IMPACT OF NEW ROAD INFRASTRUCTURE IN THE CITY OF MANIZALES (COLOMBIA) IN TERMS OF ACCESSIBILITY TIMES OF PRIVATE VEHICLES AND PUBLIC TRANSPORTATION

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ABSTRACT

In the last decade, the city of Manizales has incorporated substantial changes in its urban road infrastructure. Those changes have the common purpose to provide faster and comfortable mobility channels to the people by improving the connections in all geographical directions.

In this research, the global mean accessibility conditions offered by the urban road network between the years 2000 and 2009 are evaluated. The road networks used by private vehicles and public urban transit (PUT) are studied separately. The curves of global mean accessibility are drawn by analyzing the obtained data for each one of the given transportation modes and its evolution in the last decade.

The results point toward an improvement in motorized accessibility in those periods of more infrastructure development. The chronological analysis of changes in private vehicle and public urban transit networks prove how the private mode has been highly benefited over the public urban transit in terms of global mean accessibility.

***Keywords**: Accessibility, public urban transit, SIG, traffic.*

BACKGROUND

The activities in urban areas are directly related with the ease of mobility of goods and people and, therefore, with the existing communication facilities between different geographical zones. Commonly, the use of the transportation infrastructure network and different transportation modes could be the way to generate such physical communication factor.

Accessibility is a measure of the ease of communication that a network provides through the use of certain transportation mode [Morris et al., (1979), Zhu, X. Liu, S. (2004)]. It is possible to ascertain that this measure is closely related to the variable "distance" [Loyola et al. (2009)], and it becomes a function of the proximity of any geographical point in an area or region. However, it is valid to say that given the current technological developments, accessibility depends less and less of the actual distance to the centers of activity and on the contrary, it increasingly depends on the distance to transportation infrastructures [Gutierrez, J. (1998)] and how the infrastructure reduces the connection time between regions.

The relative accessibility is associated with the quality of the connection between two points located in the same territory; the integral accessibility quantifies the degree on interconnection of a node with other nodes in the same zone; and the global accessibility is the average of the integral accessibilities for all the nodes in the zone of study (is representative of the degree of connection of the whole network and reflects the effects of any actuation on it – see Figure 1).

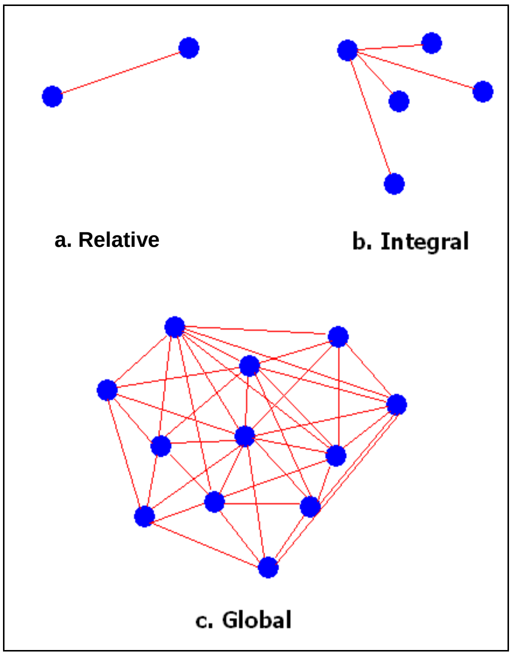

Figure 1 – Accessibility levels [Soto, Y. (2009)]

Accessibility is a basic element of territorial planning and it depends not only on the topological characteristics of the network, but also of its operational characteristics, where the average speed of operation of the flow is a key variable for the analysis [*Herce, M y Magrinya, F (2002)*], and its assessment heavily influences the precision and accuracy of the obtained results.

Knowing a fairly wide range on the implementation of accessibility measures, it is worthwhile to propose methodologies that seek real and objective comparison of different transport modes, especially when today most cities in the world are trying to implement increasingly sustainable transportation alternatives.

Finally, Manizales (Colombia) has been developing the study of Intermediate Pieces Planning (IPP), which aims to develop a methodology that seeks for greater efficiency in urban planning involving aspects of both mobility and urban development. This research is an additional resource for the definition of IPP and one of very few examples of application of this type of analysis in the city.

METHODOLOGY

The research is framed within the context of network theory. It was done during the second half of 2009 in consecutive steps, from the very conception of the idea until obtaining field data and secondary information from official sources.

The analyses are based on quantitative and spatial methods, which allow obtaining relevant results on the study variables. These methods rely on various tools related to geographic information systems (ArcGIS, TransCAD), statistics (SPSS, Minitab, and R) and geostatistics (ArcGIS, Surfer).

In general, the main results come from the processing of more than 12 million data, which together provide a framework of analysis that is reflected in the topological and operational features of each of the arcs that make up the infrastructure network.

Overview

The city of Manizales is located in the central western region of Colombia, about 5.4º North and 75.3º East, with an altitude of 2,150 meters above sea level on the Andes mountain chain. It lies at the center of the triangle constituted by Colombia’s three major cities (Bogotá, Medellín and Cali) and it has a population of about 370,000 inhabitants.

The urban shape reflects the adaptation to a very steep topography with very particular characteristics due to its geographical location. Located on the edge of the hill, Manizales allows a continuous integration with the landscape throughout its length. Thus, the urban growth has organically adapted to this topographic condition and the city is characterized by a discontinuous urban structure with an infrastructure network with gradients greater than 18%.

Processing

The first stage consisted of obtaining the digital files of Manizales' road network in 2000. Subsequently, through the search of secondary information, the geographical locations of road infrastructure projects that were developed between 2000 and 2009 were obtained and incorporated in the GIS.

The Figures 2 and 3 show the categorization of the road network in the city in 2009 and the geographic location of the road works carried out during the period of study (a total of 35 infrastructure projects), respectively. It is assumed that the insertion of a project directly impacts the average operating speeds of the arches within a radial distance of 500 meters, then the data of the arcs in that area are changed and a discretized and contextualized database for each year of analysis is created. The interventions produce substantial changes from the point of view of the city regulation as mobility, the latter being one of its fundamental objectives.

