Evaluation Based on Territorial Accessibility of the Immediate Road Intervention in the Municipality of Quibdó, Colombia

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Abstract

The structuring and empowerment of transport networks generate a strong impact on the economic and social development of a region, facilitating the interaction between users and services with the greatest possible benefit. Taking this into account, this proposal consists in carrying out the intervention and subsequent evaluation of the road infrastructure network of the municipality of Quibdó, Choco, through territorial accessibility, taking as a base the set of projects established by the municipal administration for 2025 in the Integral Mobility Plan. The evaluation of the interventions is carried out through the use of computer tools (ArcMap, Microsoft Excel, TransCad) through geostatistical models and linking socioeconomic variables (Area, Population, Housing).

Keywords: Territorial accessibility, development, road infrastructure, road intervention, savings gradient
1 Introduction

The incorporation of transport infrastructures facilitates citizen interaction with the different existing goods and services, playing a key role in the economic development of a region given its direct and indirect effects on productivity [6]. Likewise, an improvement in the quality of life is guaranteed by reducing the cost of travel for users. In this sense, Quibdó, capital of the department of Chocó, developed the set of road interventions for 2025 within the framework of the Integral Mobility Plan project, which was delivered and approved in 2015. The city of Quibdó is located in the west of Colombia about 76°39'40" of longitude east and 5°41'13" of north latitude (Figure 1). It has an altimetric variation of between 43 and 53 meters above sea level and an average temperature of 28°C [1]. It counts with a population of 115,711 inhabitants [8], located on a total surface of the 3,337.5 km2 [1]. However, its urban area is limited to 19.85 km2.

Figure 1. Geographic location of the municipality of Quibdó. Source: Authors.

Within the framework of the Integral Mobility Plan for Quibdó, it was possible to demonstrate that the mobility behavior in the city focuses on the use of motorcycles, with percentages higher than 80% in the identified vehicle fleet, distributed among individuals and motorcycle taxis [2]. On the other hand, the road infrastructure has deficiencies related to the running surface, based on the percentage of paved roads, which do not exceed 26%, as well as the state of the road surface, of which 68% are in poor condition [2]. Additionally, there is a sharp increase in travel time at the time of carrying out daily activities, in which 42% of citizens argue that this increased with respect to the previous year [18]. Taking the above into account, there is evidence of the need to intervene and improve the condition of the municipal
Evaluation based on territorial accessibility

road network, improving mobility and accessibility to the different sectors of the city. Therefore, the preparation of an analysis of territorial accessibility is proposed in order to evaluate the interventions proposed by the municipal administration for 2025 in its document of the Integral Mobility Plan.

Prior to the evaluation of the interventions, it is prudent to contextualize with the assessment tool "Accessibility", which has a large number of definitions since the second decade of the 20th century [3] that can hardly reach consensus [15]. However, there is a basic definition established by Hansen in 1959 that considers accessibility as the potential for opportunities for interaction [11]. In this case, the measure of the ease of interaction between citizens and centers of activity or services, depending on the means of transport and infrastructure used, considering all possible limitations, will be taken as a definition of accessibility [7, 10, 16]. When observing the previous definition, it is possible to identify the elements immersed in the evaluation of accessibility, which are: the infrastructure network, the means of displacement and the elements that generate or attract travelers. This is why it is possible to affirm that the linkage of the accessibility within the investigation, as tool of valuation of the interventions proposed by the municipal administration, is a good option. Some applications of accessibility from other fields of science are: land uses and transport [9, 10, 12, 14, 23], commerce [13, 24], access to services [5, 22], transport networks [19], public transport [9, 15], social exclusion [4, 20].

2 Methodology

Within the constructive process in the research, five methodological phases of consecutive character are developed, which guarantee an adequate development of the evaluation and future replications. The methodological sequence is presented in figure 2 and described below.

2.1 Collection of existing information
Within this methodological item, an inquiry about the existing information related to the city's road network and its physical and operational characteristics (speed, directionality, length, slope, type of road, etc.) was done. In the same way, the interventions proposed by the municipal administration for the future study were studied and compiled.

