrastructure, inadequate planning, and limited investment?
RQ2: How can the results of this analysis inform strategic decision-making and investment priorities to improve freight accessibility and efficiency in Colombian road corridors?
To answer these questions, we propose a novel methodology for freight accessibility analysis specifically tailored to the Colombian context. Our approach builds upon existing concepts of accessibility and mobility but adds a crucial layer of Geographic Information System (GIS)-based analysis.
GIS is designed to store, manipulate, analyze, and map geographic information [20]–[22]. This technology equips us with the capability to scrutinize the networks of freight road transport comprehensively, encompassing information about road speeds, the state of road infrastructure, and the volume of freight transported [22–24]. The use of GIS in this methodology allows us to comprehensively assess freight network performance by integrating key variables like road conditions by capturing the impact of infrastructure quality on accessibility, mobilized tons by quantifying the volume of freight using the corridor, and route connectivity by analyzing the network of routes connected to the corridor.
This novel combination of factors and GIS technology distinguishes our study from previous research, offering a more nuanced and data-driven understanding of freight accessibility in Colombia. Overall, this research seeks to develop a powerful tool for enhancing freight accessibility and efficiency in Colombia, contributing to a more robust and sustainable transportation sector. It could help to support strategic decision making in infrastructure, to identify the bottlenecks and priorities intervention to improve the flow of freight and even improve environmental sustainability.
The structure of this paper is as follows: section 2 presents a literature review on freight accessibility analysis. Section 3 describes the proposed methodology. In section 4 the results of the implementation on Colombian case are presented. Finally in section 5 conclusions are presented.

2. Accessibility Analyzed from the Land Freight Transport

Accessibility is a concept used in various fields such as urban and geographical planning, transportation planning, and even policymaking. It is a concept that can be poorly defined and understood, leading to decisions that do not solve the main problems of the analyzed area [25], [26]. Although the concept of accessibility has been developed parallel to the mobility concept, they are often confused, however, mobility refers to the performance of the transport system itself, while accessibility adds the interaction of the transport system, with additional layers of analysis (people, goods, etc.) [27]. Thus, accessibility can be defined as the ease that a transport system provides to people, goods, or entities for access to a destination. It allows to identify efficiency of a transport system, the places or nodes that should be intervened to improve efficiency, to analyze the use given to a geographical area, and to get information for decision-making for sustainable planning of the transportation system [28].

Mora et al., [24] present the generation of indicators for decision-making based on accessibility analysis. They proposed a transport model that allows controlling the inventory, analyzing, and planning the infrastructure of territory through a GIS that calculates the accessibility levels from an economic and social point of view. Aguilar et al., [29] carried out a study on the accessibility of the English population by rail to a geographical area, presenting indicators of territorial coverage, widespread accessibility and timely availability. Duran-Fernandez and Santos [23] developed a model to analyze accessibility in pathways Mexico, considering variables of regional and international markets, social variables, economic variables depending on the demand and infrastructure variables. Martínez Sánchez-Mateos et al., [30] developed a study of accessibility according to the interconnection of some areas considered of influence in the city of Madrid. To do so, initially set the study regions and transport networks that connect them to finally analyze three components: integration, interaction, and trend of competitiveness of the region. Kanuganti et al., [31] presented a methodology based on multi-criteria decision-making using fuzzy aggregation, which regards accessibility to health centers in some districts of India, considering aspects such as travel time, quality of service in the installation, and transport quality.

Applying the accessibility concept over the freight corridors analysis allows addressing problems such as traffic congestion, poor road conditions, transportation costs, and travel time, understanding the accessibility as the measure of the available opportunities for road access [32]. A road corridor accessibility can explain interaction possibilities between different territory regions, to evaluate this accessibility, it is necessary to know the available ways to access it (transport modes and types of vehicles), road's physical conditions and the social or political issues that affect the access, etc., [29].

At the present study the Medellin-Barranquilla corridor is selected based on the information presented in the Origin-Destination Survey done by the Colombia's Ministry of Transport in 2020, this survey writes down the road corridors through which most of the goods are mobilized. The Medellin-Barranquilla corridor mobilized about 20% of the cargo transported on Colombia [33].

