Evaluation of the Impact of the Construction of

“Tunel De La Línea - Colombia”, through

a Territorial Accessibility Analysis

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Abstract

This article analyzes the territorial accessibility generated by the impact on the construction of “Túnel La Línea” and the second roads located between the municipalities of Calarcá (Quindío) and Cajamarca (Tolima) in Colombia. This construction will substantially improve the communication between the south-east with the center and northeast of the country, because the existing system has a complicated topography that generates delays and increases operating expenses, especially in heavy goods vehicles. Additionally, a hypothetical case that simulates that both the current road as well as La Línea tunnel are closed will be evaluated, as it would make vehicles take an alternative route through the other roads that connects the departments of Caldas and Tolima. This accessibility analysis will be carried out using computer tools such as the TransCAD to calculate the average travel times and ArcGIS to find the isochronous curves and isochronous gradient, which allow saving the average travel time in the study area. These results will be crossed with the population and gross domestic product (GDP) to find the benefit in terms of these variables.
Keywords: La Línea tunnel, Territorial accessibility, GDP, population, Isochronous curves, Isochronous gradients

1 Introduction

La Línea tunnel, of 8.65 km in length, is one of the most important road infrastructures that are currently being executed in Colombia. This work additionally counts on the construction of the dual roads of Quindío (9,520.63 m) and Tolima (8,904.18 m), which sum a total of 20 short tunnels and 24 bridges, plus 3 additional tunnels known as the adjoining works (1,377.1 m), responsible for splicing the Quindío road with the entrance portal. It is located in the middle of the central mountain range between the municipalities of Calarcá (Quindío) and Cajamarca (Tolima). The entrance portal of the tunnel is 2,420 meters above sea level, to 19 km from Armenia; the exit portal is 37.8 km from Ibagué [24], and, once finished, it will be part of the trunk Buenaventura - Bogotá (512 km). Its construction began in December 2009 and is expected to be completed by 2020. However, since 1913, it was conceived to be built as a railroad. But the first agreement was barely signed by 1928 with the North American firm Hitchcock & Tinkler, subsidiary of the French company Regie Generale des Chemins de Fer et Travaux Publics. The tunnel for that time was designed at 2,777 meters above sea level and was designed with a length of 3.52 km [13]. Among the benefits of the construction, a reduction of 75% of accidents is projected, since the current road presents a poor geometry with steep and curved terrains with high banks. In addition, the ascent will be reduced from 3,300 meters to 2,463.5 meters above sea level and there will be a saving in distance of 10 km with respect to the existing road [25]. Among the geometric characteristics, there are: speed of design, 60 km/h; height or galibo, 4.90 m; width of the road, 10.90 m, with two lanes of 3.65 m each and pavement in concrete MR45. The vehicle flow will be divided between this new transport infrastructure and the current road. A project of this magnitude requires an analysis of territorial accessibility that allows visualizing which areas will improve their average travel time and will therefore guarantee greater savings for the construction of the new infrastructure. The departments to be analyzed, considered as a direct area of influence, are: Antioquia, Boyacá, Cauca, Caldas, Choco, Cundinamarca, Huila, Meta, Quindío, Risaralda, Santander, Tolima and Valle del Cauca (see figure 1), which cover 732 municipalities, for a total area of 382,203.18 km² of 33,896,311 inhabitants.