2.2 Linking the road infrastructure network and formulating proposals
As a next component of the methodology, the road network of the municipality is structured, considering the basis established in the Integral Mobility Plan of the city and the physical and operational characteristics collected. The road network consists of two main elements for the graphic representation and assimilation of its operation, nodes (confluence of lines or intersections) and arcs (linear elements representing roads or paths) spatially located (figure 3), which contain the physical and operational characteristics described above. The process of generating,
optimizing and linking features is done through Esri ArcMap software. After establishing the road infrastructure network, the study scenarios were formulated.

Figure 2. Used methodological sequence. Source: Authors.

Figure 3. Composition of the road networks (nodes and arcs). Source: Authors.
For this case, two situations of analysis are developed. Situation 1 or base scenario, which establishes the accessibility conditions offered by the transport network in the standard condition (2015). Subsequently, the interventions established by the municipal administration are located on the base network, resulting in the formulation of the future situation (2035). It is important to remember that the package of projects is listed in the document of the Integral Mobility Plan, considering the construction, rehabilitation and maintenance of roads.

2.3 Construction of territorial accessibility curves

Following the methodological sequence, the accessibility curves for each situation were constructed. The generation of the curves focuses on the cost in travel time for each arc, which is determined from the operating speed and its length, as shown in expression 1; where: \( T_{V_i} \) = travel time in the arc \( i \); \( L_i \) = longitude of the arc; \( V_i \) = arc speed.

\[
T_{V_i} = \frac{L_i}{V_i} \quad i = 1, 2, 3, \ldots, n
\]

Once the travel time has been obtained on each arc, the travel time vector is constructed, which determines the time elapsed on the network from a source node to a destination point, taking into account the directionality of the routes and the possibility of circulation on some sectors. Within the constructive mechanics of the vector, there is the Dijkstra algorithm, which evaluates all the possible routes from the origin node to the destination node and selects the one with the lowest travel cost [23, 24]. Subsequently, the geospatial coordinates of each node of the network considered in the calculation of the travel time are linked. With this, the Geostatical Wisard tool of ArcMap is executed and the isochronous travel curves are made. The content of the tool is based on the Kriging method as a prediction model, with a linear variogram, with which the spatial dependence between nodes of the same system is characterized as shown in expression 2; where: \( Z(x) \) = Value of the variable for a node with coordinates \( x \); \( Z(x+h) \) = following value of the sample at a distance \( h \); \( n \) = number of couples distanced by \( h \).

\[
\frac{Y(h)}{h} = \frac{\sum(Z(x+h) - Z(x))^2}{2n}
\]

2.4 Construction of savings curves

Through the use of expression 3, where: \( Ahorro_i \) = percentage of savings for the node \( i \); \( tv_{i(\text{act})} \) = travel time in node \( i \) for scenario 1; \( tv_{i(\text{fut})} \) = travel time in node \( i \) for scenario 2; the travel time values obtained for each situation are related, thus obtaining the percentage of savings achieved by the proposed interventions. Then, as in the accessibility curves, the Geostatical Wizard tool is executed to construct the savings curves.

\[
Ahorro_i \% = \left( \frac{tv_{i(\text{act})} - tv_{i(\text{fut})}}{tv_{i(\text{act})}} \right) \times 100
\]
On the other hand, a statistical analysis is performed on each maneuvers recorded at the intersections using frequency tables when the data is greater than 25. In addition, the Sturges rule is used to determine the number of frequency intervals [19, 33] and the guidelines of various authors in traffic engineering statistics for calculations of the arithmetic mean and the standard deviation for pooled data. If the number of data is less than 25, they are calculated using formulas arranged for non-grouped data [31].

2.5 Coverage ogives
As a last methodological item, an intensive search is made of the socioeconomic variables to be linked, which are population, area and number of dwellings. Next, the polygon of variables is constructed, in which the information collected is included to later be related to the accessibility curves and gradients obtained, using the ArcMap Geoprocessing intersect tool.

3 Results and discussion
As a result of the investigation of the information regarding the study, it was possible to establish the series of interventions proposed by the municipal administration for the year 2025, within the projection of the integral Mobility Plan of the Municipality (figure 4), where the construction of 1.9 km of double roads in prime sectors of the city is proposed. Huapango Phase I dual roads. 540 meters of dual roads; Dual Roads Phase I Street 30. 470 meters of dual roads; Dual Road Phase I Medrano Zone. 910 meters of dual roads.