3. Methodology

To propose a methodology that enables the analysis of accessibility, it is necessary to keep a focus on decision-making and planning policies that have a positive impact on factors such as congestion levels, transit rates through a road network, and investments in road infrastructure [25]. Some methodologies to analyze the accessibility of transport systems and road freight corridors, their metrics or indicators are described below.

3.1. Methodologies for accessibility analysis

According to the available information and the variables of interest to study accessibility, these methodologies have been used: based on infrastructure, based on land use or location, based on people, and based on utility [25], [27]. Each of the above methodologies seeks to generate metrics or indicators that integrate the variables considered of interest according to the object of analysis.

- Infrastructure-based accessibility is a methodology that globally analyzes the geographical area under analysis. The metrics used under this approach are usually the travel speed and the time lost due to congestion. However, it often does not differentiate between mobility and accessibility indicators or consider crucial components such as soil characteristics or the locations of access points.
- Accessibility based on location or land use employs distance as a metric to measure the degree of relationship between two or more points within the same area, considering the distance as a straight line between the points. The contour or curve measure, known as cumulative opportunities, indicates the number of times the analyzed area can be reached within an amount travel time, distance, or cost. The metric of potential accessibility, or gravity-based metric, requires knowledge of the potential opportunities for accessing a geographical area and the variables being analyzed.
- People-based accessibility analyzes time and space constraints for individuals. The main disadvantage is that it requires having information about each of the individuals who mobilize in the system.

- Utility-based accessibility interprets accessibility as the outcome of a series of transportation decisions. It uses metrics proposed by the theory of random utility model and entropy.
- The implementation of any of the described methodologies converges in measuring levels of accessibility to a region or a specific point. It aims to identify the factors that contribute to increased costs, travel time, and the restrictions that hinder the improvement of a transportation system [24].

3.2. Methodology proposal for accessibility analysis of a road corridor for freight transport in Colombia

This methodology presents a novel approach for accessibility analysis of the Medellín–Barranquilla logistic corridor and its geographic area of influence based on the most recent data from the origin-destination survey [33] and identifying the productive chains that use the logistics corridor. The authors use GIS tools to analyze the data on the amount of cargo and the main segments in this corridor allowing them to measure the individual accessibility index to provide information that supports decision-making in the different segments of the entire logistics corridor.

The methodology proposal for analyzing the accessibility of the road corridor is driven by five stages based on location metrics (Figure (1)). The main metric for the analysis is gravity. Identifying productive chains mobilized in the corridor is based on studies conducted by Colombia's Ministry of Transport [33] and includes the representative productive chains selection on the Medellin-Barranquilla corridor using the Pareto principle.

The incidence area definition relates to the zone near where the cargo origin-destination nodes for the road accessibility analysis are located. An analysis of the volume of cargo transported in the incidence area is condxucted, considering the tons mobilized through different routes within the corridor and the fixed distance on each side of the road. The road corridor segmentation is performed based on the analysis of cargo volume, considering the origin-destination nodes and the patterns of tons transported along them.

Various authors have proposed different methods for conducting accessibility analysis. These methods incorporate various characteristics, such as mobilization time, the presence of individuals or entities within the analysis area, and the different points from which these entities can mobilize [8], [34]. In this paper, the accessibility analysis requires dividing the road sections into subsections of approximately 50 km. Equation (1) represents the calculation of accessibility by the method of gravity [8].

$$A_{i,gw} = \sum_{j=1}^{n} O_j C_{ij}^{-2} \quad (1)$$

Where O_j represents the number of nodes that can access each subsection j and C is the cost to move from i to j. For this paper, C represents the tons transported. Table 3 describes the information required to calculate the gravity measure for accessibility using the number of x_i nodes accessing subsection and tons handled in the same subsection.

The summary weighted accessibility of the corridor is calculated using Equation (2) [8].

$$A_{pw} = \frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} P_i} \quad (2)$$

Where A_{pw} is the average weighted accessibility of all sub-sections and P_i are the mobilized tons in the section i.

Other values of interest to identify the sections that require intervention due to a low rate of accessibility are the mean and median as they consider all the values obtained in the different sections and allow comparison of the accessibility index using as a reference the logistic corridor. The equations (3), (4) and (5) represent the calculation of the mean and median if the number of sections is odd or even.