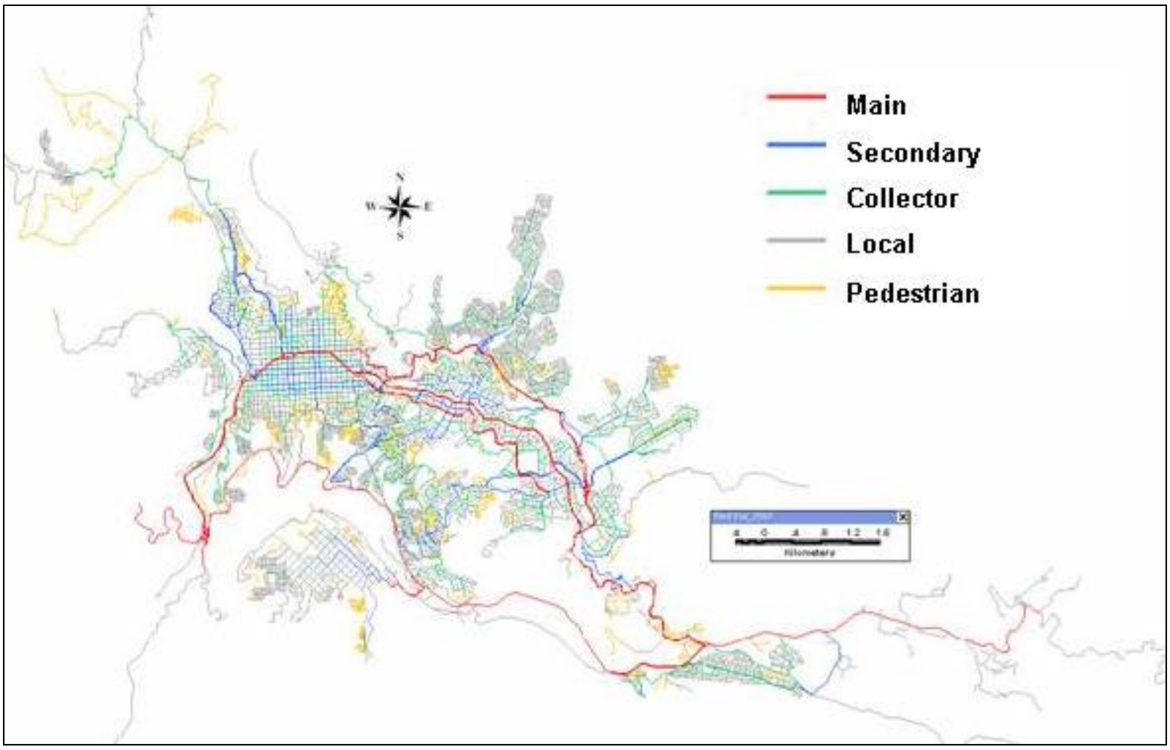

Figure 2 – Categorization of the Road Network

The digitization of the road network for the years 2000, 2003, 2006 and 2009 allowed the modeling of input data. The road network consists of 10,555 arcs and 7.086 nodes, each of them with a number of attributes like the average speed of operation in the arches and the travel time by the shortest path between each pair of nodes.

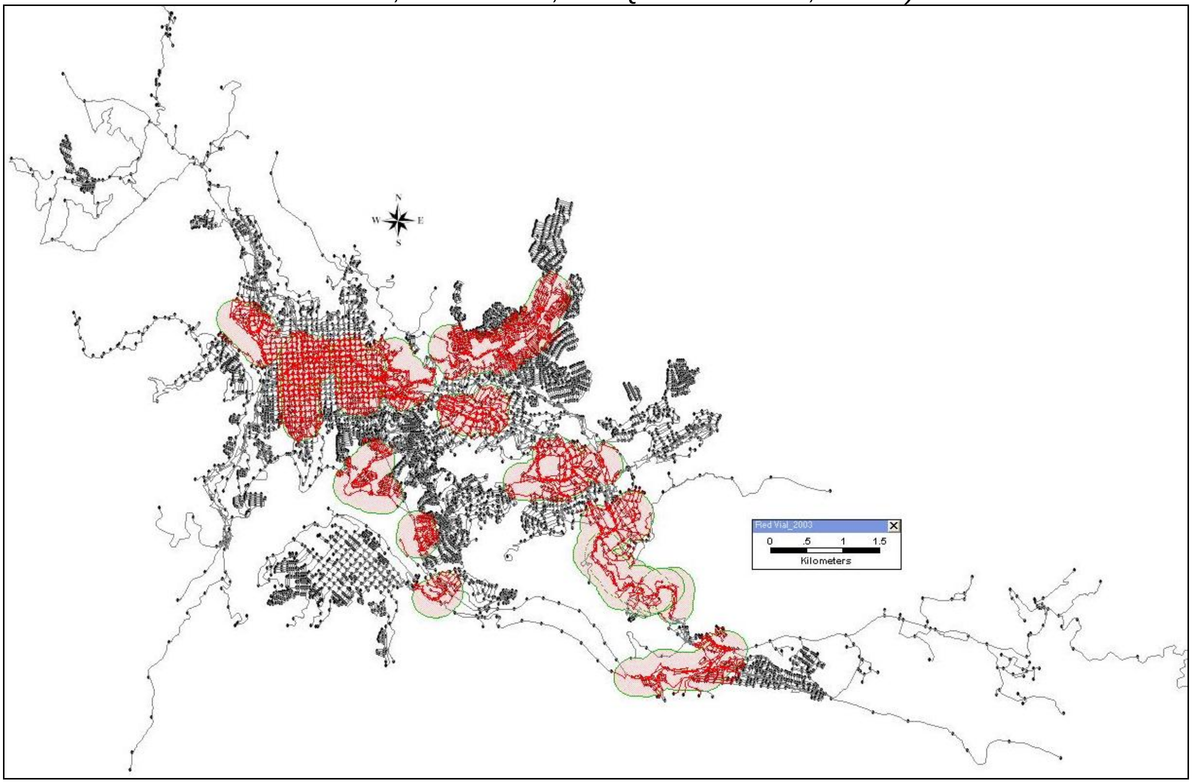

Figure 3 – Areas of direct influence of infrastructure works between the years 2000 - 2009

The value of the mean operating speed on each arc was obtained from the analysis of field data - using GPS equipment, performing a statistical analysis of data and eliminating those considered atypical. It introduces a classification of mixed road network, i.e., the proportion of the road network used simultaneously by private vehicles and public transportation is determined for the year 2009.

