UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS

DYNA
http://dyna.medellin.unal.edu.co/

Application of a prefeasibility study methodology in the selection of road infrastructure projects: The case of Manizales (Colombia)

Diego Alexander Escobar-García [a], Camilo Younes-Velosa [b] & Carlos Alberto Moncada-Aristizábal [c]

[a] *Facultad de Ingeniería y Arquitectura, Universidad Nacional de Colombia, Manizales, Colombia. daescobarga@unal.edu.co*
[b] *Facultad de Ingeniería y Arquitectura, Universidad Nacional de Colombia, Manizales, Colombia. cyounesv@unal.edu.co*
[c] *Facultad de Ingeniería, Universidad Nacional de Colombia, Bogotá, Colombia. camoncadaa@unal.edu.co*

Received: February 25th, 2015. Received in revised form: May 8th, 2015. Accepted: July 21th, 2015.

Abstract
Major cities in Colombia are currently generating urban transformation processes that involve the construction of major infrastructures, which mainly look to mitigate the adverse effects of ever-increasing road traffic. In addition, intermediate cities have made great efforts when it comes to urban planning and promote the application of prefeasibility study methodologies to make the appropriate decisions regarding the infrastructures to be built in specific places in the city. This paper discusses the results after applying a prioritization methodology as a comparative tool between two possible road infrastructures in the area of San Marcel in the city of Manizales, Colombia. The best proposal is selected based on the best coverage indicators and variables such as overall construction costs and life span: determined from information generated in traffic simulations.

Keywords: Accessibility, priorization analysis, coverage, geostatistics, urban planning.

Aplicación de una metodología a nivel de prefactibilidad para la selección de proyectos de infraestructura vial. El caso de Manizales (Colombia)

Resumen
Actualmente las grandes ciudades colombianas están generando procesos de transformación urbana que involucran la construcción de importantes infraestructuras, buscando en la mayoría de los casos, tratar de mitigar los efectos adversos del creciente tránsito automotor. Por su parte, las ciudades intermedias no ahorran esfuerzos en términos de planificación urbana, impulsando la aplicación de metodologías, que a nivel de prefactibilidad, permiten tomar decisiones respecto a las infraestructuras que se deben construir en determinados sitios de la ciudad. En este artículo se discuten los resultados de aplicar una metodología de priorización como instrumento comparativo entre dos posibles infraestructuras viales en el sector de San Marcel en la ciudad de Manizales, Colombia. Se determina cuál de las propuestas refiere mejores indicadores de cobertura, relacionando los mismos con variables como los costos globales de construcción y vida útil definida a partir de simulaciones de tránsito.

Palabras clave: Accesibilidad, análisis de priorización, cobertura, geoestadística, planeamiento urbano.

1. Introduction

Manizales is an intermediate city located in the west central region of Colombia on the central mountain chain at an altitude of 2,150 meters above sea level. It has a population of 361,422 inhabitants in an area close to 35 km^2.

Manizales is currently implementing a Mobility Plan (2010-2040) [1] and several infrastructure projects have been implemented during the last few years, which have changed the mobility characteristics in specific sectors of the city.

A Geographic Information System (GIS) was used in this research to collect current and future road network information based on each of the proposals.

The accessibility isochronous curves were calculated using the GIS geospatial visualization capabilities and geostatistical software. These curves were then used to calculate studies of geospatial coverage of the variables area, population and number of households.

Given its capacity to store information and to integrate the different models related to a specific territory [2] GIS facilitates understanding in greater detail of means of transport accessibility characteristics. The use of algorithms [3], such as the shortest path algorithm, provides researchers with the necessary tools to simulate the impact of insertion of a given infrastructure.

From the geographical point of view, accessibility is a measure of the ease of communication between a group of communities or activities, which is achieved by using different means of transport [4]. This concept has become very important in urban and regional planning, and has been applied in regional economic planning and in Location Theory since the second decade of the twentieth century. [5]. Accessibility has become a primary element of urban planning in the use of quantitave criteria to determine future land use in order to achieve greater social welfare through appropriate sector planning [6].

There are various definitions of the term, but the classic was provided by Hansen in the early second half of the last century ". "…the potential of Opportunities for interaction. "[7]. The models built on accessibility measures are commonly based on the distance and attraction between network nodes [8]. However, accessibility is nowadays more related to the distance of means of transport and the savings in connection time between different regions [9].

Factors such as location of the nodes, number of nodes, transportation network and population distribution affect accessibility [10]. However, the new mobility paradigm includes other factors such as the quality of means of transport, proximity to land use, and infrastructure characteristics such as cost, safety, comfort, and environment, among others [11].

Accessibility has been widely used in other fields of knowledge, such as analysis of service location [12-14], operation of means of transport [15,16], analysis of social cohesion [17,18], demographic analysis [19], economic development [20-22], sustainability [23,24], tourism [25], and social networks [26], among others.

Accessibility in Colombia has been a measure rarely used because the true potential of this type of analysis is not very well understood. However, there are some real examples of the application of these methodologies at both regional [27] and urban [28-30] levels.

Currently, accessibility analysis is becoming an important factor for plan evaluation and infrastructure projects [31], and in many cases the improvement of accessibility is one of the criteria used in evaluations [32]. Moreover, there are a variety of dynamic simulation models at urban levels [33-35] as well as accessibility models involving infrastructure insertion analysis [36,37] and its spatial-temporal impact on urban growth.

Therefore, accessibility must be recognized as a primary need [38] as it defines people's access to basic services such as health, education and employment as a priority. This shows how many countries can eliminate class differences by increasing access to basic services and satisfying basic needs as one of the objectives related to transportation [39].

This research includes an infrastructure prioritization methodology based on the following variables: accessibility, traffic microsimulation results and global and preliminary construction costs. The methodology, results and major conclusions are addressed in the following chapters.

2. Methodology

There are principally six phases in this methodology: In the first phase, the official network of the city of Manizales was obtained and the operating speed information was loaded in the database [1,29].

In the second phase the intervention alternatives in the road infrastructure were georeferenced.

In the third phase calculations were made of the Global Media Accessibility offered by the network of the existing transport infrastructure and the curves for each of the alternatives were evaluated.

In the fourth phase calculations were made on the impact on savings in Average Travel Time - ATT provided by each one of the alternatives.