The term accessibility is defined as the degree of greater or lesser ease that human beings have, apart from their physical and cognitive conditions, of using a service or some type of infrastructure. It also corresponds to the right that each individual has to enter and travel somewhere with the greatest possible comfort and autonomy [20]. It is the ease of reaching destinations, the key in the use of land and the measure of transport development [3]. However, this word was used for the first time in the 1920s in the theory of location and regional economic planning, becoming important when transport planning started [1]. By the 1950s, the term
accessibility was defined as the potential interaction between two zones or territories involving factors such as: work zones, speed, vehicular volume, land uses, etc. [11]. Then, in the 1970s, it was defined as a function of the use of private vehicles in areas of attraction [4] and the ease with which different points of activity can be reached using a particular transportation system [15], [18]. It is also measured in terms of ease with which citizens can reach a variety of services and goods, which is useful for the evaluation of transport and regional plans [27]. The term accessibility has been extended with the inclusion of transport infrastructures, which modify the conditions of accessibility, constituting a key element in regional development policies [22]. But Biehl was who studied the relationship between infrastructures and the regional development in depth in a report presented to European communities [2].
An analysis of territorial accessibility serves as a social, economic and impact indicator of land use [23] and not only depends on the characteristics of the network, but also on the average speed of flow operation, which is defined as the distance traveled divided by the elapsed time [26]. Accessibility is closely related to the variable "distance", converting it into a function that depends on the existing proximity between geographic points of an area or region [7]. However, it depends lesser of the distance to the centers of activity and on the contrary, it depends more and more on the transport structures [11]. Many factors affect accessibility, including mobility, quality and availability of transportation options, mobility substitutes and land use patterns [14]. One of the benefits of applying this methodology is that it can diagnose urban mobility and, thus, evaluate the different transport systems in a city which will provide better accessibility to its users [8]. The construction of new infrastructure such as a road or tunnel in a certain sector can be simulated and one can know if it will really bring savings in time and mobility benefits [19], [17]. In recent years, some regions of Colombia have been interested in applying territorial accessibility analysis in different investigations; for example, the city of Bogotá, where an accessibility estimation methodology was developed as a tool for evaluating transport policies in developing countries. [12] In the city of Manizales, specifically in the national university, several studies have been conducted, led by one of the authors with the support of engineers who are part of the research team [16].

2 Methodology

The methodology used for the development of this analysis was carried out in 8 stages. Computational tools such as TransCAD and ArcGIS were used to calculate the minimum travel times and to obtain the isochronous curves and isochronous gradient, respectively (see figure 2).

2.1 Selection of study area and road networks

The analyzed region is made up of 13 departments of Colombia (Antioquia, Boyacá, Cauca, Caldas, Chocó, Cundinamarca, Huila, Meta, Quindío, Risaralda, Santander, Tolima and Valle del Cauca), from which the primary and secondary road networks were obtained in the engineering office of the National University of Colombia, Manizales, and the hostosm.org page [21].

2.2 Georeferencing of the study area

Through the use of the ArcGIS software, the primary and secondary roads join in a global network, where speed attributes are entered, and the length of the arcs and travel time are calculated. A total of 3 scenarios were analyzed: stage one (1) corresponds to the road in current conditions; in stage two (2), the route of La Línea tunnel and the second roads of Quindío and Tolima adjacent to the current road was made; and in scenario three (3), the existing road was removed and it was simulated
that the vehicles had to cross through an alternative road section that connects the southeast with the center and north-east of the country, located between the departments of Caldas and Tolima.

![Figure 2. Methodology of the investigation. Source: Authors.](image)

### 2.3 Evaluation of average travel times

Once the length of the arcs and the travel times in the three scenarios have been calculated, the minimum travel time matrix between each node in the TransCAD program is used, which uses the Dijkstra algorithm. This algorithm is very useful because it allows finding the shortest route in a network that contains a large number of nodes [28]. Then the average travel time ($T_V$) is calculated, exporting the sum of the minimum travel time ($\sum$) to Excel and then dividing it by the expression, where $N$ means the number of nodes (see expression 1).

$$ T_V = \frac{\sum_{i=1}^{n} t_{vi}}{N-1} \quad i = 1,2,3,\ldots,n; j = 1,2,3,\ldots,n $$ (1)
2.4 Calculation of the half-time isochronous curves

With the average travel time calculated in the three scenarios, the network nodes with their respective information (coordinates and average travel times) are entered in the ArcGIS program and through the "Geostatistical Wizard" option, the respective geostatistical analysis is performed for the obtaining of the isochronous curves of the three scenarios. This analysis was based on the ordinary Kriging method with linear semivariogram as a prediction model of the average travel times, which allows to predict the value of a point through a linear combination of the n random variables where there is no measurement data (see expression 2) [9].

\[ Z(x_0) = \lambda_1 Z(x_1) + \lambda_2 Z(x_2) + \lambda_3 Z(x_3) + \cdots + \lambda_n Z(x_n) = \sum_{i=1}^{n} \lambda_i Z(x_i) \]  

(2)

2.5 Calculation of the isochronous curves of average time in relation to the population and gross domestic product (GDP) variables

The population and GDP information is entered into the shapefile attributes tables of the departments and municipalities and is intersected by the "Intersect" command with the isochronous curves of the three scenarios.