Figure 4. Road interventions in the future situation. Source: Authors.
3.1 Territorial accessibility

3.1.1 Current situation

As a result of the evaluation of territorial accessibility in the current situation (2015), figure 5 is shown, in which the behavior in travel time offered by the road network of the municipality at intervals of 0.5 minutes without interventions is appreciated. The lowest travel time obtained is identified in blue, which is located in the downtown sector with a value of 12 minutes. As a counterpart, towards the peripheries of the city, the greatest travel time is highlighted in red, with a value of 33 minutes in the Futuro and Obapo neighborhoods. The behavior observed is due to the very structure of the road network, which has a large branch with 4 main lines of movement that must support the traffic of the municipality. Figure 6 shows the variation in coverage by variable generated in the current situation, it is possible to identify a strong coverage in relation to the population and number of dwellings, achieving 70% in a travel time of less than 20 minutes, which highlights a high concentration of the population towards the center sector of the municipality. On the other hand, the surface presents a linear behavior in its coverage, with a value of 50% for a travel time of 21 minutes.

Figure 5. Territorial accessibility curves for the current situation. Source: Authors.
3.1.2 Future situation
Once the road interventions proposed by the municipal administration have been established, the accessibility assessment is carried out, from which figure 7 was obtained as a result. It shows the variation in travel time at 0.5 minute intervals.

![Figure 6. Accumulated percentage of coverage by population, area and number of households in the current situation. Source: Authors.](image)

![Figure 7. Territorial accessibility curves after road intervention. Source: Authors.](image)
The minimum value in travel time is 13 minutes, which, as in the current situation, focuses on the center of the city. However, there is a growth of the blue zone towards the southern part of the figure. The maximum displacement value presents a reduction in the peripheries, decreasing from 33 minutes to 32. However, it continues to present difficulty of access in the peripheries. As a complement to the accessibility curves, figure 8 is shown, which shows the behavior in coverage generated by the road infrastructure network after the interventions. The population and dwellings present an almost identical behavior with a coverage percentage of 70% in less than 20 minutes. It is important to remember that the population to the future situation considers the expansion provided by the DANE (121,114 inhabitants, 32,627 households). Therefore, despite the fact that coverage is lower in relation to the current situation, a greater accessibility to a greater number of citizens is being guaranteed. On the part of the area representative curve, it keeps a linear trend with a slight jump over 19 minutes, decreasing its travel time to 50% in relation to the initial situation.

Figure 8. Accumulated percentage of coverage by population, area and number of households in the future situation Source: Authors.

3.1.3 Savings Curves

In order to determine the impact in relation to the initial situation, figure 9 was obtained, in which the variation in percentage is appreciated every 5 units of the improvement in travel time obtained in the future situation. It is appreciated that most of the surface achieves savings of up to 5% and 10%, however, the maximum value is on the eastern sector with a value of up to 25%. Taking into account the image, it is possible to affirm that the proposed interventions for 2025, generate a strong impact on accessibility, guaranteeing a better mobility and improvement in the quality of life as the population requires less time to make their trips.
Figure 10 shows the variation in the savings in perceived coverage. The behavior of the ogives is similar to each other, with marked variations of up to 5 and 10%. Additionally, it can be inferred that, due to their location, the proposed interventions affect the variables considered in the same way.

4. Conclusions

The interventions made by the municipal administration show an improvement in the accessibility of the municipality, facilitating traveling for citizens living in the peripheries. This is based on the results obtained in savings, with percentages higher than 10% for these areas. The level of coverage by population and housing in the future situation, present minimal decreases in relation to the baseline scenario. However, the increase in population over the years is a crucial element of research, therefore, interventions for 2025 guarantee a better displacement of citizenship.

Figure 9. Percentage curves of savings perceived. Source: Authors.
It is possible to affirm that the Territorial Accessibility as an element of evaluation of road interventions, guarantees a correct and effective management of results and possible decision making. In the same way, the graphic interpretation of the results is sufficiently clear for users.

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