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (3)$$

Where x_i is the accessibility value on the subsection i, and n is the number of subsections.

$$\tilde{x} = x_{\left(\frac{n+1}{2}\right)}, \text{ if n is odd} \quad (4)$$

$$\tilde{x} = \frac{x_{(n/2)} + x_{(n/2+1)}}{2}, \text{ if n is even} \quad (5)$$

Where n is the number of subsections.

Fig.1. Methodology stages for accessibility analysis in road corridors for freight transport in Colombia

4. Result and Discussion

The methodology development described in Figure (1) is presented below. The origin-destination survey [33] is considered an information source, and a GIS is used to support displaying this information.

4.1. Productive chains selection

In the road corridor Medellin-Barranquilla a total of 98 productive chains are mobilized [33]. The identification and selection of productive chains that are representative for freight transport on the selected corridor, allows an accessibility analysis considering the products with greater economic importance according to their percentage share of the freight. The Pareto principle is used to categorize the productive chains. Products with greater mobilization in the road corridor and a cumulative percentage not exceeding 70% of the total tons mobilized are classified in category A. Table 1 presents the representative productive chains mobilized in the road corridor. Category A encompasses 22 out of 98 chains within the road corridor. Additionally, 22 productive chains were classified under category B, while 54 fell into category C.

4.2. Incidence area definition

The incidence area defines the distance within which the nodes and the network that connects the corridor will be analyzed. An incidence area of 50 km is defined for the freight mobilization in the Medellin-Barranquilla corridor, considering the actual distance from the nodes to the freight corridor.

Figure (2) presents the routes located around the logistics corridor, connecting generation and reception nodes for freight within the incidence area. Based on the origin-destination survey [33], 54 municipalities serve as both origins and destinations for productive chains. These nodes are linked to the road corridor within a 50 km distance.

4.3. Freight volume analysis

Table 2 presents the representative production chains mobilized through the different routes connecting to the road corridor within the incidence area, as well as the percentage of total value mobilized by each representative productive chain at each node, and the cumulative percentage of the total mobilized freight.

We drew a heat map to visualize the load generation and reception nodes in the productive chains (Figure (3)). It shows that the origin-destination nodes (Medellín and Barranquilla) have a higher concentration of productive chains. In the west, one node has a high freight concentration (Montería). Freight generation and reception along the Sahagún-Sabanalarga route are low despite the high number of nodes.

Tab.1. Identification of representative production chains in the corridor Medellin-Barranquilla

Productive chain	Mobilized Freight (%)	Accumulated	Productive chain	Mobilized Freight (%)	Accumulated
Stone, sand, gravel, and dirt	8.21%	8.21%	Cattle	2.05%	54.51%
Corn	6.12%	14.34%	Chocolate, sweets, and ranch groceries	2.03%	56.54%
Iron and Steel	5.81%	20.15%	Glassware and glass containers	1.99%	58.53%
Cement, lime, and plaster	5.57%	25.71%	Forages and livestock feed	1.79%	60.32%
carbonated soft drinks	4.77%	30.49%	Roots and Tubers	1.66%	61.98%
Other items National Market	4.22%	34.71%	Building work. cement tiles	1.63%	63.61%
Beers and fermented beverages	4.20%	38.91%	Fruits except bananas	1.60%	65.21%
Wood	2.86%	41.76%	Animal manure	1.51%	66.72%
Milk unmanufactured	2.83%	44.60%	Various hardware	1.41%	68.13%
Rice	2.81%	47.41%	Wheat flour	1.33%	69.47%
Mails and parcels	2.73%	50.14%	Other productive chains	30.53%	100.00%
Meat and fish	2.32%	52.45%			