In the fifth phase calculations were made of the percentages of area, population and number of households covered by ATT curves obtained from the analysis of global average accessibility in each one of the alternatives.

And in the sixth, a sensitivity analysis was undertaken according to the variability of the characteristics of life span, global construction costs and savings in ATT.

2.1. Secondary information

The infrastructure network for the Mobility Plan of Manizales, provided by the local administration, was instrumental in making the calculations for territorial accessibility. The network has loaded information relating to operating speeds, which was provided by GPS equipment installed in different types of vehicles.

2.2. Georeferencing of the alternatives

In this phase, the alternatives to infrastructure intervention were georeferenced using the road network as base information. Fig. 1 shows the sector under study and the arcs of the existing road network are highlighted.

New arcs, corresponding to each alternative, are incorporated taking into account the designs on phase II. The future operational features were defined in each alternative.

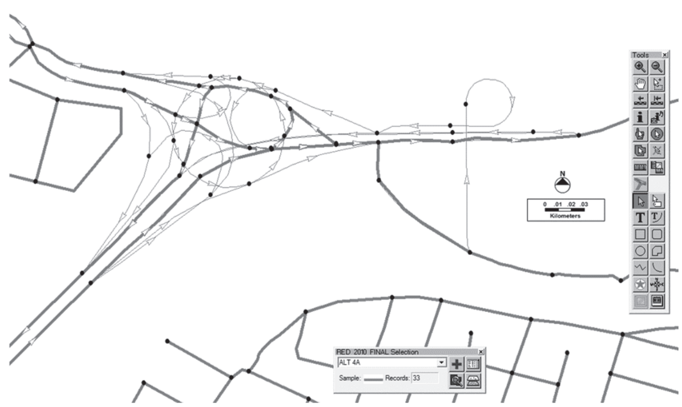


Figure 1. Graph of the existing road network and approach of the sector under study.
Source: Own source based on the graph provided by the Mobility Plan of Manizales [1].

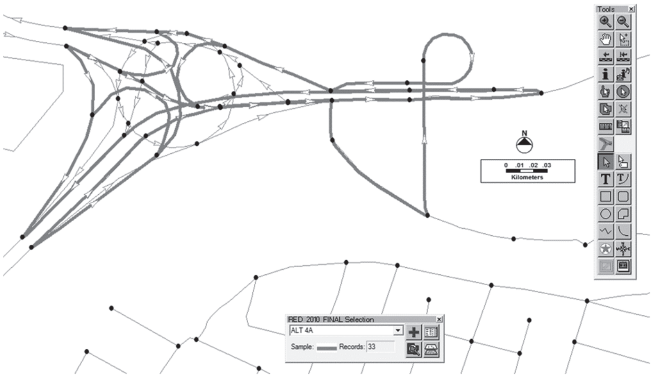


Figure 2. Graph of the road network including the insertion of alternative 4A.
Source: Own source based on the graph provided by the Mobility Plan of Manizales [1].

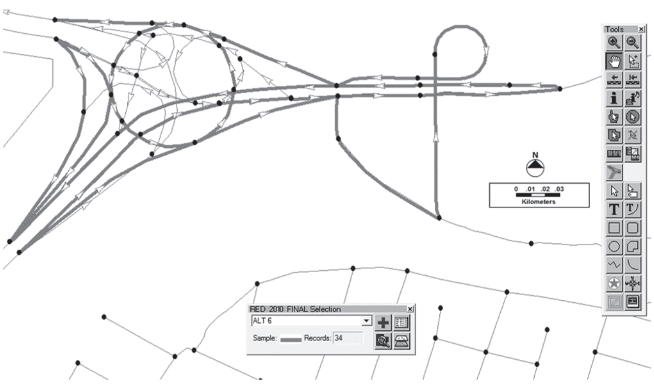


Figure 3. Graph of the road network including the insertion of alternative 6.
Source: Own source based on the graphic provided by the Mobility Plan of Manizales [1].

Figs. 2 and 3 show an approach of each graph with the insertion of the alternatives to be evaluated: in this case alternative 4A and 6 respectively.

2.3. Calculation of urban territorial accessibility

The urban Territorial Accessibility was analyzed using the ATT vector (Tvi), which represents the average travel time from node i to the other network nodes. The GIS algorithm was used for this calculation to obtain the lower impedance (shortest path) between a specific node and the other nodes in the network, forming a unimodal matrix.

The matrix of minimum average travel time was designed using the unimodal matrix and also the information of average operating speed in each arc. The ATT is minimized between each and every node in the network. After that, the vector of average travel time (Tvi, eq.1) was obtained.

$$\overline{T_{vi}} = \frac{\sum_{j=1}^{m} t_{vi}}{(n-1)} \quad i=1,\ 2,\ 3,\ldots,\ n;\ j=1,2,3,\ldots,\ m \qquad (1)$$

Where Tvi = minimum average travel time between node i and the other nodes in the network; i = number of network nodes. The ATT vector obtained (n x 1) is related to the geographical coordinates (longitude and latitude) of each of the nodes to generate a matrix of order (n x 3). Isochronous curves of average travel time were generated using this matrix to analyze urban Territorial Accessibility for both the current infrastructure and for each of the alternatives under consideration. The ordinary kriging method was used along with linear semivariogram as an average travel time prediction model.

2.4. Calculation of the impact on average travel time – ATT

Once the isochronous curves for the current infrastructure and for each of the other two alternatives of infrastructural intervention are calculated, the gradient on average travel times for each alternative was determined.

The gradient was calculated in terms of the percentage of ATT taking into account the hypothesis that there is an improvement in operating speeds of the vehicles in the new infrastructure. The ATT is reduced depending on the current average travel time.

2.5. Coverage analysis

The urban area of the city of Manizales is 35.1 Km2, has about 361,422 inhabitants, 83,868 households and approximately 115 neighborhoods.

The gradient curves of time savings in ATT in each of the alternatives under study were related using a GIS and taking into consideration the available demographic information. It was possible to estimate the percentage of population, area and number of households covered by a given gradient curve of time savings. Similar applications of coverage have been made in other contexts [40].

3. Results and discussion

3.1. Global Media Accessibility offered by the current network structure

The following will show excerpts from the analysis of global average accessibility for the city of Manizales. These results are the basis for the calculation of gradients in saving percentages in ATT. These excerpts have been documented in the Mobility Plan of the city of Manizales [1,28]. Fig. 4 shows the ATT isochronous curves in terms of Global Media Accessibility in Manizales. In general, the city is covered by isochronous curves of between 25 and 67.5 minutes.