With the obtained database, the study passed to its second stage, where several analysis were made because we had, simultaneously, the road network data and operating speed and travel time on each arc, both for private vehicle and public transportation. The matrix of average travel times between all nodes of the network was calculated, thus obtaining the vector of average travel times for the shortest path from each node of the network to others.

With the aid of geostatistical software (Surfer 2009 ®), it was possible to apply interpolation models for the variable "average travel time of each node" to obtain the curves of Global Mean Accessibility (isochronous) for each year of study. For the analysis of the road network used by private vehicles, it was possible to study the transformation of the network for the years 2000, 2003, 2006 and 2009. For public transportation, it was only possible to analyze the network used in 2009 given the lack of information about this mode of transport for prior years.

The isochronous curves allow identifying in which areas of the city there were significant changes, a result that is obtained by comparing the vectors of average travel time for each scenario. The values of average travel time obtained in the vector are statistically treated, which allows reliable forecasts of variable “average travel time” at different points within the territory.

The third stage of the study analyzes the evolution of isochronous curves of accessibility for private vehicles obtained for the years 2000, 2003, 2006 and 2009; likewise, it makes a comparison between the isochronous curves of accessibility obtained for both modes of transport in 2009. The quantitative comparison between the two modes of transport clearly shows how the private vehicle has been the most benefited from the several works carried out in the city.

The research offers some valuable charts showing the areas of the city that have been most benefited as a result of the construction of new transport infrastructure. It also allows finding certain relations for comparing results with, for example, land use or category of the road network that connects a particular area.

Computations

The information processing requires different calculations according to each stage of the research. First, the calculation of the average speed of operation and its allocation in each arc of the studied networks is done; then, the travel time by shortest path from each node of the network to others is calculated; next, the value of the Global Mean Accessibility for each node is calculated; and, finally, the vector of average travel times is statistically validated to determine which model of data interpolation has to be implemented to obtain the isochronous curves.

Speeds

The speed is calculated for each arc and one-second interval using the information obtained with GPS aboard test vehicles. Three parameters were obtained: (1) the vehicle speed at every second in the i^{th} arc; (2) the average speed of i^{th} arc, and (3) the average speed of each arc in each path. The second-to-second speed between two points 1 and 2 was determined as:

$$v_i = 3.6\sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \qquad (1)$$

Where:

v_i : Speed (kilometers per hour).

x_1, y_1 : Coordinates of point 1 (meters).

x_2, y_2 : Coordinates of point 2 (meters).

This parameter is useful for examining the speed variations within a particular arc, and it was specifically used to determine the stop rates when the obtained value was zero.

The second speed parameter, namely the average speed of travel in the arc, was determined as the ratio of the length of the arc to the difference in the passing time through the initial and final nodes:

$$v_i^a = 3.6 \frac{l_a}{t_2 - t_1} \qquad (2)$$

Where:

v_i^a : The i[th] speed in the arc *a* (kilometers per hour).

l_a : Length of the arc *a* (meters).

t_1 : Passing time at the first node (seconds).

t_2 : Passing time at the second node (seconds).

Finally, the average speed in the arc is calculated by:

$$\overline{V_a} = \frac{\sum_{i=1}^{n} V_i^a}{n} \qquad (3)$$

Where:

$\overline{V_a}$: Average speed of arc *a* (kilometers per hour).

n : Number of times a vehicles passes in the arc *a*.

This speed is calculated for each arc of the entire road network, and then used to determine the impedances and to implement the time model.

Global Mean Accessibility

The Global Mean Accessibility is analyzed from the vector of average travel time (T_{vi}), which represents the average travel time from node *i* to other nodes of the network. This indicator tends to favor the points located at the center of a network because travel times from these nodes to others are small due to its geographical location.

To asses this indicator, GIS use an algorithm that calculates the shortest distance between a specific node and other nodes in the network, forming a unimodal matrix of distances. With this matrix and the average operating speed of each arc, the matrix of minimum average travel times is calculated, which minimizes travel time between all nodes in the network.

Once the matrix of minimum average travel times is obtained, the vector of average travel time (T_{vi}) can be calculated by the following equation:

$$\overline{T_{vi}} = \frac{\sum_{j=1}^{m} t_{vi}}{(n-1)} \quad i = 1,2,3,\ldots,n \ ; \quad j = 1,2,3,\ldots,m \qquad (4)$$

Where:

n: Total nodes of the network.

$\overline{T}_{vi}$: Minimum average travel time between the node *i* and other nodes in the network.

$\sum_{j=1}^{m} t_{vi}$: Sum of the minimun travel times between the node *i* and other nodes in the network.

Subsequently, the vector of average travel time (n x 1) is related to geographic coordinates (longitude and latitude) of each node to create the matrix of order (n x 3), which allows the drawing of isochrones of average travel time for the area of analysis and for each of the networks.

To obtain the isochronous curves, it is necessary to define which interpolation method should be used. For this, certain statistical assumptions that the variables must fulfill have to be verified.

The first hypothesis is to verify the normality of the data with the Kolmogorov–Smirnov's nonparametric test; if the vector of time turns out to be not normal, it is transformed using the Box-Cox algorithm. The second hypothesis is to verify the existence of stationarity; this is done with scatter plots between the vector of average travel time and geographic position (longitude and latitude, respectively) in order to determine the trend that must be removed from the interpolation model. The third hypothesis considers that the statistical variance must be finite.