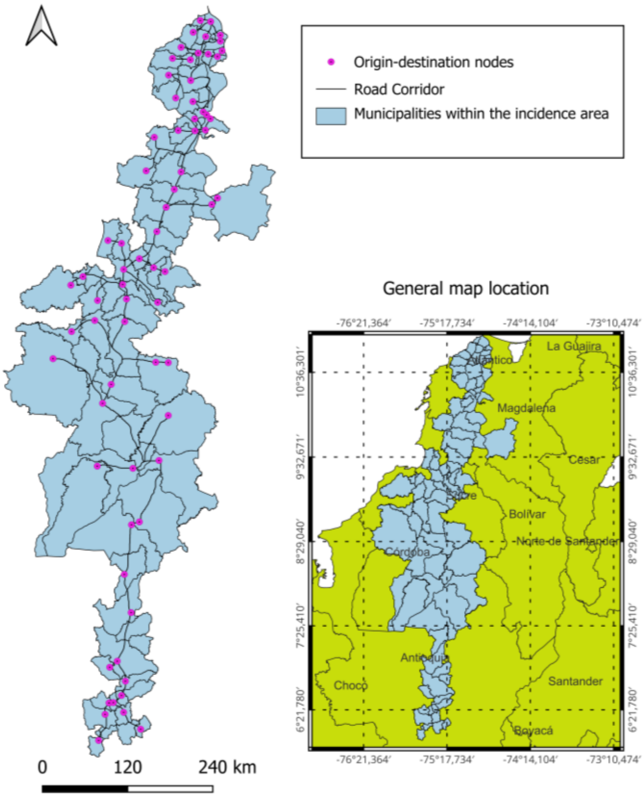

Fig.2. Incidence area map of the road corridor

Tab.2. Mobilization of representative productive chains in origin-destination nodes inside the incidence area

Mun[1]	RPC[2]	CP[3]	Mun[1]	RPC[2]	CP[3]	Mun[1]	RPC[2]	CP[3]
Medellín	62.9%	20.6%	Chima	12.7%	50.4%	Santa Lucía	78.4%	65.9%
Copacabana	24.3%	20.7%	Momil	22.9%	50.4%	Suan	76.4%	66.0%
Girardota	17.3%	20.8%	Lorica	64.8%	51.2%	Campo de la Cruz	32.9%	66.2%
Santa Rosa de Osos	56.7%	22.3%	Sampués	68.7%	51.3%	Ponedera	82.0%	67.0%
Entrerrios	43.2%	22.5%	Sincelejo	72.0%	57.9%	Sabanalarga	64.1%	67.2%
Yarumal	48.2%	23.2%	Tolú	84.6%	58.9%	Luruaco	93.5%	67.8%
Cáceres	0.0%	23.2%	Toluviejo	93.2%	61.8%	Repelón	82.7%	68.0%
Ayapel	90.4%	23.3%	Corozal	44.7%	63.7%	Baranoa	66.0%	68.7%
Puerto Libertador	0.0%	23.3%	San Juan de Betulia	100.0%	63.7%	Polonuevo	47.0%	68.8%
Planeta Rica	88.8%	27.2%	Sincé	66.7%	63.9%	Usiacurí	60.4%	68.8%
Montería	72.3%	44.7%	Ovejas	91.3%	64.0%	Piojó	2.9%	68.8%
Pueblo Nuevo	96.2%	44.8%	El Carmen de Bolívar	82.8%	64.7%	Santo Tomás	84.4%	69.2%
San Marcos	79.4%	46.4%	Zambrano	92.0%	64.8%	Palmar de Varela	81.0%	69.2%
Buenavista	0.0%	46.4%	San Jacinto	69.6%	64.9%	Juan de Acosta	74.6%	69.4%
Ciénaga de Oro	34.8%	46.7%	San Juan Nepomuceno	75.9%	65.0%	Malambo	68.8%	69.7%
Cereté	41.4%	48.7%	Arjona	75.3%	65.1%	Galapa	97.0%	70.0%
Sahagún	84.3%	50.2%	Arroyo Hondo	75.5%	65.4%	Soledad	79.2%	70.2%
Chinú	37.7%	50.4%	Mahates	83.0%	65.4%	Barranquilla	68.0%	100.0%

[1]Municipality [2]Representative Productive Chains percentage [3]Cumulative mobilized percentage