The lowest isochronous curve is of 25 minutes covering a wide sector between Avenida Santander, Avenida Kevin Angel and the downtown area of Manizales. This area currently benefits from the best possible accessibility in the city. It is concluded that 50% of the population and 50% of the number of houses are covered by ATT of up to 29.5 minutes, while 50% of the urban area are covered by ATT of up to 32.5 minutes.

3.2. Gradient of global media accessibility. Alternative 4A

Once the Global Media Accessibility of Manizales is calculated, taking into account modifications to the graph corresponding to Alternative 4A, the vector of average travel time is compared in both the current infrastructure and in alternative 4A.

Figure 4. Global Media Accessibility curves in Manizales.
Source: Escobar and García (2012) [29].

Figure 5. Approach gradient curves in terms of percentage of savings in ATT. Alternative 4A.
Source: Authors´own calculation.

Figure 6. Gradient curves in terms of percentage of savings in ATT. Alternative 4A.
Source: Authors´ own calculation.

A kriginig prediction model with linear semivariogram was applied in the geostatistical analysis. Fig. 5 shows an approach to the sector under study and the behavior of the curves is observed within the Enea neighborhood. Fig. 6 shows the configuration of these curves throughout the city of Manizales.

If chosen, Alternative 4A would provide a percentage of savings in ATT throughout the entire city and sectors located to the east (La Enea neighborhood) would have a percentage savings in ATT of maximum 3% of the current ATT. Table 1 shows the results of relating the gradient isochronous curves with the sociodemographic information of Manizales.

Fig. 7 was built using a more detailed analysis of the results. It shows the relationship between the percentage of coverage and the percentage of savings in ATT in each of the analyzed variables.

The percentage of area, population and number of households covered by each gradient isochronous curve was calculated. In the variable area, the gradient curve of 0.5% covers 70%. It is observed that 17% of the population might have an average saving of 1% in ATT regarding the initial ATT. Regarding the variable number of households, stratum 1, having the lower gradient curve, is the stratum reporting higher coverage percentages.

If chosen, Alternative 4A would have a final saving percentage of 0.8% in ATT in relation to the initial ATT for approximately 43% of coverage of the three variables.

3.3. *Gradient of Global media accessibility. Alternative 6*

Once the Global Media Accessibility is calculated taking into account the modifications done to the graph of Alternative 6, the same calculation of gradient is done in

Table 1.
Percentage of area, population and number of households covered by gradient curves in saving percentages of ATT in Alternative 4A.

Isochronous Curve % Savings	Area		Population		Households	
	Km^2	%	N° People	%	N° Houses	%
0,5	24,7	70%	283.510	78%	62.888	75%
1,0	8,3	24%	62.665	17%	17.215	21%
1,5	0,7	2%	1.623	0%	611	1%
2,0	0,5	2%	3.860	1%	984	1%
2,5	0,5	1%	4.520	1%	1.047	1%
3,0	0,4	1%	5.243	1%	1.128	1%
Total	35,1	100%	361.422	100%	83.873	100%

Source: Authors´own calculation.

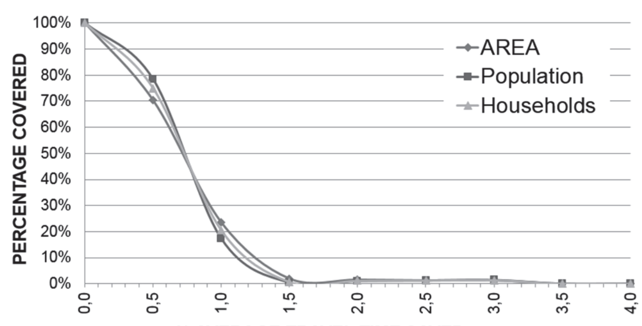


Figure 7. Relationship between the percentage of coverage and the percentage of savings in ATT. Alternative 4A.
Source: Authors´ own calculation.


Figure 8. Approach gradient curves in saving percentages in average travel time. Alternative 6.
Source: Authors´ own calculation.

Table 2.
Percentage of area, population and number of households covered by gradient curves in saving percentage of ATT in Alternative 6.

Isochronous curve % Savings	Area		Population		Households	
	Km^2	%	N° of people	%	N° Houses	%
0,5	18,8	54%	270.414	75%	59.921	71%
1,0	12,4	35%	72.307	20%	19.041	23%
1,5	1,6	4%	2.221	1%	862	1%
2,0	0,6	2%	1.511	0%	534	1%
2,5	0,6	2%	3.565	1%	931	1%
3,0	0,9	3%	8.414	2%	1.939	2%
3,5	0,2	1%	2.856	1%	616	1%
4,0	0,0	0%	136	0%	29	0%
Total	35,1	100%	361.422	100%	83.873	100%

Source: Authors´ own calculation.

Figure 9. Gradient curves in saving percentages in average travel time. Alternative 6.
Source: Authors´ own calculation.

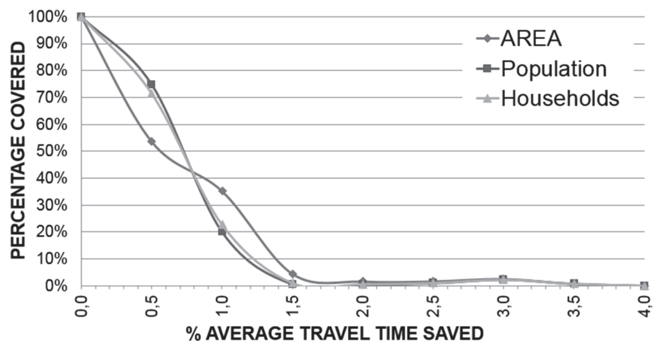


Figure 10. Relationship between the percentage of coverage and the percentage of savings in ATT. Alternative 6.
Source: Authors´ own calculation.

Alternative 4A. A kriginig prediction model with linear semivariogram is applied in the geostatistical analysis. Fig. 8 shows an approach to the sector under study and also the behavior of the curves in the Enea neighborhood.