Spatial variability is related to the change of data regarding their distance and orientation. The measure of the variance in geostatistics is the semivariance, which is defined by Equation 5:

$$\bar{\gamma}(h) = \frac{\sum \left(Z(x+h) - Z(x)\right)^2}{2n} \qquad (5)$$

Where:

Z(x): Variable value at site x.

Z(x + h): Sample value that is separated a distance *h* from the above.

n: Number of pairs of data that are separated such distance, *h*.

This function displays the properties of spatial dependence of the process and is calculated for several distances *h*. From the results of this function a semivariogram is calculated, which is the graphical representation of the semivariance of the data with distance between pairs of observations.

Even if the vector is not normal, the Box-Cox transformation make possible to use a statistical interpolation method, such as Kriging, if the vector presents homoscedasticity (all random variables in the sequence or vector have the same finite variance).

Finally, the ordinary Kriging's method with spherical semivariogram was adopted as the interpolation method to predict the average travel time, and cross-validation is done on the data in order to ensure statistically reliable results. In this process, observed values are compared with the values estimated with the interpolation model selected, bearing in mind that using a linear regression is possible to establish adequate or inadequate accuracy of the model used to predict the data.

MAIN RESULTS

The Road Network

Table I shows the length and speed of operation of the road network according to the functional category of the arcs in each year of study and for private vehicle mode of transportation. Throughout this decade, a total of thirty-five (35) road works were built: two (2) were completed in the triennium 2000 to 2003, eight (8) in the triennium 2003 to 2006 and twenty-five (25) in the triennium 2006 - 2009 (See Figure 3).

It is noted that the city road network has grew, in almost a decade, from 676.6 to 689.5 kilometers, which represents an increase of 12.9 kilometers, i.e., the network grew 1.9% in length. The main streets show the bigger shift in its share in total network length. The analysis of network length covered in each category indicates an adequate distribution of these values according to the AASHTO criteria [ASSHTO (2001)].

Table I – Length and speed of operation in the road network according to the category of the arcs for each year

Road Category	2000		2003		2006		2009	
	Length. (Km.)	Average Speed (Km. /h.)	Length. (Km.)	Average Speed (Km. /h.)	Length. (Km.)	Average Speed (Km. /h.)	Length. (Km.)	Average Speed (Km. /h.)
Main	61.1	30.7	63.2	32.6	64.4	34.6	68.9	37.9
Secondary	54.3	24.0	54.3	24.9	55.3	25.7	56.3	27.2
Collector	98.9	22.2	98.9	22.7	99.5	23.3	100.0	24.1
Local	369.6	14.0	370.5	14.4	370.6	14.7	372.8	17.7
Pedestrian	92.7	2.0	92.7	2.0	92.7	2.0	91.6	2.0
Total	676.6		679.7		682.4		689.5	

Reviewing the categorization of roads with real average speed values that were obtained from analysis of the database (see Table I), one can see that the main network has the largest average speed, as expected. Likewise, the local network presents the smallest velocity of the system, while the secondary network shows average speeds slightly lower than those normally indicated in technical literature.

It is found that between 2000 and 2009, the average speeds of operation have increased in greater proportion in local and main roads. However, Figure 4 shows, for example, that ranges of average speed of operation in the central sector of the city do not have a direct correspondence with the functional category of the road. There is a clear lack of traffic management within this area, which has no road corridors with a common functionality with respect to its operating speed, a situation that directly impacts the overall average results of accessibility.

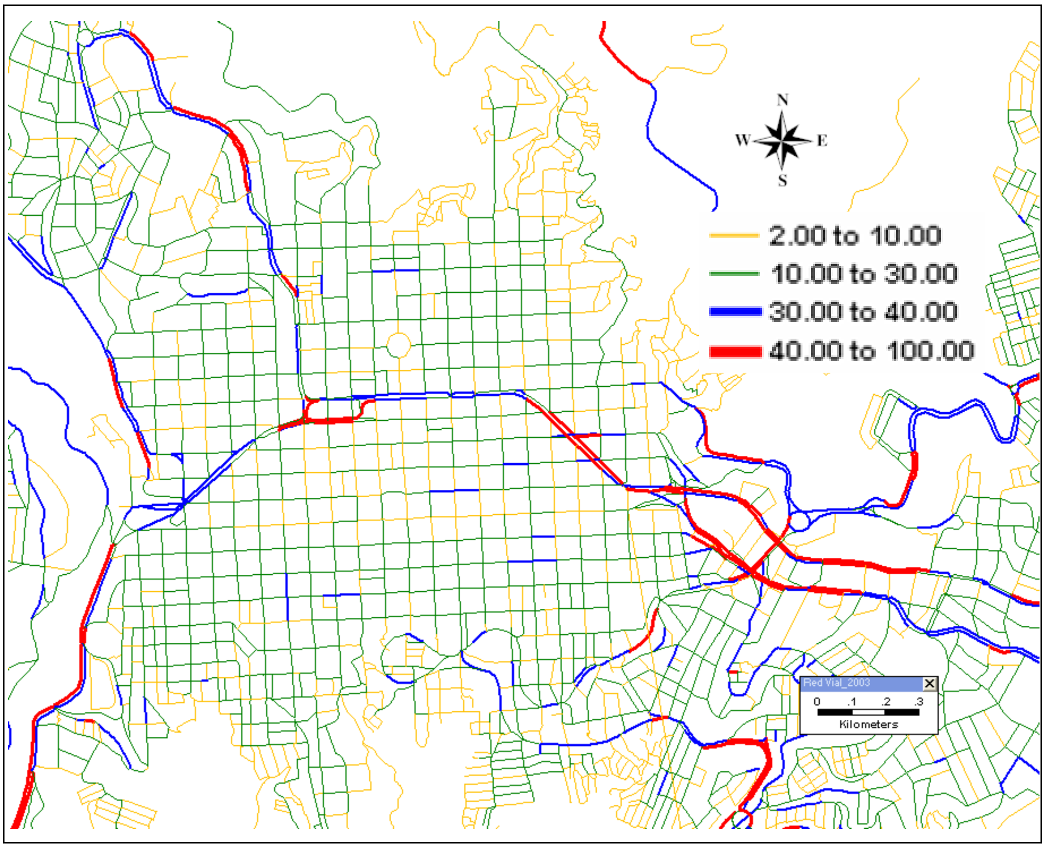

Figure 4 – Ranges of operation speeds (Km/h) in the center of the city. Private Vehicle - 2009.