2.6 Calculation of the gradient isochronous curves

After finding the average travel times for the three scenarios in Excel, the average travel time of the current scenario (Esca) is subtracted with that of the future scenario (Escf). The result of this operation is divided over the current scenario (Esca), and multiplied by 100 to obtain the savings gradient (% GS) as a percentage (see expression 3). Finally, the ArcGIS program is entered again, and a geostatistical analysis is performed, which yields the isochronous gradient curves that show the distribution of savings in each scenario.

\[ \%GS = \left( \frac{\text{Esc}_a - \text{Esc}_a'}{\text{Esc}_a} \right) \times 100\% \]  

(3)

2.7 Calculation of the gradient isochronous curves of average time in relation to the population and gross domestic product (GDP) variables

The intersection between the shapefile of departments and municipalities with the isochrone gradient curves is executed. In this way, it was found that percentage of population, GDP and area had the best and lowest savings in the study area.

3 Results and Discussion

3.1 Isochronous curves of average travel times in the three scenarios

The intersection between the shapefile of departments and municipalities with the gradient isochronous curves is executed. In this way, a percentage of the results of the geostatistical analysis for the three scenarios shows that the region is covered
by an average travel time between 8 and 20 hours (see figure 3). The five departments with the least time or greater accessibility in scenarios 1, 2 and 3 are: Quindío, Risaralda, Cundinamarca, Caldas and Tolima (see table 1). Population, GDP and area had the best and lowest savings in the study area.

Figure. 3. Isochronous curves a) scenario 1, b) scenario 2, c) scenario 3. Source: Authors.

3.2 Spatial analysis of the isochronous curves of average time in relation to population, GDP and area variables in the three scenarios
In scenario 1, the 3.79% of the population, 3.26% of GDP and 1.85% of the area had an average travel time of 8 hours. It should be noted that, in the 10-hour interval, there was a greater percentage of population and GDP, benefited with 24.73% and 25.94% respectively. However, the area with the greatest coverage corresponds to
the 12-hour intervals with 16.20%. On the other hand, 55% of the population, GDP and area are covered by an average travel time between 10.16 and 12.31 hours; and 95.27% of the population, 95.28% of GDP and 88.38% of the area are covered for an average travel time of between 8 and 15 hours (See figure 4).

<table>
<thead>
<tr>
<th>DEPARTMENT</th>
<th>WEIGHTED AVERAGE TRAVEL TIME BY THE AREA OF EACH DEPARTMENT (HOURS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SCENARIO 1</td>
</tr>
<tr>
<td>Quindío</td>
<td>8.39</td>
</tr>
<tr>
<td>Risaralda</td>
<td>9.39</td>
</tr>
<tr>
<td>Cundinamarca</td>
<td>9.84</td>
</tr>
<tr>
<td>Caldas</td>
<td>9.89</td>
</tr>
<tr>
<td>Tolima</td>
<td>9.98</td>
</tr>
<tr>
<td>Valle del cauca</td>
<td>10.54</td>
</tr>
<tr>
<td>Huila</td>
<td>11.35</td>
</tr>
<tr>
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<tr>
<td>Antioquia</td>
<td>13.31</td>
</tr>
<tr>
<td>Meta</td>
<td>13.98</td>
</tr>
</tbody>
</table>

Table 1. Percentage of average travel time weighted by the area. Source: Authors.

In scenario 2, 9.56% of the population, 9.89% of GDP and 3.10% of the area had an average travel time of 8 hours. It should be noted that in the 10-hour interval, there was a greater percentage of population and GDP benefited with 24.03% and 25.02% respectively. However, the area with the greatest coverage corresponds to the 12-hour interval with 16.77%. On the other hand, 55% of the population, GDP and area are covered by an average travel time interval between 10.0 and 12.01 hours; and 95.64% of the population, 95.68% of GDP and 89.12% of the area are covered for an average travel time between 8 and 15 hours (see figure 5).

In scenario 3, 0.09% of the population, 0.07% of GDP and 0.12% of the area had an average travel time of 8 hours. It should be noted that in the interval of 11 hours, there was a higher percentage of population, GDP and area coverage with 26.21%, 26.11% and 17.96% respectively. 55% of the population, GDP and area are covered by an average travel time between 10.73 and 12.5 hours; and 95.11% of the population, 95.09% of GDP and 87.81% of the area are covered by an average travel time between 8 and 15 hours (see figure 6).
Figure 4. Accumulated percentage analysis of the population, GDP and area variables with respect to the average travel time, a) scenario 1, b) Scenario 2, c) scenario 3. Source: Authors.
3.3 Spatial analysis of the isochrones curves of gradients for scenario 1 vs scenario 2 and scenario 1 vs scenario 3

The intersection between scenarios 1 and 2 results in isochronous gradient curves that represent percentages of savings in the average travel time between 1% and 4% (see Figure 5a). The five (5) departments with the greatest savings are: Quindío, Valle del Cauca, Risaralda, Tolima and Choco. On the other hand, the intersection between scenarios 1 and 3 results in isochrone gradient curves that represent percentages of savings between 1 and -25% in the average travel time (see figure 5b). The five (5) departments with the greatest loss in the case where the high way of La Línea is closed are: Quindío, Valle del Cauca, Tolima, Risaralda and Choco.