A brief comparison of the curves obtained in Alternative 4A (see Fig. 5) shows that Alternative 6 would provide the Enea neighborhood with better service of transport given the fact that the gradient curves refer to a greater coverage in higher saving percentages of ATT. Fig. 9 shows the configuration of these curves throughout the city of Manizales.

If chosen, Alternative 6 would provide the entire city with saving percentages in ATT, and sectors located to the east (La Enea neighborhood) would benefit from savings percentages in ATT of maximum 4%; a value higher than the one obtained in Alternative 4A.

The percentage of area, population and number of households covered by each curve was calculated relating the gradient isochronous curves obtained from the sociodemographic data of Manizales. Table 2 shows the summary of the overlay data.

The gradient curve of 0.5% covers 54% in the variable area and 20% of the population could experience an average savings in ATT of 1% compared to the current infrastructure. The percentage distribution of coverage of number of households shows that stratum No. 1 manifests a higher percentage of number of households covered in the lower gradient curve; similar situation found in alternative 4A.

After making a more detailed analysis of the results, it was possible to find the relationship between the percentage of coverage and the percentage of savings in ATT for each of the variables. See Fig. 10.

Alternative 6, with approximately 41% coverage of the three variables, would provide a 0.8% of saving percentages in ATT compared to the initial ATT. It is to note that the percentage of coverage at the point where the area, population and number of households converge is slightly above 40% and very similar in both alternatives. However, the configuration of the curves is different.

3.4. *Comparison of results for Global media accessibility and alternatives*

An objective comparison is done regarding the percentages of coverage for each of the variables in each alternative. Fig. 11 separately and comparatively shows the results obtained while taking into account the variable area, population and number of households covered.

Regarding the variable area, there is a greater coverage in saving percentages, superior to 1%, in ATT. This is due to the characteristics of population density of the area covered by such curves and to the differences in the configuration of the curves obtained in both intervention alternatives. The configuration of the curves is very similar in the variable urban population and number of households covered.

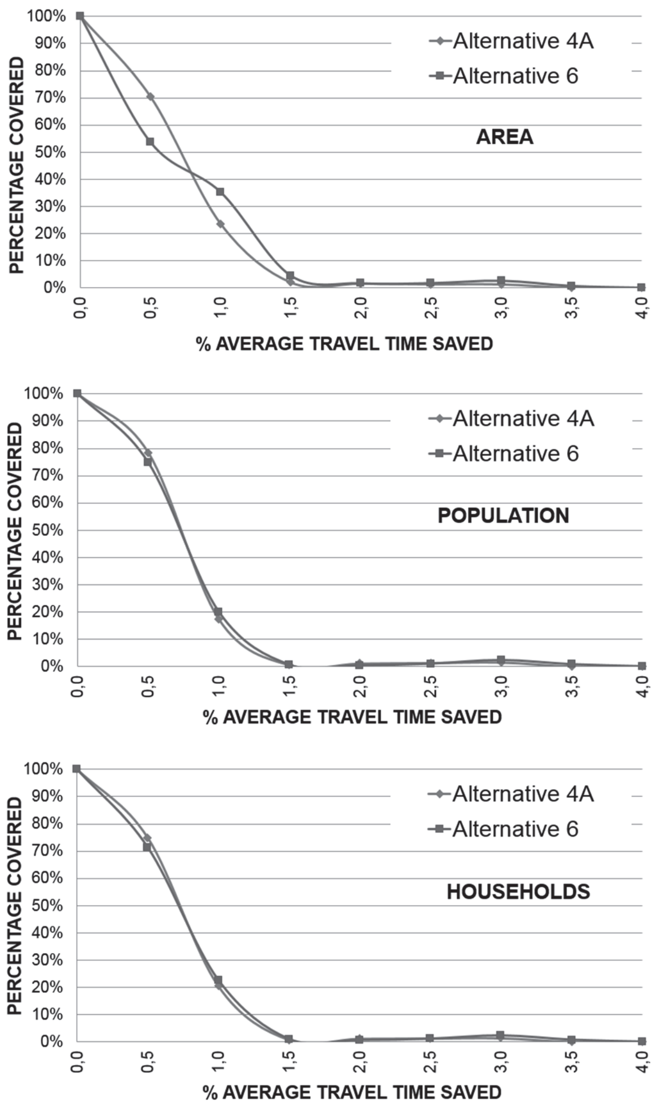


Figure 11. Comparison of results. Variables area, population and number of households.
Source: Authors´ own calculation.

Even though the percentage coverage of the variable population and number of households are similar due to their geospatial distribution, it is concluded that Alternative 6 demonstrates more favorable results than Alternative 4A in terms of a supply model of transport and saving percentages in ATT. These results are determined by the calculation of coverage percentages and cannot be verified simply by observing the graphs.

Calculating the number of households covered according to socioeconomic stratum manifests that the higher the stratum the higher the percentage of coverage of a gradient upper curve (see Fig. 12). For example, there is a high percentage of coverage (over 90%) for the gradient curve of 0.5%, in both alternatives for stratum 1. However, the percentage coverage decreases for stratum 6 (up to 60 %) but increases to almost 30% in the gradient curve of 1% in savings in ATT.

Coverage of households in stratum 3 was achieved with gradient curves exceeding 3% savings in average travel time. This result reflects residential activity in La Enea neighborhood. These results are higher in Alternative 6 than in Alternative 4A as this is the point in which the difference between the two alternatives is higher regarding supply models.

It is important to note the results obtained in stratum 5, where the gradient curve of 1% in ATT savings, presents greater coverage than the gradient curve of 0.5%. This is a very positive situation due to the fact that there is a strong possibility of further decreasing the average travel time in stratum 5, in which vehicle purchasing power is considered high. It was found that over 50% of households in Stratum 5 might reduce their average travel time by up to 1%.

Performing a weighted analysis of the saving percentage in ATT in each variable shows that Alternative 4A would provide a 0.66% saving in ATT regarding the variable population, while Alternative 6 would generate a 0.72% savings in ATT.

Performing the same analysis regarding the variable number of households gives that Alternative 4A reports a saving percentage of 0.69% while Alternative 6 reports a saving percentage of 0.74%.

Finally, performing the same analysis regarding the variable area demonstrates that Alternative 4A generates a percentage saving of 0.72% and Alternative 6 reaches 0.87%. Table 3 shows the results of weighing the saving percentage in ATT by socioeconomic strata and by Alternative regarding the variable number of households.