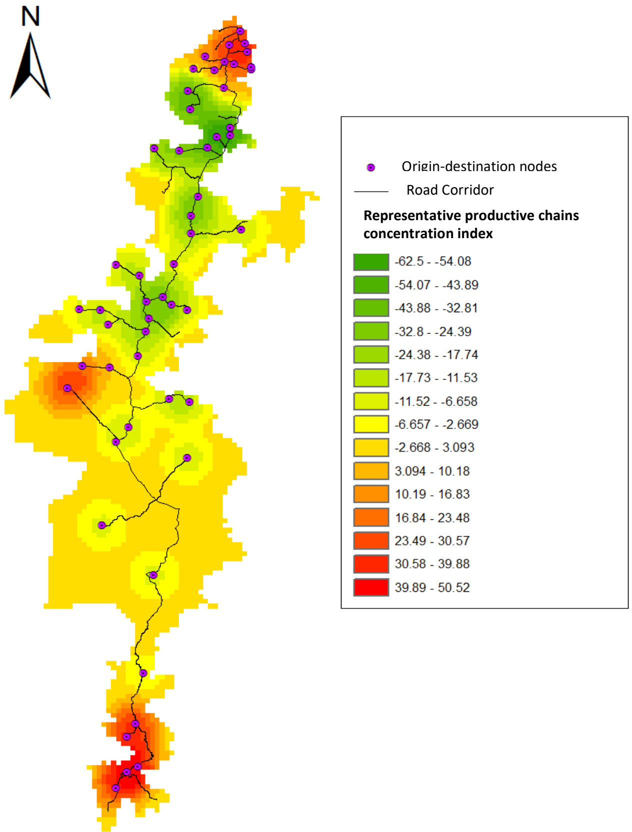

Fig.3. Heat Map for representative productive chains in the logistics corridor

4.4. Road corridor segmentation

We consider the amount of freight transported to and from the different points connected to the road corridor as a criterion for the section road corridor definition. Figure (4) identifies the freight distribution transport through the different routes that supply the logistics corridor.

Figure (5) shows the four sections identified in the road corridor and the corresponding nodes inside the incidence area.Figure (4) shows four peaks corresponding to the increase in accumulated freight. It also identifies the nodes that define the sections of the road corridor: the Medellín-Planeta Rica section accounts 27.24% of the freight, the Montería-Sampués section mobilizes 24.02% of the freight, accumulating 51.26% of freight transportation. The Sincelejo-Soledad section transports 18.98% of the cargo, accumulating 70.24%, and Barranquilla is positioned as the fourth section in terms of freight volume as a node mobilizing 29.76% of the total representative productive chains through the road corridor.

