Savings Gradient as an Evaluation Tool in the Implementation of Long Term Road Interventions.

Case Study: Quibdó, Colombia

Diego A. Escobar and Jorge A. Montoya

Universidad Nacional de Colombia – Sede Manizales. Facultad de Ingeniería y Arquitectura. Departamento de Ingeniería Civil. Cra 27 # 64-60
Manizales 170004, Colombia

Carlos A. Moncada

Universidad Nacional de Colombia – Sede Bogotá. Facultad de Ingeniería. Departamento de Ingeniería Civil y Agrícola. Ciudad Universitaria edificio 214 Oficina 417, Bogotá, 111321, Colombia

Abstract

The evolution of cities is limited by different problems that must be solved. One of these is the linking of the transport infrastructure network to the strong population and vehicular growth. In order to solve it, the implementation of new road structures and adaptations should be formulated and strengthened. In the following investigation, a territorial accessibility analysis is suggested in order to evaluate the interventions proposed by the municipal administration within the framework of the Integral Mobility Plan for the City of Quibdó for 2045, based on geostatistical models, and the linking of socioeconomic variables through the use of computer tools.

Keywords: Accessibility, transport infrastructure, urban development, mobility, geostatistics

1 Introduction

Quibdó, capital city of the department of Chocó, is located on the western side of
Diego A. Escobar et al.

Colombia in the so-called pacific region. It is geographically located at 76°39'40" east longitude and 5°41'13" north latitude (Figure 1) [1]. The municipality has an average temperature of 28°C and an elevation between 43 and 53 meters above sea level. It is positioned on the equatorial clams and has high rainfall that feeds its most important river, the Atrato. The total area of the municipality is 3,337.5 km2, of which 19.85 km2 [1] belong to its urban area, where 107,634 of its inhabitants —that is, 93.02% of its total population— lived in by 2015 [7].

In relation to the behavior of the mobility of the city, the greater proportion of vehicles in circulation on the roads are motorcycles, surpassing 80% of the total vehicles, however, there is poor control over this automotive park [2]. On the other hand, the behavior of vehicles throughout the day presents 3 strong peaks, in which citizens generally perform their daily activities. The times of greatest impact are: between 5:30 - 7:30, 11:00 - 13:00 and between 17:00 - 19:00 [2]. The public perceives that there is an increase in travel time on the road network, as 42% of the population considers that the trips made within it take more time than in previous years. Motorcycles and motorcycle taxis, which account for 66%, are the main means of transport used [21]. The citizen satisfaction regarding the means of transport used achieved a 58% of approval. However, there was a 20% of dissatisfied citizens that manifested the need to observe the shortcomings in favor of a better displacement. Figure 2 shows the structure of the road network and the geographical conformation of the city of Quibdó, showing the strong branching and discontinuity in the roads, mainly due to the topographical variation and the lack of urban control in the constructions. Due to the structure and composition of the road network, the municipal administration has been obliged to make considerable interventions in order to improve the mobility of the population. These interventions are established in the document of the Integral Mobility Plan of the
municipality. Taking into account the above, it is proposed to carry out the analysis of the impact through territorial accessibility, of the suggested interventions for 2045 in the city, considering variables such as population, area and number of dwellings.

Figure 2. Structure and conformation of the municipality of Quibdó.

Before approaching the research, it becomes very important to know, learn and internalize elements and concepts related to accessibility, which is defined in its most minimal expression as the possibility of accessing something. However, a more technical definition can be observed since 1959, when accessibility was defined as the potential of opportunities for interaction [11]. Other ways of observing accessibility focus on the perception of the term as a "measure" of the ease with which a citizen can access destinations or opportunities [6, 25], depending on the mode of transport used [18], the activity to be performed and the existing limitations [10, 24]. In this way, three main components can be assumed when addressing accessibility: the "origin", which represents the users of the system on a starting point; the "destination", the place or point of high attraction for mobilization; and the "trajectory", which indicates the best way to take to access the destination [16]. Additionally, it can be inferred that by means of these elements numerous types of analysis can be developed as well as factors of affectation [12, 15, 23]. Some examples of the application of accessibility in various fields of studies are: transport planning and optimization [8, 10, 15, 16, 19], infrastructure [13, 20], social exclusion [4], commerce and services [9, 14, 26].

2 Methodology

The proposed research methodology is based on a series of five consecutive steps
(Figure 3), which guarantee an effective and correct evaluation of the input data and results obtained. The sequence of steps is described below:

**Figure 3. Methodology of the investigation.**

### 2.1 Acquisition and assessment of the road infrastructure network of the municipality of Quibdó

As a fundamental element for the preparation of the research, acquiring the road infrastructure network of the city is necessary, which is established in its base form (Figure 4) in the diagnostic document of the Mobility Plan [2]. The road network is based on two main elements, nodes (points of intersection of several elements of a network) and arcs (continuous line joining two points or intersections of a network), located spatially by coordinate systems. Each arc of the road network has a series of characteristics of an existing road: length, speed, rolling surface, directionality of the track, identification of the track, among others. After obtaining the base network, the corresponding calibration and debugging was performed in order to ensure the correct execution of the calculations. The process was done using Esri's ArcMap tool.