If chosen, Alternative 4A would provide stratum 3 with 0.82% and stratum 5 with 0.79% savings in ATT. However, if chosen, Alternative 6 would provide stratum 3 with 0.91% and stratum 5 with 0.81% savings in ATT. In general, Alternative 6 shows higher saving percentages in ATT than Alternative 4A.

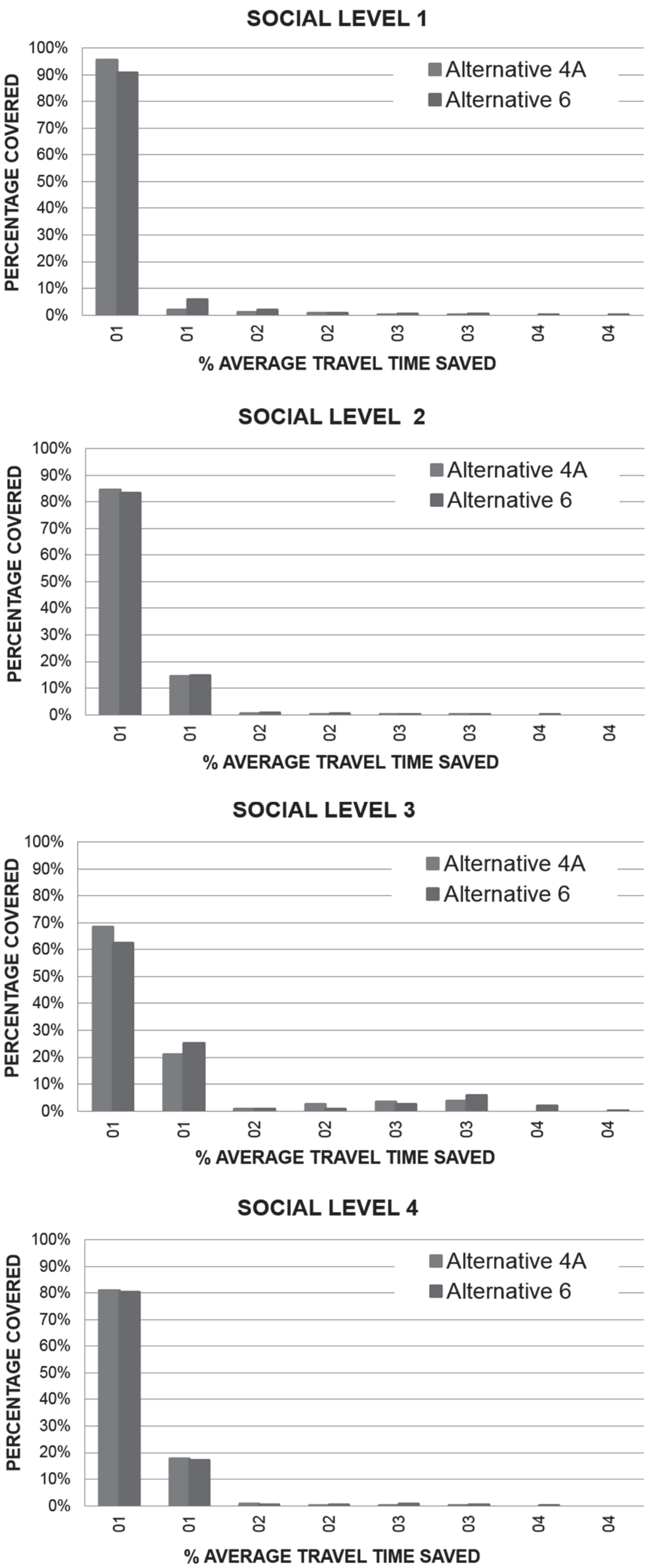
3.5. Prioritization analysis

The prioritization analysis used in this research considers three variables that complement each other. The first deals with simulation results of traffic and demand, in other words, the life span calculated using traffic studies. The second deals with the analysis of urban territorial accessibility that defines the percentage saving in ATT obtained with the building of each alternative. The third deals with the preliminary construction cost of the alternatives. Alternative 4A yielded better results from the simulation and demand as it had a life span of twenty (20) years, while Alternative 6 had a life span of seven (7) years.

From the point of view of supply models, that is from the territorial accessibility analysis, and giving equal importance to the variables area, population and number of households, it was decided that Alternative 4A reported a weighted average saving percentage of 0.69% while Alternative 6 reported 0.78%.

Alternative 4A reported preliminary costs of approximately \$8 million U.S dollars while Alternative 6 reported preliminary costs of approximately \$6.5 million U.S dollars (2014 prices).

Table 4 shows the rating or scores in each alternative, assigning the best result a value of five points for each of the three variables that make up the prioritization study and provides a score directly proportional to the highest score in the second option.



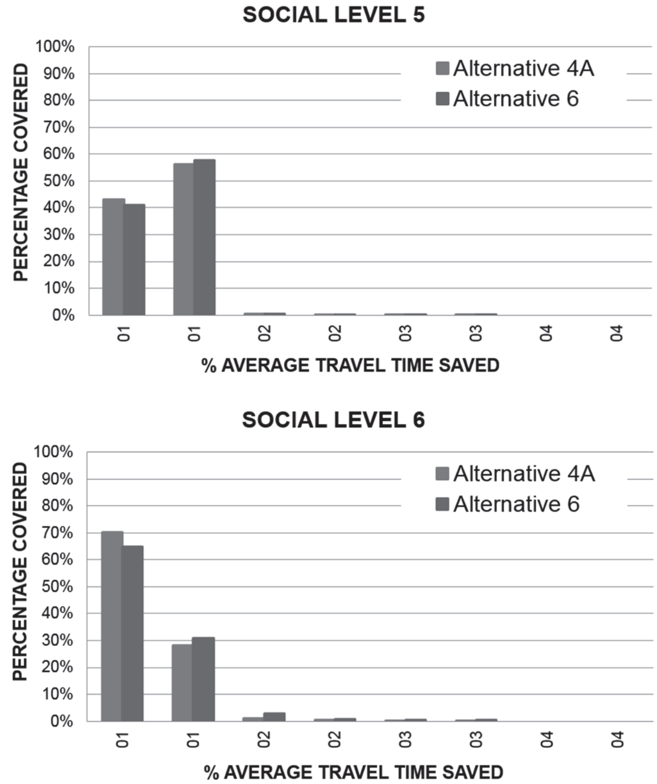


Figure 12. Comparison of results in terms of social levels. Variables area, population and households.
Source: Authors´ own calculation.

