Calculation of Turns Costs in Accessibility Models.

Case Study: Manizales, Colombia

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Abstract

Transport supply models, such as territorial accessibility, have been used over the years as a method of urban planning and transportation in various cities around the world. In this sense, it is essential to execute these models in reality as much as possible in order to make better decisions. Territorial accessibility models use the road infrastructure network and average speeds to calculate travel times. Using the Dijkstra minimum path algorithm, the minimum route in the road network can be found which includes the global turn costs since, hypothetically, the vehicles use more time when performing these maneuvers. In the city of Manizales, the turn costs have been determined in a subjective way, in the year 2011, in 69 seconds when turning left and 60 seconds when turning right, which has been used in various investigations of territorial accessibility in recent years. This investigative work seeks to update these turn costs for the city of Manizales in an empirical way. Videos will be recorded in 20 intersections according to a prioritization order described, which will be further analyzed taking into account the time spent by vehicles (cars, trucks, buses and motorcycles) when turning left and right. Subsequently, a statistical analysis is carried out to determine the new turn costs for use in territorial accessibility models for the city of Manizales.
Keywords: Turn Costs, Accessibility models, shortest path, empirical research

1 Introduction

Transportation models have been used for decades as methods for the planning and construction of cities, facilitating the provision of investments and efficient future policies, since people must travel to meet different needs such as work, recreation, education and health [26, 35]. According to [24], these are a simplified representation of reality, so in the different types of model (abstract and physical) replicating what happens in it as close as possible was intended. In this sense, the models try to replicate different conditions that transport has in reality, such as speeds and vehicular volume, by combining data collection in the field and mathematical prediction abstract models [24]. The transport supply models, which are understood as a service, aim to measure their level in certain circumstances [24]. As a transport supply model, accessibility aims to measure the opportunities for interaction that people have in a city by measuring the relationship between urban equipment and the road infrastructure network [18]. In order to execute these models in reality, different methods have been used, such as geographic information systems (GIS) for the construction of the road infrastructure network [11], the calculation of operating speeds through GPS, and the inclusion of global turn cost at the moment of calculating the minimum routes [10]. In this sense, it is essential to have the global turn costs (by left and right turn) for each city because each of them has different mobility conditions. In this research article, the methodology used to calculate the turn costs in the city of Manizales, Colombia, is presented, which had been determined in 2011 subjectively in 60 seconds for the right turn and 69 seconds for the left turn [10]. These have been used in different territorial accessibility analyses carried out to date in the city, so obtaining an updated turn costs, with an empirical basis, will bring the accessibility models closer to the reality of mobility in the city.

Manizales (Figure 1) is the capital of the department of Caldas, located in the western part of Colombia on the central mountain range at 2150 meters above sea level on average, which makes it a steep city where the construction and expansion processes are difficult [28]. On the other hand, by 2018, it has approximately 400,138 inhabitants, according to the official population projections of the National Administrative Statistics Department (DANE for its acronym in spanish) [8]. On the other hand, in terms of mobility, according to the quality of life report of the cities network carried out in 2017 in Manizales, 51% of citizens use public transport as the main mode of transportation, followed by motorcycles at 19%, walking at 14% and private cars at 10%. Bicycles obtained 1% of the daily trips for this period. Likewise, there are records of 158,000 cars (50% cars, 47% motorcycles and 3% others) which represents an increase of 102% compared to the 2009 registry and a motorization rate of 398 vehicles per thousand inhabitants, a high sum compared to cities such as Bogotá (198), Medellín (337) and Cartagena (110) [21].
As for the turn costs is has been used frequently as a complement to the Dijkstra’s algorithm of minimum paths (1959) [9] which is used by various transport modeling software to find the optimal route between two nodes connected by arcs of the road network by minimizing a given variable, often travel time or distance [6, 13, 34, 39]. Over the years, several researchers have made improvements to this algorithm, seeking to solve the various shortcomings that it has [35, 36], especially when analyzing networks of large size [7, 30, 32].

Fig. 1: Manizales location. Source: Authors.

Accessibility models have been used in transport and territory planning since the 1950s when Hansen (1959) [18] defined it as "the potential for interaction opportunities" and also proposed the method of gravity as a measure for calculation. Later, Pirie (1979) [26] compiled the different investigations that had been made in this topic, finding different methods of calculation such as distance measures, topological, gravity, accumulated opportunities, among others. On the other hand, Ingram (1971) [20] made a classification of accessibility in relative accessibility, which is the measurement between two points of the road network and integral accessibility which is the measure between one point of the road network with respect to the others. The global average accessibility, which is the measure between all the nodes in the network, complements this classification. In 2001, Geurs & Ritsema van Eck (2001) [14] defined four different components of the concept: land use, transport, temporary and the individual. They also presented the different perspectives on which the accessibility measures are based: infrastructure, locations, people and utilities [15]. Accessibility models have been used over the years by different researchers in various topics such as: land use [38], transportation planning [17], social exclusion and accessibility [16], health facilities [5], location and supply of public bookstores [25]. In addition, in Manizales, different accessibility
studies have been carried out, taking into account the turn costs, since 2011 in areas such as: health equipment [12], commercial [23, 40], public bicycles and cycle-route network [4], impact of new transport infrastructures [22], among others.