Furthermore, Table II shows the length and speed of operation of the public transit network according to the category of the road, and their comparison with the whole road network (used by private vehicles) for the year 2009. It is found that there are 204.2 kilometers of road network for the operation of public transit, representing 34.1% of the total road network of the city (excluding walkways).

The public transit covers 21.1% of the total length of main streets and collector streets of the network. The 87.0% of the main network has a mixed functionality, while in the local network this percentage is less than 10.0%. A high percentage of local streets could be used to operate public transit; also, it would be possible to prioritize the use of certain corridors, currently mixed, to specialize in one mode of transport. It is possible to relate the category of roads with gradient isochronous curves which are obtained by comparing the global mean accessibility offered by the two modes of transport; this allows identifying areas with disadvantage for using urban transit.

Table II – Length and speed of operation in the road network according to the category of the arcs for urban transit and comparison with the road network of private vehicles (2009)

Road Category	Public Transit			Private Vehicle			% of total road network in both modes
	Length (Km.)	% of total road network	Average Speed (Km. /h.)	Length (Km.)	% of total road network	Average Speed (Km. /h.)	
Main	59.9	10.0%	21.6	68.9	11.5%	37.9	87.00%
Secondary	43.4	7.3%	16.8	56.3	9.4%	27.2	77.14%
Collector	66.7	11.1%	14.1	100.0	16.7%	24.1	66.66%
Local	34.2	5.7%	12.9	372.8	62.3%	17.7	9.17%
Total	204.2			598.0			

The Figure 5 shows the Manizales' CBD (Central Business District or downtown), where the arcs with mixed functionality are highlighted according to the range of speeds of operation in public transit. One can observe that a high number of arcs in this sector have operating speed below 10 kilometers per hour. Table III contains an analysis of the length of the public transit network with respect to different ranges of average speed of operation, and it shows that approximately 42.0% of the public transit network has speeds below 15 kilometers per hour.

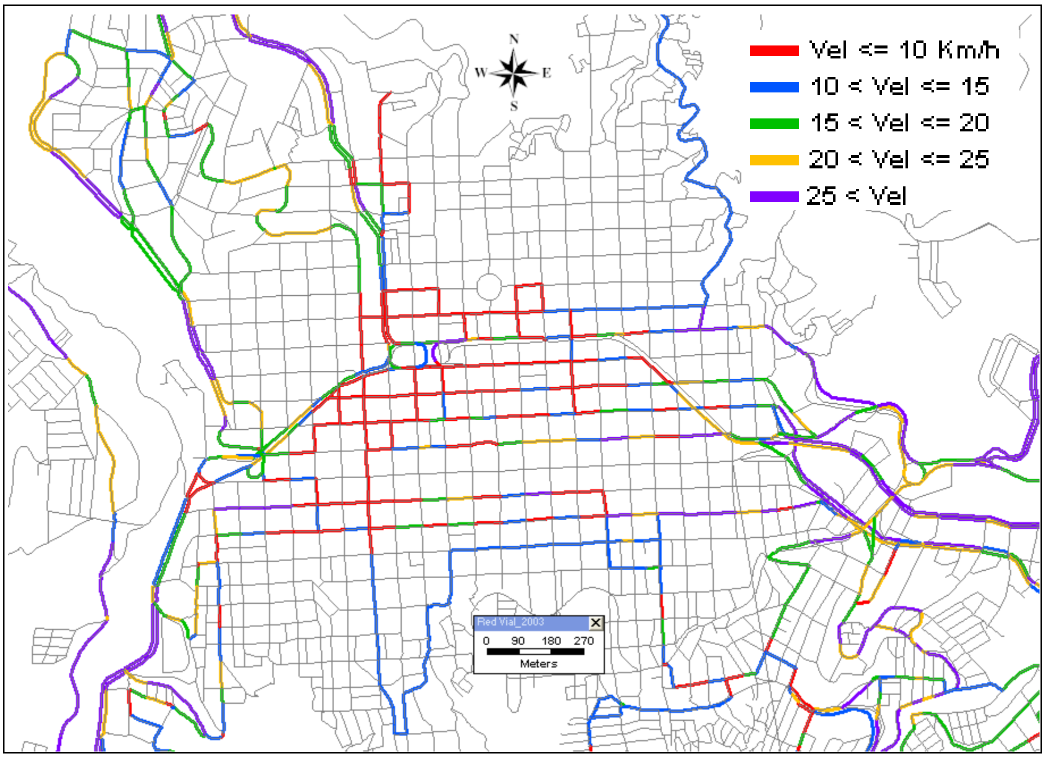

Figure 5 – Ranges of operation speeds (Km/h) in the Center of the city. TPCU – 2009

It is concluded that over 50.0% of the length of the public transit network belongs to streets categorized as main and secondary, finding that a high percentage of the length of the main network has operating speeds above 20 kilometers per hour, while for other categories, most of its length has operating speeds under 15 kilometers per hour.

Table III – Length and speed of operation in the road network used by public transport, according to the category of the arcs for the year 2009.

Road Category	Actual average speed of public transit (Km. /h.)					Total length (Km.)	% of total public transport road network
	< 10	10 - 15	15 - 20	20 - 25	> 25		
	Length (Km.)						
Main	5.3	5.9	7.4	11.8	29.5	59.9	29.4%
Secondary	8.1	9.8	9.3	7.9	8.3	43.4	21.3%
Collector	16.9	18.2	14.5	9.0	8.0	66.7	32.6%
Local	10.2	11.0	7.1	1.3	4.7	34.2	16.7%
Total	40.5	44.9	38.3	30.0	50.5	204.2	
% of total public transport road network	19.8%	22.0%	18.8%	14.7%	24.7%		

The above discussion shows, not only that the main network plays a pivotal role in the operation of public transport, but there is also the need for a better vehicular management in secondary, collector and local streets in order to increase the operating speed at least to 18 kilometers per hour.