Table 3.
Saving Percentage in ATT weighted by the number of households in each socioeconomic stratum and each proposed alternative.

Social Level	Alternative 4A	Alternative 6
1	0,54	0,58
2	0,58	0,60
3	0,82	0,91
4	0,60	0,63
5	0,79	0,81
6	0,66	0,71
Total	0,69	0,74

Source: Authors´ own calculation.

Table 4.
Scores of the variables in the prioritization analysis in each alternative.

Alternative	Life span	% ATT savings	Preliminary costs
4A	5,0	4,4	4,1
6	1,8	5,0	5,0

Source: Authors´ own calculation.

Giving equal value to the life span, ATT savings and preliminary costs variables shows that Alternative 4A would have a final score of 4.5 (within a scale of 0 to 5, 5 being the highest and 0 the lowest) and Alternative 6 a score of 3.9. The recommendation is thus to build Alternative 4.

However, it would be possible to generate a sensitivity analysis by performing a gradual analysis of the weight of each of the variables to show the variation of the score assigned to each alternative depending on the weight defined

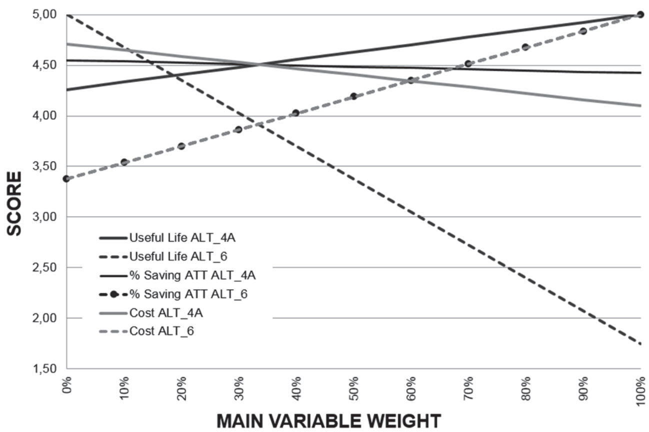


Figure 13. Sensitivity analysis according to gradual change of the main variable.
Source: Authors´ own calculation.

in each variable. Considering each of the variables to be the main variable of gradual change and equally distributing the weight of the remaining two variables, the values of the scores obtained are graphed.

Fig. 13 shows the sensitivity curves in each alternative according to the gradual change of the variable defined as the main one. For example, if life span is taken as the main variable it would refer to an important variation in the weight assigned to this variable according to the score, thus getting a greater score variation in Alternative 6.

4. Conclusions

It is concluded that the values of saving percentages in ATT seem low because they correspond to the comparative of a particular intervention point in the city regarding the current situation and not an intervention of an entire vehicular corridor as presented in the Mobility Plan. In other words, from the point of view of a transport model,, an insertion of an infrastructure that is configured as a mobility corridor, whether new or rehabilitated, is more visible than the insertion of an infrastructure on a specific site in the city.

However, it is considered that the results show global percentages of saving in ATT and these savings very well qualify the impact of each of the analyzed alternatives in the entire city of Manizales.

It is noted that depending on the weight given to the three variables analyzed, the result would be the recommendation to build either alternative. However, there are combinations of weights of the three variables that yield similar results in terms of the final score.

It was found that 4A is the best recommended Alternative to be built because even though this alternative offers lower saving percentages in ATT than Alternative 6, and preliminary construction costs higher than Alternative 6, its life span is much higher than the life span of Alternative 6. This was defined after microsimulation and demand analysis.

It is also concluded that the definition of the weight of the variables in the analysis of prioritization depends exclusively on the main purpose for the interventions or on the constraints identified in the global project.

After making the proper prioritization calculation of Alternatives 4A and 6 and after analyzing the results, it is considered that the construction of Alternative 4A is the most viable. It is necessary to clarify that this prioritization analysis did not include environmental issues that might impact the results one way or another.

References

[1] Alcaldía de Manizales, Secretaría de Tránsito y Transporte. Plan de Movilidad de la ciudad de Manizales 2010 – 2040. Universidad Nacional de Colombia – Sede Manizales. Manizales, Abril 2011.

[2] Gómez, M., y Barredor, J.I., Sistemas de información geográfica y evaluación multicriterio en la ordenación del territorio. Ra-Ma Editorial. 2da. Edición. Madrid, 2005.

[3] Zhang, H. and Gao, Z., Bilevel programming model and solution method for mixed transportation network design problem. Journal of Systems Science and Complexity, [Online]. 22 (3), pp. 446-459, 2009. [Date of reference July 24th of 2012]. Available at: http://www.sysmath.com/jweb_xtkxyfzx/EN/Y2009/V22/I3/446

[4] Morris, J., Dumble, P. and Wigan, M., Accessibility indicators in transport planning. Transportation Research, [Online]. A, 13, pp. 91-109, 1978. [Date of reference September 21th of 2012]. Available at: http://projectwaalbrug.pbworks.com/f/Transp+Accessib+-+Morris,+Dumble+and+Wigan+(1979).pdf

[5] Batty, M., Accessibility: In search of a unified theory. Environment and Planning B: Planning and Design, [Online]. 36, pp. 191-194, 2009. [Date of reference November 6th of 2012]. Available at: http://www.envplan.com/abstract.cgi?id=b3602ed

[6] Kibambe, J.P., Radoux, J. and Defourny, P., Multimodal accessibility modeling from coarse transportation networks in Africa. International Journal of Geographical Information Science, [Online]. 27 (5), pp. 1005-022, 2013. [Date of reference December 23th of 2012]. Available at: http://www.tandfonline.com/doi/abs/10.1080/13658816.2012.735673#.VHP5bPmG8uc

[7] Hansen, W., How accessibility shapes land use. Journal of the American Institute of Planners, [Online]. 25 (2), pp. 73-76, 1959. [Date of reference December 23th of 2012]. Available at: http://www.tandfonline.com/doi/abs/10.1080/01944365908978307#.VHPikfmG8uc