After the introduction, the research methodology for the calculation of the turn costs for left and right in the city of Manizales is presented, followed by the presentation and discussion of results and the main conclusions of the investigation.

2 Methodology

Next, each of the four (4) stages that are part of the investigation will be described plus a stage where the input data is collected. In Figure 2, the flow diagram that describes the methodology can be seen.

Fig. 2: Investigation Methodology. Source: Authors.

2.1 Entry Data
In this preliminary stage of the investigation, it is necessary to georeference the road intersections that will be considered in the analysis of turnaround times, for which it is necessary to obtain its longitude and latitude, that is, its location in the city of Manizales. This is a necessary input for its later prioritization analysis where the intersections to be studied in the investigation will be determined.

2.2 Classification of road intersections and prioritization analysis
Classification of road intersections: First of all, it must be taken into account that road intersections have different classifications. In the first instance, they are classified according to the plane in which the conflicts are found, so there are "At-grade intersections" and “Grade-separated intersections" or “interchanges" (Figure
3, A and B). The "At-grade" intersections have all their crossings in the same plane while the "interchanges" intersections have different levels of infrastructure so the conflicts between the different crossings, the congestion and the waiting time are diminished. This study will focus on the analysis of at-grade intersections because it is in these where the greatest number of conflicts between turnarounds and direct flow occur while the grade-separated intersections are designed to reduce this type of conflicts.

Fig. 3: At grade intersections (A) and Interchanges (B). Source: Author’s

On the other hand, at-grade intersections can be classified according to the type of flow channeling. In this: I) simple intersection, in which there is no channeling of flows of any kind, II) intersection with channelization of differentiated flow by infrastructure, in which infrastructure is allocated to separate the left or right turns, III) intersection with signs canalization, in which there is a differentiated flow for turning to the left or right by horizontal and vertical signaling. Likewise, the road intersections have classification according to the number of access branches, from 2 to 6 or more. Lastly, in the classification of road intersections, the traffic regulation method will be taken into account, distinguishing between those that are regulated by traffic lights and those that have regulation by STOP or GIVE WAY signaling. Figure 4 shows the synthesis of the classification that will be used in this investigation for the at-grade intersections.

Priorization analysis of road intersections. In this section, the method used to determine the prioritization of road intersections will be described. Five (5) different variables are studied, each of which will have a score from 1 to 10 as maximum score. In the end, each intersection will be able to obtain 50 as the maximum rating, making it more prone to the turn costs analysis by the grades that are closest to 50. Next, each of the analyzed variables is described:

1. **Variable 1, Traffic channeling:** this variable takes into account the type of channeling per traffic described in the classification of intersections, giving greater value to those that increase the turnaround time at intersections due to waiting time in queue. For the simple channel type, there will be a score of 10 because the waiting times are assumed to be greater because the cars that turn left or right share the flow with those that perform the other maneuvers. For
intersections with channeling with traffic signs there is a rating of 8 because they have a flow separation but it is not definitive, as in the intersections with channeling by infrastructure that have a rating of 7.

Fig. 4: Classification of At-grade intersections. Source: Author’s

2. **Variable 2, Type of traffic regulation**: this variable considers the type of traffic regulation that the intersection has. The intersections regulated by traffic light obtain a score of 10 because the waiting time of the vehicles grows considerably compared to the intersections regulated by signals type STOP or GIVE WAY which reach a rating of 5.

3. **Variable 3, Number of turnarounds**: in this variable, the number of turnarounds to be analyzed at each intersection is quantified. Thus, the left turns that have conflict with direct traffic add 5 points to the variable, while the direct left or right turn adds 3 points to the variable. Finally, the qualification of all the turnarounds is added being 10 the maximum that can be registered.

4. **Variable 4, Intersection location**: in this variable, the location of the intersections is classified according to the road hierarchy present in the Territorial Ordinance Plan (POT for its acronym in Spanish) of the city, urban planning instrument for the period 2017-2031 [2], according to which the city has the urban road subsystem composed of the urban arterial road network where the main arteries (10), secondary arteries (8) and collector roads (7) are located. On the other hand, there is have the complementary road network, which has local roads (5), pedestrian, semi-pedestrian and marginal landscaping, which have no final qualification because the interest of this research is focused on the turn costs times automobiles so intersections that have a high traffic flow are observed.