Figure 5. Gradient isochronous curves, a) scenario 1 Vs scenario 2; b) scenario 1 Vs scenario 3. Source: Authors.

3.4 Spatial analysis of the gradient isochrone curves of average time in relation to the population, GDP and area variables for scenario 1 vs scenario 2 and scenario 1 vs scenario 3

In the analysis of scenario 1 Vs scenario 2, the 43.66% of the population, 42.60% of GDP and 72.70% of the area have minimum savings of 1%; while 1.32% of the population, 0.83% of GDP and 0.23% of the area have maximum savings of 4%. The 19.03% of the population, the 15.06% of GDP and the departments that cover 7.50% of the total area obtained savings between 2 and 4% in the average travel time, which means that 80.97% of the remaining population, 84.94% of GDP and 92.5% of the area obtained savings between 0 and 2% (see figure 6a).
On the other hand, in the analysis of scenario 1 Vs scenario 3, the 0.001% of the population, 0.001 of GDP and 0.002% of the area had maximum losses of -25%; while 50.79% of the population, 52.32% of GDP and 60.14% of area did not present any type of savings or losses. The 13.89% of the population, 14.02% of GDP and 23.53% of the total area obtained savings between 0 and 1%, which indicates that 86.12% of the population, 85.98% of GDP and 76.46% of the area total recorded a loss between -25 and 0% (see figure 6b).

![Figure 6a](image1.png)

![Figure 6b](image2.png)

Figure 6. Accumulated percentage analysis of the population, GDP and area variables with respect to the average travel time, a) scenario 1 vs scenario 2, b) scenario 1 vs scenario 3. Source: Authors.

4 Conclusions

The analyzed region comprises 13 of the 32 departments of Colombia, which in population, gross domestic product (GDP) and area represent 68.03%, 78.28%, and 33.07% respectively. The primary road network analyzed corresponds to 50.23% of the total Colombian territory, without adding the length of La Línea tunnel and the dual roads of Quindío and Tolima that are under construction.
Making a comparison between the isochronous curves of scenarios 1 and 2, it is observed that for the time interval of 8 hours, the beneficiary population will go from 3.79% to 9.56%, the GDP from 3.26% to 9.89%, and the area increases from 1.85% to 3.10%. This suggests that when La Línea tunnel and the dual roads are in function, the population benefited with this time interval will be 2.5 times greater than the population of the current scenario, while the GDP will be 3.03 higher and the area 1.68 times higher. Making a comparison between the isochronous curves of scenarios 1 and 3, it is observed that for the time interval of 8 hours, the population will go from 3.79% to 0.09%, GDP from 3.26% to 0.07%, and the area decreases from 1.85% to 0.12%. This suggests that in the hypothetical case that La Línea is closed, the beneficiary population will decrease 42.11 times, GDP 46.57 times and area 15.42 times.

If the two departments located in the area of direct influence are compared, it would be observed that the department of Quindio has a better percentage of savings (3.30%) than the department of Tolima (2.08%), since the direction of the vehicular flow of La Línea tunnel and the secondary roads will be in the direction of Quindio-Tolima. This means a shorter, direct stretch, with less slopes and a design speed of 60 km/h thanks to its 20 short tunnels and 24 additional bridges, while the existing road will be in the Tolima-Quindio direction, being still a road section of difficult traffic with many curves and high slopes.

In the event that La Línea will be totally closed due to a collapse or an accident, the vehicles traveling to the center or northeast of the country must take the high way, which connects the departments of Caldas and Tolima, and which would bring a considerable increase of time for those users who come mainly from some regions of the coffee region and from the south-east of the country. In case of this event, the five departments with the greatest average time loss would be: Quindio with -15.07%, Valle del Cauca with -7.75%, Tolima with -4.37%, Risaralda with -3.46% and Choco with -1.71%. This indicates that the five departments with the longest average time savings when La Línea tunnel and its roads are finished would also be the five most affected in case this route does not work.

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