### 2.2 Generation of scenarios and location of interventions

Once the road infrastructure network has been refined and calibrated, the calculation scenarios are established taking into account the year of creation of the network, 2015, as well as the projection proposed in the Mobility Plan for 2045. Baseline scenario - 2015: the year 2015 is considered as a baseline scenario, since it is the year in which the Mobility Plan of the city was delivered and on which the road infrastructure network is defined. It is important to clarify that no interventions were made in this scenario, only the condition of access offered by the network in
this year is evaluated. Future Scenario - 2045: In this scenario, the road interventions of the document of the Integral Mobility Plan for 2045 [3], linked to the vehicular network of the base year, are proposed, to later evaluate the accessibility of the new offer. The proposed interventions consider improvements, rehabilitations and road constructions, as well as the implementation of bridges and a vehicular tunnel.

Figure 4. Composition of nodes and arcs for the municipality network.

2.3 Territorial accessibility

In order to evaluate the impact of interventions throughout the city, the use of global accessibility is considered, which evaluates the interaction of all the nodes of the network with each other, that is, evaluates the facility to move from each origin, to the different existing destinations and vice versa. The construction of the curves is based on obtaining travel times on each arc, which is obtained from Expression 1, where $t_v_i$ is the travel time in $i$, $l_i$ the length of the arc and $v_i$ speed.

$$
t_v_i = \frac{l_i}{v_i} \quad i = 1,2,3,...,n
$$

Next, by using the Dijkstra algorithm (which evaluates the travel cost between arcs) [22], the minimum path between nodes is evaluated. With these, the vector of average travel times is constructed by means of Expression 2, achieving linking the travel cost from each source node to the other nodes of the network. From the equation: average travel time from node $i$ to the other network node $v_{ij}$, travel time from node $i$ to node $j$ and $n$ total number of evaluated nodes. After obtaining
the vector of average travel times, they are related to the geographical coordinates of each node and thus constitute the table of travel times, which, through the use of computer tools, allow the construction of territorial accessibility curves.

\[
\overline{t_{vi}} = \frac{\sum_{j=1}^{n} t_{vij}}{n-1} \quad i = 1,2,3, \ldots, n; \quad j = 1,2,3, \ldots, n
\]  

(2)

2.4 Savings calculation

The savings calculation or calculating the savings gradient allows a comparative analysis of the impact generated by the proposed interventions in the future scenario. The construction of the curves for this item is based on the vector of saving times, which is obtained by Expression 3 when relating the time of future travel with the current one. In the equation: \( ahorro_i \) is the savings percentage obtained in node \( i \), \( t_{v_{i(act)}} \) is the travel time in node \( i \) for the current scenario (2015) and \( t_{v_{i(fut)}} \) is the time of travel in node for the future scenario (2045). Finally, the savings time results are linked to the coordinates, completing the savings table, which builds the savings curves from the computer tools.

\[
ahorro_i (\%) = \left( \frac{t_{v_{i(act)}} - t_{v_{i(fut)}}}{t_{v_{i(act)}}} \right) \times 100
\]  

(3)

2.5 Linkage of variables and calculation of coverage

Once the accessibility and savings curves have been obtained, the crossing polygon was constructed with the variables to be related: population, area and number of dwellings; which are linked through ArcMap in its extension "Geoprocessing" - "intersect". Finally, using Microsoft Excel, the coverage graphs are constructed with the results obtained from the crossing between the accessibility curves and the variables.

3 Results and discussion

3.1. Proposed interventions for 2045

In order to improve mobility in the city of Quibdó, the municipal administration, through the implementation of the Integral Mobility Plan proposes the intervention of the road infrastructure network in a total of 32.4 km, which represent 34.9% of the total length of intervention proposed in the Mobility Plan. The construction, rehabilitation and improvement of roads, are considered within the package of interventions, in addition to the incorporation of a tunnel and vehicular bridges [3]; the interventions can be seen in Figure 5.
The following projects are included in the intervention plan: Construction of 11.4 km of roads, currently underway; Rehabilitation of 170 m and improvement of the functionality of 15.6 km, in addition to the preventive maintenance of roads that currently refer to pavement in good condition; Construction of dual roads of 430 m, viaduct, towards the airport sector; Construction of a dual road of 800 m, corresponding to the extension of the existing one at the airport; Construction of a dual road of 1,730 m located between the roundabout of the airport and the exit to Medellin; Construction of two vehicular bridges towards the northeastern sector of the city; Construction of a vehicular tunnel that guarantees the connection between the north and south of the city. It is necessary to highlight that the proposed interventions for 2045 are a set of complementary projects to the interventions to be carried out until 2030. That is, the assessment of mobility for 2045 considers the total impact of the proposed interventions since the end of the Mobility Plan, until the implementation of the projects for the scenario under study.