5. **Variable 5, Relationship with road accident analysis**: the road intersections that have relation with traffic accident analysis will have a higher score, reaching 10 points, while those that are not within these analyses will have 5 points. In the city of Manizales, Phase I and II of road safety audits were carried out in corridors
and road intersections of high accident rate with the support of the City Hall of Manizales, the National Road Safety Agency (ANSV for its acronym in Spanish) and the National University of Colombia, Manizales campus [1, 3].

These variables are analyzed in each georeferenced intersection, studying those that have the highest rating. Table 1 shows a summary of the variables analyzed and their respective rating.

Table 1 Intersection prioritization analysis variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
<th>Classification</th>
<th>Qualification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traffic channeling</td>
<td>Simple intersection</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intersection channeled by traffic signs</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intersection channeled by infrastructure</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Type of traffic regulation</td>
<td>Traffic light</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STOP or GIVE WAY</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Number of turnarounds</td>
<td>Turn left with direct traffic conflict</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simple left turn</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simple right turn</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Location of the intersection</td>
<td>Main Artery road</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary Artery road</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collector road</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local Way</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Relationship with road safety analysis</td>
<td>There is a record of road safety audits</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>There is no record of road safety audits</td>
<td>5</td>
</tr>
</tbody>
</table>

2.3 Field data collection
At this stage of the investigation, it is sought to record the turnaround times at the intersections, given in the order of prioritization of stage 1. To take better advantage of the data collected, it was decided to take a video record for an approximate time of 45 to 60 minutes of the intersections using a Canon T5 camera, facilitated by the Audiovisual Production Center of the National University of Colombia Manizales headquarters (CEPAUN for its acronym in Spanish), which allows registering videos from 480 p to 1080 p. The video record was analyzed in the next stage.

2.4 Analysis of data collected in the field
In this stage, the videos recorded in the intersection are analyzed, recording the time
it takes each vehicle (car, truck or motorcycle) to make the left or right turnaround maneuver at each intersection. For this, the maneuvers to be analyzed are taken into account according to the recommendations given by the RILSA institute [29]. 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 Turn costs calculation
In this last stage of the methodology, the penalties for left and right turns to be used in transport models were calculated, taking into account the results obtained in the preliminary stage of data analysis and the various types of intersections studied. In addition, the characteristics of the intersections studied will be taken into account.

3 Results and discussion

3.1 Classification and analysis of prioritization of intersections
Figure 5 shows the twenty (20) intersections with the highest rating according to the prioritization analysis described above.

![Figure 5. Location of analyzed road intersections. Source: Authors.](image)

Among the intersections prioritized for analysis, 45% belong to a channel with
horizontal signaling. On the other hand, 50% of the intersections have a traffic light as a means to regulate traffic while the rest have STOP or GIVE WAY sings as a regulatory means. Likewise, 45% of the intersections are located on a main artery of the city, which makes the flow of vehicles permanent. On the other hand, it is important to record that there are a total of 14 intersections that have been analyzed in road safety studies, which represents 34% of the total intersections that have been the subject of this same analysis. Finally, the study of the left turns that have conflict with direct traffic is important for the investigation so that 75% of the intersections to analyze have at least one of these turns.

### 3.2 Statistical analysis and calculation of turnaround times in analyzed intersections

Table 2 shows the time that left and right turns (seconds) take, which results from the statistical analysis with frequency tables of which the arithmetic mean is taken as the data representing the largest amount of data in each analyzed intersection.

#### Table 2 Turn costs (arithmetic mean) to left and right at each intersection

<table>
<thead>
<tr>
<th>Road Intersection</th>
<th>Time (seconds)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Turn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35.23</td>
<td>23.28</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11.63</td>
<td>3.56</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>37.31</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>50.17</td>
<td>65.27</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>6.41</td>
<td>8.80</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6.81</td>
<td>5.37</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>42.67</td>
<td>51.90</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>49.05</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>51.44</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>35.42</td>
<td>4.74</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>35.68</td>
<td>31.43</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>4.67</td>
<td>35.77</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>9.80</td>
<td>4.67</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>24.20</td>
<td>47.11</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>38.50</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>69.86</td>
<td>29.90</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>50.77</td>
<td>52.88</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>37.32</td>
<td>35.38</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>3.18</td>
<td>7.02</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>13.58</td>
<td>11.14</td>
<td></td>
</tr>
</tbody>
</table>