[8] Curl, A., Nelson, J. and Anable, J., Does Accessibility Planning address what matters?. Transportation Business & Management, [Online]. 2, pp. 3-11, 2011. [Date of reference September 22th of 2012]. Available at: http://www.sciencedirect.com/science/article/pii/S2210539512000041

[9] Gutiérrez, J., Redes, espacio y tiempo. Anales de geografía de la Universidad Complutense, [Online]. 18, pp. 65-86, 1998. [Date of reference May 9th of 2012]. Available at: http://revistas.ucm.es/index.php/AGUC/article/viewFile/AGUC9898110065A/31393

[10] Burkey, M., Decomposing geographic accessibility into component parts: methods and an application to hospitals. Annals of Regional science, [Online]. 48 (3), pp. 783-800, 2012. [Date of reference April 19th of 2012]. Available at: DOI: 10.1007/s00168-010-0415-3

[11] Litman, T., Beyond roadway level-of-service: Improving transport system impact evaluation. [Online]. Victoria Transport Policy Institute. February 2014. [Date of reference January 5th of 2015]. Available at: http://www.vtpi.org/CGOP_LOS.pdf

[12] Calcuttawala, Z., Landscapes of information and consumption: A Location analysis of public libraries in calcutta, in Edward D. Garten, Delmus E. Williams, James M. Nyce (eds.). Advances in Library Administration and Organization, [Online]. Vol. 24, Emerald Group Publishing Limited, pp.319-388, 2006. [Date of reference August 13th of 2012]. Available at: http://www.emeraldinsight.com/doi/pdfplus/10.1016/S0732-0671%2806%2924009-4. DOI: 10.1016/s0732-0671(06)24009-4

[13] Park, S., Measuring public library accessibility: A case study using GIS. Library & Information Science Research, [Online]. 34 (1), pp. 13-21, 2012. [Date of reference September 12th of 2012]. Available at: http://www.sciencedirect.com/science/article/pii/S0740818811000958

[14] Higgs, G., Langford, M. and Fry, R., Investigating variations in the provision of digital services in public libraries using network-based GIS models. Library & Information Science Research, [Online]. 35 (1), pp. 24-32, 2013. [Date of reference January 15th of 2013]. Available at: http://www.sciencedirect.com/science/article/pii/S0740818812000977
[15] Cao, X. and Li, L., Accessibility distribution impact of intercity rail transit development on Pearl River Delta Region in China. CICTP 2012: Multimodal Transportation Systems—Convenient, Safe, Cost-Effective, Efficient. Proceedings of the 12th International Conference of Transportation Professionals. Beijing, China, [Online]. pp. 1719-1730, 2012. [Date of reference August 12th of 2013]. Available at: http://ascelibrary.org/doi/abs/10.1061/9780784412442.175
[16] Botero, R., Murillo, J. and Jaramillo, C., Decision strategies for evaluating pedestrian accessibility. Revista DYNA, [Online]. 78 (168), pp. 28-35, 2011. [Date of reference September 14th of 2014]. Available at: http://dyna.unalmed.edu.co/en/ediciones/168/articulos/a03v78n168/a03v78n168.pdf
[17] Schürman, C., Spiekermann, K. and Wegener, M., Accessibility indicators. Berichte aus dem Institut für Raumplanung, [Online]. 39, IRPUD, Dortmund, 1997. [Date of reference November 23th of 2013]. Available at: http://spiekermann-wegener.de/pub/pdf/IRPUD_Ber39.pdf
[18] López, E., Gutierrez, J. and Gómez, G., Measuring regional cohesion effects of large-scale transport infrastructure investment: An accessibility approach, European Planning Studies, 16 (2), pp. 277-301, 2008. DOI: 10.1080/09654310701814629
[19] Kotavaara, O., Antikainen, H. and Rusanen, J., Population change and accessibility by road and rail networks: GIS and statistical approach to Finland 1970–2007. Journal of Transport Geography, [Online].19 (4), pp. 926-935, 2011. [Date of reference October 16 2012]. Available at: http://www.sciencedirect.com/science/article/pii/S0966692310001948
[20] Rietveld, P. and Nijkamp P., Transport and regional development. In: J. Polak and A. Heertje, Eds., European Transport Economics, European Conference of Ministers of Transport (ECMT), Blackwell Publishers, Oxford. 1993.
[21] Vickerman, R., Spiekermann, K. and Wegener, M., Accessibility and economic development in Europe. Regional Studies, 33 (1), pp. 1-15, 1999. DOI: 10.1080/00343409950118878
[22] Mackinnon, D., Pirie, G. and Gather, M., Transport and economic development. In: R. Knowles, J. Shaw, & I. Docherty, Eds., Transport Geographies: Mobilities, Flows and Spaces, Blackwell Publishers, Oxford, 2008, pp. 10-28.
[23] Cheng, J., Bertolini, L. and Clercq, F., Measuring sustainable accessibility. Transportation research board: Journal of the Transportation Research Board, 2017, pp. 16-25, 2007. DOI: 10.3141/2017-03
[24] Vega, A., A multi-modal approach to sustainable accessibility in Galway. Regional Insights, 2(2), pp. 15-17, 2011. DOI: 10.1080/20429843.2011.9727923
[25] Kastenholz, E., Eusébio, C., Figueiredo, E. and Lima, J., Accessibility as competitive advantage of a tourism destination: The case of Lousã, in Field guide to case study research in tourism, hospitality and leisure. In: K.F. Hyde, Ryan, C. and Woodside, A.G. (eds.). Advances in Culture, Tourism and Hospitality Research, 6, [Online]. Emerald Group Publishing Limited, pp. 369-385, 2012. [Date of reference April 15th of 2014]. Available at: http://www.emeraldinsight.com/doi/abs/10.1108/S1871-3173%282012%290000006023
[26] Sailer, K., Marmot A. and Penn, A., Spatial configuration, organisational change and academic networks. ASNA 2012 – Conference for 'Applied Social Network Analysis', Zürich, Switzerland, [Online]. 2012. [Date of reference December 18th of 2012]. Available at: http://discovery.ucl.ac.uk/1381761/
[27] Escobar, D., García, F. and Tolosa, R., Análisis de accesibilidad territorial a nivel regional. Tesis. Facultad de Ingeniería y Arquitectura. Universidad Nacional de Colombia. ISBN 9789587612776. Manizales, March 2013.
[28] Escobar, D. and García, F., Territorial accessibility analysis as a key variable for diagnosis of urban mobility: A case study Manizales (Colombia). Procedia - Social and Behavioral Sciences, [Online]. 48(0), pp. 1385-1394, 2012. [Date of reference April 10th of 2012]. Available at: http://www.sciencedirect.com/science/article/pii/S1877042812028509
[29] Escobar, D., García, F. y Tolosa, R., Diagnóstico de la Movilidad urbana de Manizales. Facultad de Ingeniería y Arquitectura. Universidad Nacional de Colombia. ISBN 9789587611281. Manizales, March 2012.
[30] Escobar, D. y Urazan, C., Accesibilidad territorial: Instrumento de planificación urbana y regional. Revista Tecnura, Edicion Especial, pp. 241-253, 2014.
[31] Gutiérrez, J., Condeco-Melhorado, A. and Martín, J., Using accessibility indicators and GIS to assess spatial spillovers of transport infraestructure investment. Journal of Transport Geography, 18, pp. 141-152, 2012. DOI: 10.1016/j.jtrangeo.2008.12.003
[32] Karou, S. and Hull, A., Accessibility modelling: predicting the impact of planned transport infrastructure on accessibility patterns in Edinburgh, UK. Journal of Transport Geography, [Online]. 35, pp. 1-11, 2014 [Date of reference July 5th of 2014]. Available at: DOI:10.1016/j.jtrangeo.2014.01.002
[33] Liévano, F. and Olaya, Y., Agent-based simulation approach to urban dynamics modeling. Revista DYNA, [Online]. 79(173), pp. 34-42, 2012. [Date of reference December 9th of 2014]. Available at: http://dyna.unalmed.edu.co/en/ediciones/173-II/articulos/a04v79n173-II/a04v79n173-II.pdf
[34] Li, Q., Zhang, T., Wang, H. and Zeng, Z., Dynamic accessibility mapping using floating car data: a network-constrained density estimation approach. Journal of Transport Geography, [Online]. 19, pp. 379-393, 2011. [Date of reference September 17th of 2014]. Available at: http://www.sciencedirect.com/science/article/pii/S0966692310001158
[35] Mesa, M., Valencia, J. y Olivar, G., Modelo para la dinámica de un vehículo a través de una secuencia de semáforos. Revista DYNA, [Online]. 81(184), pp. 138-145, 2014. [Date of reference October 17th of 2014]. Available at: http://dyna.unalmed.edu.co/en/ediciones/186/articulos/v81n186a19/v81n186a19.pdf
[36] Zhu, X. and Liu, S., Analysis of the impact of the MRT system on accesibility in Singapore using an integrated GIS tool. Journal of Transport Geography, 4(12), pp. 89-101, 2004. DOI: 10.1016/j.jtrangeo.2003.10.003
[37] Chen, S., Claramunt, C. and Ray, C., A spatio-temporal modelling approach for the study of the connectivity and accessibility of the Guangzhou metropolitan network. Journal of Transport Geography, [Online]. 36, pp. 12-23, 2014 [Date of reference August 15th of 2014]. Available at: DOI: 10.1016/j.jtrangeo.2014.02.006
[38] Halden, D., The use and abuse of accessibility measures in UK passenger transport planning. Transportation Business & Management, [Online]. 2, pp. 12-19, 2011. [Date of reference July 9th of 2013]. Available at: http://www.sciencedirect.com/science/article/pii/S2210539511000022
[39] Jones, P., Developing and applying interactive visual tools to enhance stakeholder engagement in accessibility planning for mobility disadvantaged groups. Transportation Business & Management, [Online]. 2, pp. 29-41, 2011. [Date of reference June 28th of 2013]. Available at: http://www.sciencedirect.com/science/article/pii/S2210539511000320
[40] Straatemeier, T., How to plan for regional accessibility?. Transport Policy, [Online].1, pp. 127-137, 2008. [Date of reference October of 2012]. Available at: http://projectwaalbrug.pbworks.com/f/Transp+Accessib+-+Straatemeier+(2007).pdf