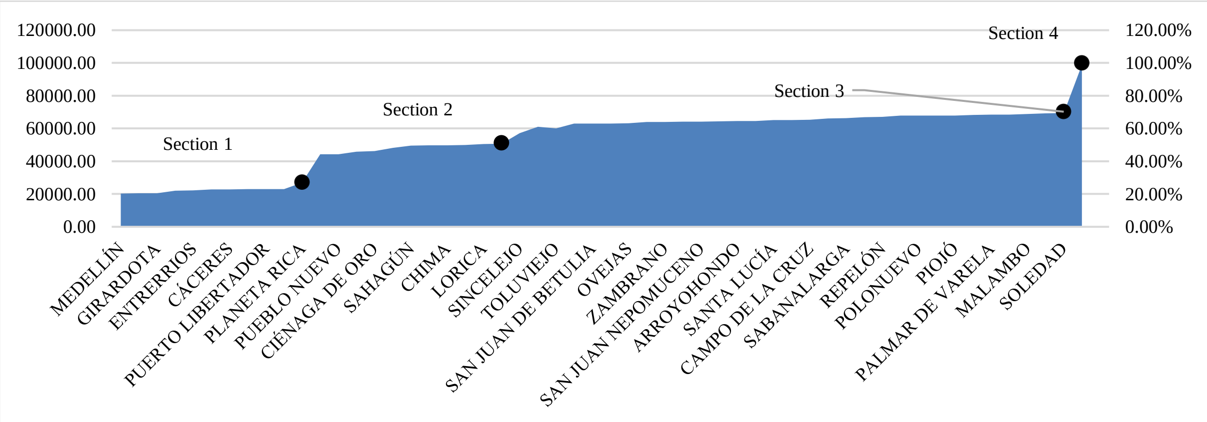

Fig.4. Cumulative percentage of tons mobilized through the road corridor

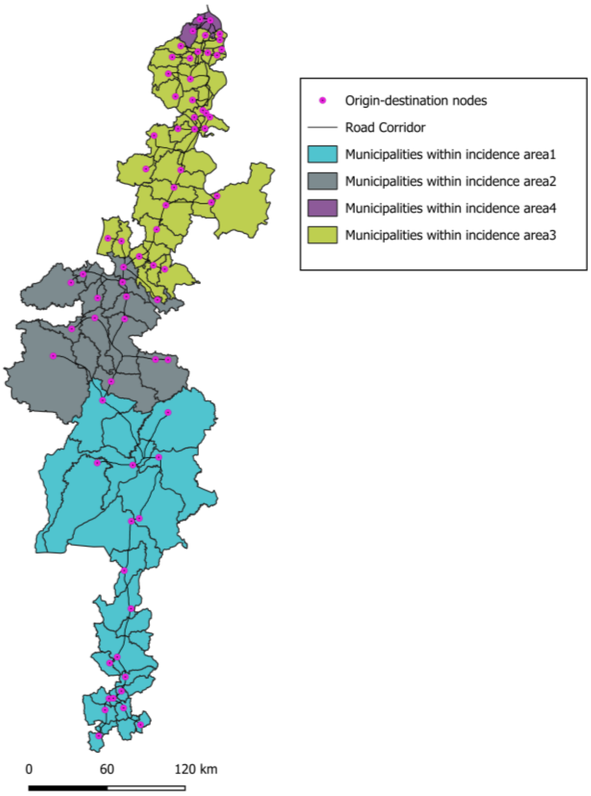

Fig.5. Segmentation of the road corridor

4.5. Accessibility analysis

This study considered accessibility metrics proposed in [8]. Furthermore, we considered accessibility as a performance measure that allows inference about freight access to the road corridor. Table 3 shows the accessibility analysis using the gravity metric, considering the number of nodes that access each subsection and the tons mobilized on it.

The accessibility analysis shows an average accessibility level of 0.027 in the corridor between Medellín and Sampués (Subsections 1.1 to 2.2), which increases to 1.5 in subsection 3.1, but experiences between Palmitas on the road to Ovejas and Puerto Giraldo, where the accessibility level increases to 14.06. Interestingly, despite Section 4 being the focal point for most of the productive chains, it demonstrates the lowest accessibility level in the corridor (excluding the subsection with an accessibility level of 0.0). This is because subsection 4 consists of only one node. By evaluating the accessibility of the corridor using equation 2, a resulting value of 0.00055 is obtained. This value allows us to interpret that the subsections with lower indices require concentrated efforts to enhance the overall accessibility of the corridor. Regarding the mean value, a distant value of 1.0542 is obtained, primarily due to the low robustness of this metric towards extreme points. The median accessibility index is 0.00068, serving as a central value from which the highest and lowest values can be identified.

The subsection with the highest accessibility level is Santa Rita-Puerto Giraldo-Soledad, with an index of 14.06, while the Ventanas-Valdivia – Puerto Valdivia-El Doce and Puerto Valdivia-El Doce-Puerto Belgica subsections exhibit the lowest values, both with an accessibility index of 0.0. Figure (6) illustrates the accessibility levels along the entire road corridor.

5. Conclusions

The use of accessibility, as a measure of analysis of the state of road networks and the performance of land freight transport, allows for the identification of areas that require improvement to enhance the responsiveness of the transportation industry in satisfying the demand between generating and receiving nodes. By employing an accessibility analysis methodology for a road corridor, this research sheds light on characterizing the areas that generate and receive significant cargo. This characterization differentiates the accessibility analysis from the metropolis within the road corridor.