Global Mean Accessibility in Private Vehicle

The Figure 6 show isochronous curves of global mean accessibility obtained for 2000 and 2009, respectively. In general, for both years, the city is covered between isochronous curves of 15 to 45 minutes, which expanded their coverage areas when the new infrastructures were built. A correspondence between the extension of isochronous curves and the functional categorization of the road was found more clearly in 2009.

Manizales is considered by many a monocentric city, i.e., with a central source of social and economic activities (Points A & A' in Figure 6). However, today it should be considered as a polycentric city, given that over the past years, at east of downtown (Point D & D'), an important point of economic exchange has developed, represented by numerous offices, shopping malls, entertainment places and financial services. One can observe that the dynamic of isochronous curves between 2000 and 2009 is to reduce the travel time to the new financial and economic center of the city.

For both years, the area that offers greater accessibility is covered by the isochronous curve of 17.5 minutes (inner red line) and then spread westbound and eastbound (Point A 'and B') instead of southbound or northbound. The difference in the area covered by the isochronous curve is quite significant between 2000 and 2009 (Points A' & B' versus Points A and B), with an improved accessibility from 20.0 to 17.5 minutes curve.

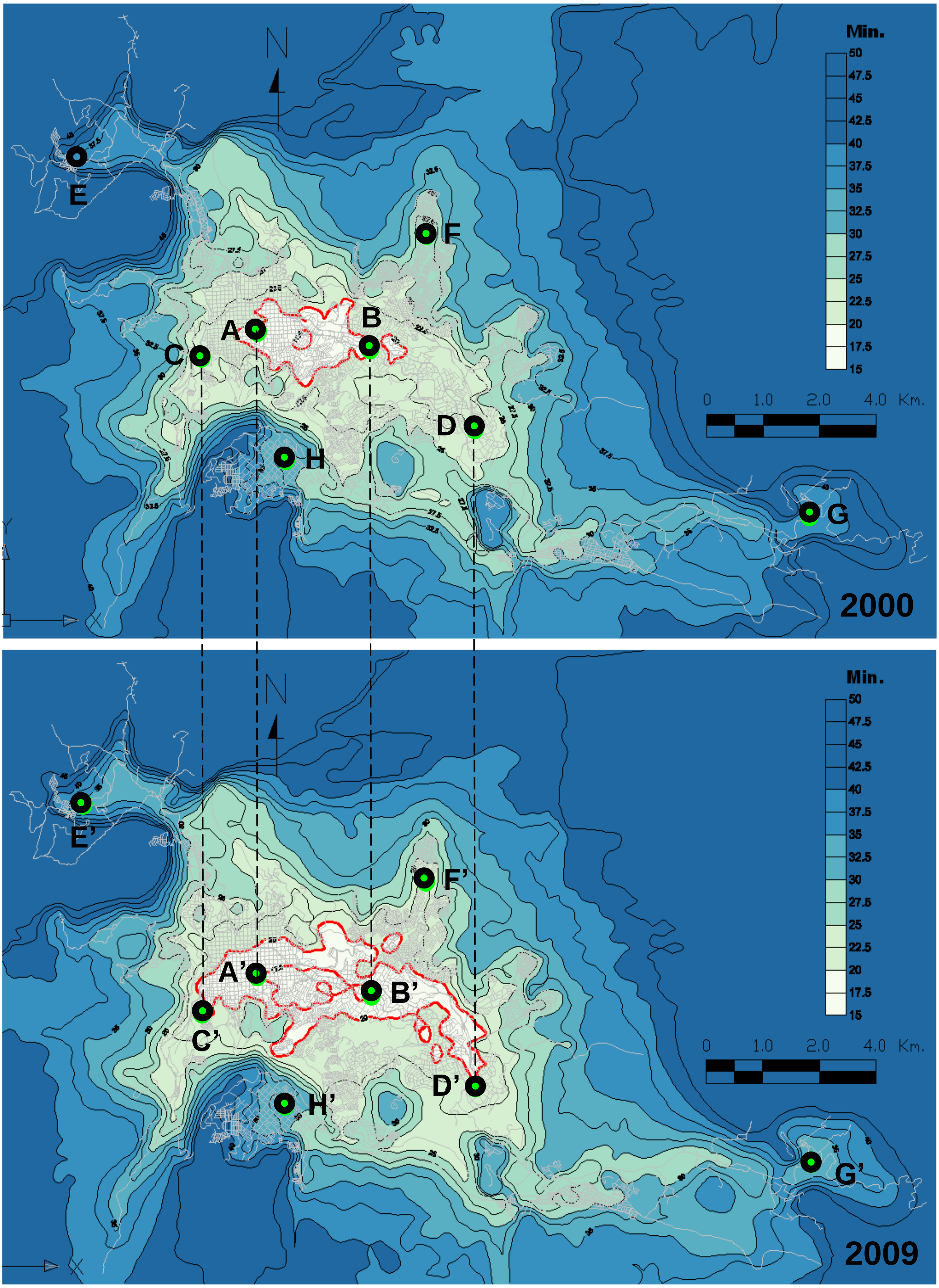

Figure 6 – Global Mean Accessibility in 2000 y 2009, respectively (ordinary Kriging with spherical semivariogram model)

By comparing the Points C 'and D' with Points C and D for the years 2009 and 2000, respectively, it appears that the isochronous curve of 20 minutes is extended more westward toward the new economic center of the city, increasing its covered area from approximately 2.0 square kilometers in 2000 to 5.3 square kilometers in 2009. The increase of the area covered by this isochronous curve matches exactly the location of the main corridor of the city (imaginary line joining Points CABD), which connects the economic centers of the city (Points A and D).