In this case, it can be observed that the intersection with the highest left turn times is intersection 16 with 69.86 sec., which is located on a main road where there is a
high vehicular volume. In addition, it has traffic light regulation with very high cycle times and multiple phases due to the various maneuvers allowed in it. On the other hand, intersection 4 has the highest right turn time (65.27 sec) because, like intersection 16, it is on a main arterial road. Likewise, in this intersection, the right turn has separation infrastructure, although the regulation by traffic light increases the turn time for the vehicles analyzed. Otherwise, intersection 19 has the lowest left turn times (3.18 sec), mainly because traffic regulation is carried out by STOP signs, which causes the analyzed vehicles to have a shorter waiting time at the intersection. In addition, the vehicular flow is smaller due to the location of the intersection on a secondary arterial route. However, for the right turn times, the lowest time corresponds to the intersection 2 with 3.56 sec, which has characteristics similar to the aforementioned intersection. Likewise, there are 4 intersections (intersection 3, 8, 9 and 15) for which there are no records of turns times to the right because the video capture did not allow to distinguish the entire turning maneuvers at the time of analysis.

3.3 Turn Costs
There will be two different scenarios for calculating the turn costs. The first one is where the penalties are calculated by turning left and right with the totality of the data of each intersection determining the general penalty for the city of Manizales. Second is the one where the calculation of the penalties per turnaround is made according to the type of traffic regulation that the intersection has. Table 3 shows the result of the penalties per turnaround in the first scenario where a total of 4219 times recorded in the 20 intersections considered for the study were analyzed. The penalties correspond to the calculation of the arithmetic mean for grouped data.

Table 3. General turn costs obtained by empirical way

<table>
<thead>
<tr>
<th>Turn</th>
<th>Number of data analyzed</th>
<th>Time (seconds)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>1554</td>
<td>29.69</td>
<td>4.97</td>
</tr>
<tr>
<td>Left</td>
<td>2665</td>
<td>34.84</td>
<td>5.51</td>
</tr>
</tbody>
</table>

In this case, it can be seen how the penalties for left turn are 15% higher, which indicates that, in general, it takes more time for cars to make this maneuvers. Table 4 shows the result of the penalties per turnaround in the second scenario where the traffic regulation method was taken into account at the time of calculation. For this scenario, it can be observed how the turnaround times are greater for intersections that have traffic lights as traffic regulation, mainly due to the waiting time of the registered vehicles due to the cycle time of each traffic light phase. Also, the penalties for right (46.03 sec) and left (45.73 sec.) are very similar for intersections because there is only 0.3 seconds difference between them. It is important to highlight how the penalty for left turn is almost 3 times more than the penalty for
right turn. On the other hand, for the intersections that have STOP or GIVE WAY signs as traffic regulation the penalties for turnaround are much smaller, reaching 5.83 seconds for the right turn and 17.25 seconds for the left turn.

Table 4. Turn costs according to the type of traffic regulation

<table>
<thead>
<tr>
<th>Type of traffic regulation</th>
<th>Turn</th>
<th>Number of data analyzed</th>
<th>Time (seconds)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic light</td>
<td>Right</td>
<td>892</td>
<td>46.03</td>
<td>6.12</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>1648</td>
<td>45.73</td>
<td>6.06</td>
</tr>
<tr>
<td>Stop or give way signs</td>
<td>Right</td>
<td>662</td>
<td>5.83</td>
<td>3.86</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>1017</td>
<td>17.25</td>
<td>6.42</td>
</tr>
</tbody>
</table>

4. Conclusions

The prioritization analysis is important to decide which intersections should be analyzed. According to the city in which the study is carried out, it is recommended that 50% of the intersections analyzed correspond to traffic light intersections. On the other hand, it is important that the total number of intersections represents at least 25% of intersections analyzed in road safety studies due to the relationship that will exist with traffic accidents, the number of conflicts and the number of turnarounds that are made.

At the time of the video capture at each intersection, it is important to record the total maneuvers of the vehicles so that for some intersections two or more video cameras will be necessary, if this is done at street level. The records can also be recorded from a high point to obtain better perspective of the intersection. Undoubtedly, the best option would be to make the video with the help of a drone, which allows recording from a much greater perspective, facilitating the subsequent analysis of the data. For the analysis of videos, a software of detection of maneuvers that allows to facilitate the time it takes to make a turn of the vehicles in each intersection should be used.

The general penalty for the city of Manizales resulted in 29.69 seconds for the right turn and 34.84 seconds for the left turn. When taking into account the type of regulation at the intersection, these penalties change considerably, reaching 46.03 seconds for right turn and 45.73 seconds for left turn at intersections with traffic light, while for intersections with regulation by STOP or GIVE WAY, the turn costs reach 5.83 seconds for the right and 17.25 for the left.

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