Tab.3. Accessibility Analysis of the road corridor

Section	Subsection	Origin	Destination	Nodes	Tons	Accessibility (Gravity)
1	1.1	Medellín	La Aldea restaurant Don Matías	3	20530.9285	0.00067857942
	1.2	Don Matías	Llanos de Cuivá (Yarumal)	2	1651.97628	0.00013183842
	1.3	Llanos de Cuivá (Yarumal)	Ventanas Valdivia	1	699.8011	0.00000204198
	1.4	Ventanas Valdivia	Puerto Valdivia (El Doce)	0	0	0
	1.5	Puerto Valdivia (El Doce)	Puerto Belgica	1	0	0
	1.6	Puerto Belgica	La Apartada (Córdoba)	2	137.9	0.00111551875
	1.7	La Apartada (Córdoba)	Planeta Rica	1	3888.4004	0.00000006614
2	2.1	Planeta Rica	La Ye (El Viajano)	4	18940.9171	0.00640150333
	2.2	La Ye (El Viajano)	Sampués (to Sincelejo)	8	4796.58305	0.23081664145
3	3.1	Sampués (to Sincelejo)	Los palmitos (to Ovejas)	6	12449.5952	1.50045422304
	3.2	Los palmitos (to Ovejas)	San Jacinto (2 km before Ovejas)	3	960.744	0.00026232159
	3.3	San Jacinto (2 km before Ovejas)	Carreto (El Tigre)	3	298.334	0.00099870744
	3.4	Carreto (El Tigre)	Santa Rita (Puerto Giraldo)	5	1059.8737	0.01345852503
	3.5	Santa Rita (Puerto Giraldo)	Soledad	14	3979.73364	14.05830927723
4	4.1	Soledad	Barranquilla	1	29406.8159	0.00000000116

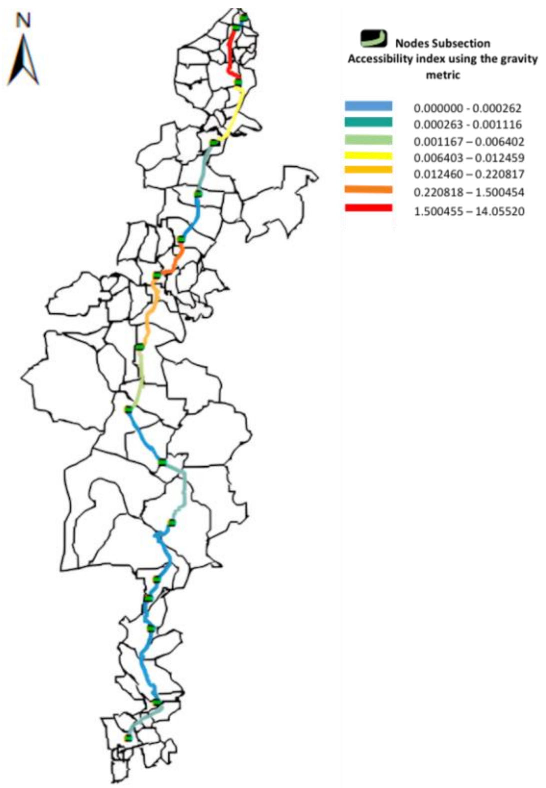

Fig.6. Accessibility of the road corridor

Regarding the results, those areas with low accessibility levels, determined by the number of nodes accessing the road corridor, require investments in road development. A cargo generation investment would enable nodes not currently included in the incidence area to access the road corridor and facilitate the transportation of productive chains. Considering the weighted accessibility of the corridor and the median, a section to prioritize investment in cargo generation is from Ventanas (Valdivia) to La Apartada (Córdoba), as the number of tons transported to and from the nodes along this route is not significant.
Concerning infrastructure investment to increase the road corridor accessibility, three sections are suggested for consideration: Llanos de Cuivá (Yarumal) to Ventanas (Valdivia); La Apartada (Cordoba) to Planeta Rica and Barranquilla. In the three sections, only one node accesses the corridor even though the load generated is similar. As a result, lower accessibility rates are reflected than the weighted accessibility of the road corridor.
As future research, it is possible to investigate into alternative measures for assessing the state of road networks and the performance of land freight transport, in addition to accessibility, to gain a more comprehensive understanding of their impact on transportation systems. Additionally, Further examination of the specific factors contributing to low accessibility levels in certain areas, including an analysis of the physical infrastructure, road connectivity, and potential bottlenecks, to identify targeted interventions for improving access. Furthermore, Comparative studies across different regions or countries to evaluate the generalizability of the findings and determine if similar patterns of accessibility and freight generation exist, providing insights for policymakers and industry stakeholders.

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