Analyzing the outskirts of the city, one can observe that they have improved their accessibility, for example, in the northeastern sector (Point E) there is a marked expansion of the isochronous curve of 35 minutes for the years of analysis. A similar pattern is evident in the southwestern sector (Point G). In the north sector (Point F), the curve of 25 minutes extends its coverage considerably, as this sector is one of those who benefited most from the integration of road works between 2000 and 2009.

On the other hand, in the south sector (Point H) is clearly seen that the variation of isochronous curves between 2000 and 2009 is virtually imperceptible. This sector is in the Municipio de Villamaría (or "Marysville", another municipality) which, despite being adjacent to Manizales, is not a major beneficiary of the works carried out between 2000 and 2009, as its road network connects with Manizales in one site only. It is precisely because of the lack of a connection between Manizales' southeast sector and Villamaría that the latter shows not substantial changes to their travel times, so one can conclude that the infrastructure works carried out between 2000 and 2009 did not impact the area.

As a result of the analysis of the areas covered by the isochronous curves, one can see in Figure 7 that the area covered by them increases every three years. For example, by the year 2000 the area covered by the isochronous curve of 30 minutes was 28.3 square kilometers, while for 2009 was 33.5 square kilometers, giving an increase of this 18.5%. A similar situation is obtained by comparing the evolution of the areas covered by the isochronous curves of 20 and 25 minutes, which increased their surfaces a 100% for the first case and approximately 40% for the latter.

Now, with the vectors of minimum connection times for each year (2000, 2003, 2006 and 2009), one can calculate the relative change between pairs of nodes by comparing the years 2000 – 2003, 2000 – 2006 and 2000 – 2009. Gradient curves of Global Mean Accessibility were obtained for those periods, in order to study the variation in accessibility given the infrastructure works carried out in three, six and nine years.

The Figure 8 shows the gradient curves relating to three (2000 – 2003), six (2000 – 2006) and nine years (2000 – 2009). The red lines indicate the infrastructure works carried out in each period. It was possible to study the correspondence between the geographic location of the works and the curve gradient that covered. In about a decade, the Manizales' road network was amended by a total of 35 infrastructure projects, where approximately 5.0% of these were made in the first triennium, 25% in the second and 70% in the third.

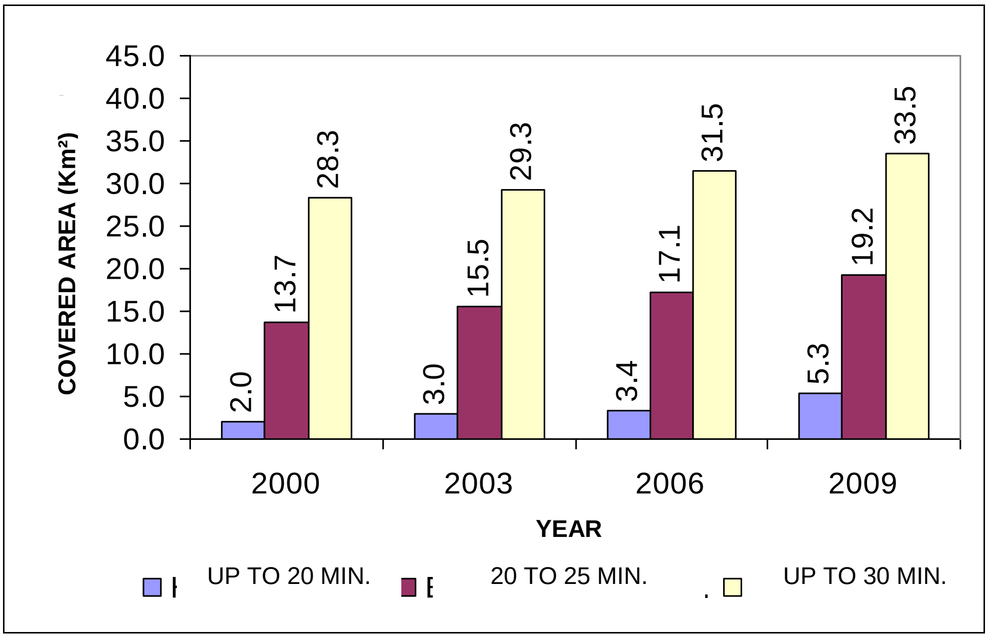

Figure 7 – Area covered by the isochronous curves of Global Mean Accessibility in private vehicle 2000 – 2009.

The results of the analysis between the years 2000 – 2003 (See Figure 8, 2000 – 2003) indicate that a large proportion of the city has a relative gain for minimum travel time between 2.0% and 4.0%, i.e. a decrease in these percentages of the average travel time of the year 2000. The area with the biggest gain indicate a gradient above 6.0% (Figure 8, 2000 – 2003, Point A) and it has industrial and high income residential uses. The areas identified with the Points B are residential with different income levels; the southwestern sector has high income level and the northeastern sector a middle income level. Both sectors have relative gains of time greater than 4.0%. There are areas of the city (delimited by a blue line) that present relative gains of time up to 2.0%, including a large geographical central area (Point C) which shows gaps in southeast – northwest communication, the areas designated by the Points D with neighborhoods of low income and, the peripheral areas identified with Point E.

One can conclude that between 2000 and 2003, the biggest impact in terms of relative gain of time appeared in a large industrial sector of the city (Point A), while the areas that have reported a lower relative gain of time are residential zones with a large proportion in middle and lower income levels.

The results of the analysis between the years 2000 – 2006 (See Figure 8, 2000 – 2006) indicate that practically the whole city had gains of time greater than 2.0%, but there are sectors with more than 8.0% (Points A, B, C, D and E) and others with less than 2.0% (blue line).

The greatest relative gains of time are in industrial areas (Point A), residential areas with high income level (Points A & B) and residential areas of middle income level (Points C & D). Comparing with previous results, one can see a greater impact of the works, from the point of view of the network topology, in the six (6) years period.