Figure 5. Proposed interventions for 2045.

3.2 Accessibility analysis

3.2.1 Base scenario – 2015

As a result of the evaluation of territorial accessibility in the base scenario, Figure 6 is presented, where the variation in travel time for citizens is taught at 0.5 minute intervals. It is clearly identified that the downtown area of the city presents the best mobility condition, largely due to the high density of roads within the municipality. On the other hand, the peripheral or extreme areas of the city require a longer travel time, its maximum value being 33 minutes in the northern part. Although the travel
time in Quibdó is less in comparison to other cities in the world [5, 17], it is not prudent to say that it has excellent accessibility because, despite the extension of the municipality, there may be many delays.

Figure 6. Territorial accessibility for the baseline scenario.

Figure 7 shows the variation in coverage by population, area and number of homes, according to the time of travel in the city. The behavior of the population curves and the number of dwellings shows a high concentration of citizens within the urban area, by covering 50% in a travel time of 16 minutes. For the case of the area variable, the behavior is differentiated from the others, taking a straight line trend, covering 50% in a time less than 22 minutes.

Figure 7. Coverage curves by population, area and number of dwellings in the base scenario.
3.2.2 Future scenario – 2045

As a result of the accessibility generated by the interventions proposed by the municipal administration, Figure 8 is obtained, which shows the variation in travel time of accessibility at 0.5 minute intervals. As in the current scenario, a minimum value of 13 minutes is presented to the downtown area.

![Territorial accessibility for future scenario](image)

Figure 8. Territorial accessibility for future scenario.

In Figure 9, the level of coverage generated by the interventions for 2045 can be seen. However the upper limit was reduced to 32 minutes. There is a decrease in travel time to the airport sector and departure to Medellin, as in the south-west sector, achieving travel times of less than 18 minutes, or that translate into a better use of time for other tasks every day. There is great similarity between the curves, with a travel time value of less than 19 minutes for a 50% coverage. It is important to remember that this scenario considered the population and housing growth according to the DANE. In relation to the base scenario, there is an increase in travel time. However, the growth of the variables between scenarios is considerable, going from 107,634 inhabitants to 146,213 inhabitants, that is, an increase of 36% and from 28,932 homes at 37,631 (30%) [3].

3.2.3 Savings percentage

Figure 10 shows the results obtained for the travel time savings of the future scenario (2045) with respect to the base scenario (2015). The variation is seen at intervals of 2.5% with perceptions up to 35% savings.
It is observed that the greatest saving is given to the eastern sector of the city towards the exit to Medellin and the municipal airport with a percentage of up to 35%, largely due to the intervention of the dual roads, which guarantees a better travel time for citizens. However, there are reductions to the northern and central sectors, with a predominant value of up to 2.5%. In Figure 11, the savings values are observed according to the variables considered, it is important to emphasize that for this scenario the population and dwellings for 2045 are linked. Then there is a 50% saving perception of the population of up to 5%, which although it is not too big, can be significant depending on the amount of trips made throughout the day.
On the other hand, the area achieved the greatest impact of the interventions with savings of up to 10% for 50% of its surface area.

![Savings gradient as an evaluation tool](image)

Figure 11. Savings curves generated by the future scenario with respect to the base scenario.

### 4. Conclusions

Within the evaluation of the accessibility of the municipality of Quibdó in the base scenario, it can be seen the marginality of the resident population in the outskirts is obliged to make trips with higher time costs, which limits its use throughout the day to perform different activities.

The behavior of the coverage graphs shows a strong tendency to reside in the vicinity of the city center, possibly due to the low development of road infrastructure, forcing citizens to locate sectors from which they can easily access the center of commerce and activities of the city.

The proposed interventions in the future scenario provide better accessibility throughout the territory, mainly towards the peripheries of the city, at the exit to Medellín, in which it is possible to reduce the travel time to 35%, guaranteeing the use of outdoor areas and improving the mobility of citizens.

**Acknowledgements.** The authors express their gratitude to the young people belonging to the research groups in Urban Planning and Sustainable Mobility assigned to the National University of Colombia, Manizales. Likewise, they recognize the support of the engineers Diego Fernando García, Juan David Zuluaga and Juan Manuel Holguín for their contribution in the elements necessary for the preparation of the investigation.

**References**


D. Escobar, F. García, Análisis de accesibilidad a Nodos de Actividad en Manizales (Colombia), Facultad de Ingeniería y Arquitectura, Universidad Nacional de Colombia, Manizales, 2012.


Received: July 3, 2018; Published: July 31, 2018