D.A. Escobar-García, received his BSc. Eng in Civil Engineering in 1999 from the Universidad Nacional de Colombia, his MSc. degree in Civil

Engineering in 2001 from the Universidad de los Andes, Colombia, and his PhD in land management and transport infrastructure in 2008 from the Universidad Politécnica de Cataluña, España. From 1999 to 2001 he worked for road construction companies and since 2001 he has worked for the Universidad Nacional de Colombia. He is currently a professor in the Civil Engineering Department, of the Architecture and Engineering Faculty in the Universidad Nacional de Colombia, in Manizales, Colombia. His research interests include: accessibility, sustainable models transit and transport planning, simulation, modeling and forecasting in transport, and forecasting using geostatistical techniques.
ORCID: 0000-0001-9194-1831

C. Younes-Velosa, received his BSc. Eng in Electrical Engineering in 1999 from the Universidad Nacional de Colombia, his MSc. degree in High Voltage Engineering in 2002 from the Universidad Nacional de Colombia, PhD in Electrical Engineering from the Universidad Nacional de Colombia and received degree in Law from Universidad de Manizales in 2014. Since 2006 he has worked as a professor in the Electric, Electronic and Computing Engineering Department of the Architecture and Engineering Faculty in the Universidad Nacional de Colombia, in Manizales, Colombia. His research interests include: Energy Policy on lighting, Renewable Energy Sources and Transport Regulation, Electromagnetic Compatibility and Lightning Protection.
ORCID: 0000-0002-9685-8196

C. A. Moncada-Aristizábal, received his BSc. Eng in Civil Engineering in 2000 from the Universidad Nacional de Colombia, his MSc. degree in Transport Engineering in 2005 from the Universidad Nacional de Colombia and his MSc. degree in lnfrastructure Planning in 2010 from the University of Stuttgart, Alemania. From 2013, he has been developing his PhD in transport at the Universidad de los Andes, Colombia. He worked as transport planner consultant for the Ministry of Transportation in medium and small sized cities. He is currently a Professor in the Civil and Agricultural Engineering Department -Faculty of Engineering- at the Universidad Nacional de Colombia, in Bogotá. His research interests include: transport demand models transit and transport planning, simulation, modeling and forecasting in transport.
ORCID: 0000-0003-3745-6880