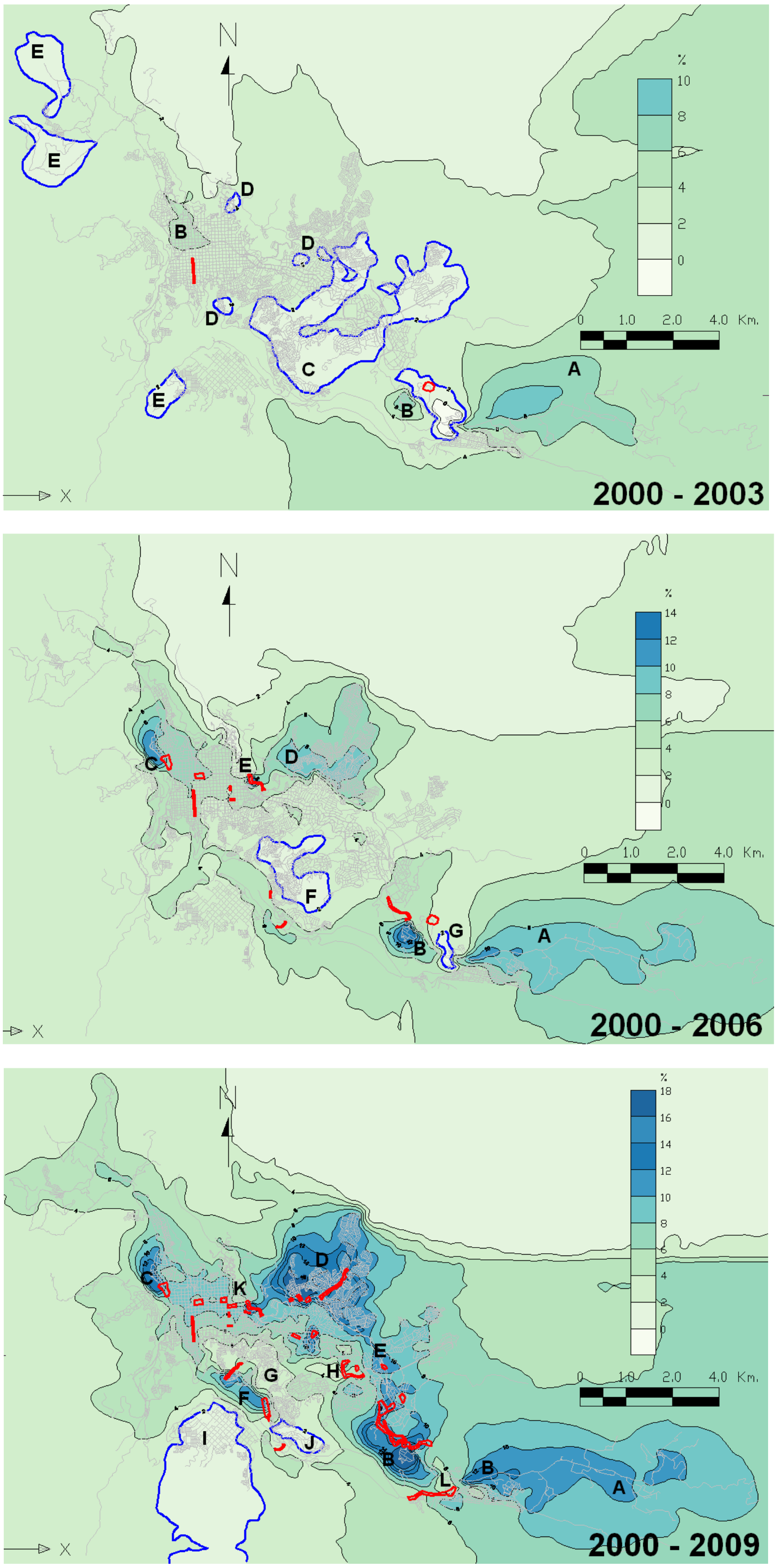

Figure 8 – Relative gradient curves for three (2000 – 2003), six (2000 – 2006) and nine years (2000 – 2009) (ordinary Kriging with spherical semivariogram model)

There are areas that have improved its accessibility, for example the northern east – west connection (Points C, E & D) and its southern parallel (Points A & B). Also, there are areas that show little relative gain, which coincide with residential areas of middle and low income. It can be concluded that by the year 2006, infrastructure works positively impacted the city, especially in its northern and southwestern sectors.

For a period of nine (9) years, the impacts of infrastructure works are even more visible, finding a direct relationship between the location of infrastructure and areas of relative gain of time greater than 10.0% (Figure 8, 2000 – 2009, Points A, B, C, D, E, F).

Among the areas of the city that report higher relative gain of connection time, there are industrial land (Point A), residential areas of high income level (Point B) and residential areas of middle income level (Points C & D). The results of six (6) and nine (9) years are analogous. There is a greater impact of the works on the connection north – southwest (imaginary line joining the Points D, E, B & A) and to a lesser extent on the southeast connection.

There are areas where the impact of the works was less than 2.0% of relative gain of time (Points I & J), corresponding to residential areas of middle and lower income levels. Highlighted areas with relative time gain between 2.0% and 4.0% coincide with residential areas of middle and low income (Point G) and educational land use (Point H). The above areas show that there is a palpable gap in the southeast – northwest connection (imaginary line joining the Points I, F, G, H, E).

Likewise, there are Points as H, K and L that reflect bottlenecks in relative gain of time, indicating that they are areas which should have future interventions to the road network.

Global Mean Accessibility in Public Transit and Comparison with Private Vehicle Accessibility

The Figure 9 shows the results of the analysis of Global Mean Accessibility offered by public transit mode, as isochronous curves for the road network in 2009.

It is emphasized that the public transit network was defined with field measurements (January – February 2010) using GPS on public transit vehicles. This allowed obtaining the actual road network and its operational features as the average speed of operation.

In general, it can be seen that using public transit, isochronous curves range from 30 to 60 minutes. Isochronous curve of 30 minutes (red line in Figure 9, TPCU – 2009) covers a central area of the city, which includes the core of economic activities with the highest hierarchy (Point A) and residential areas with high to moderate population density.

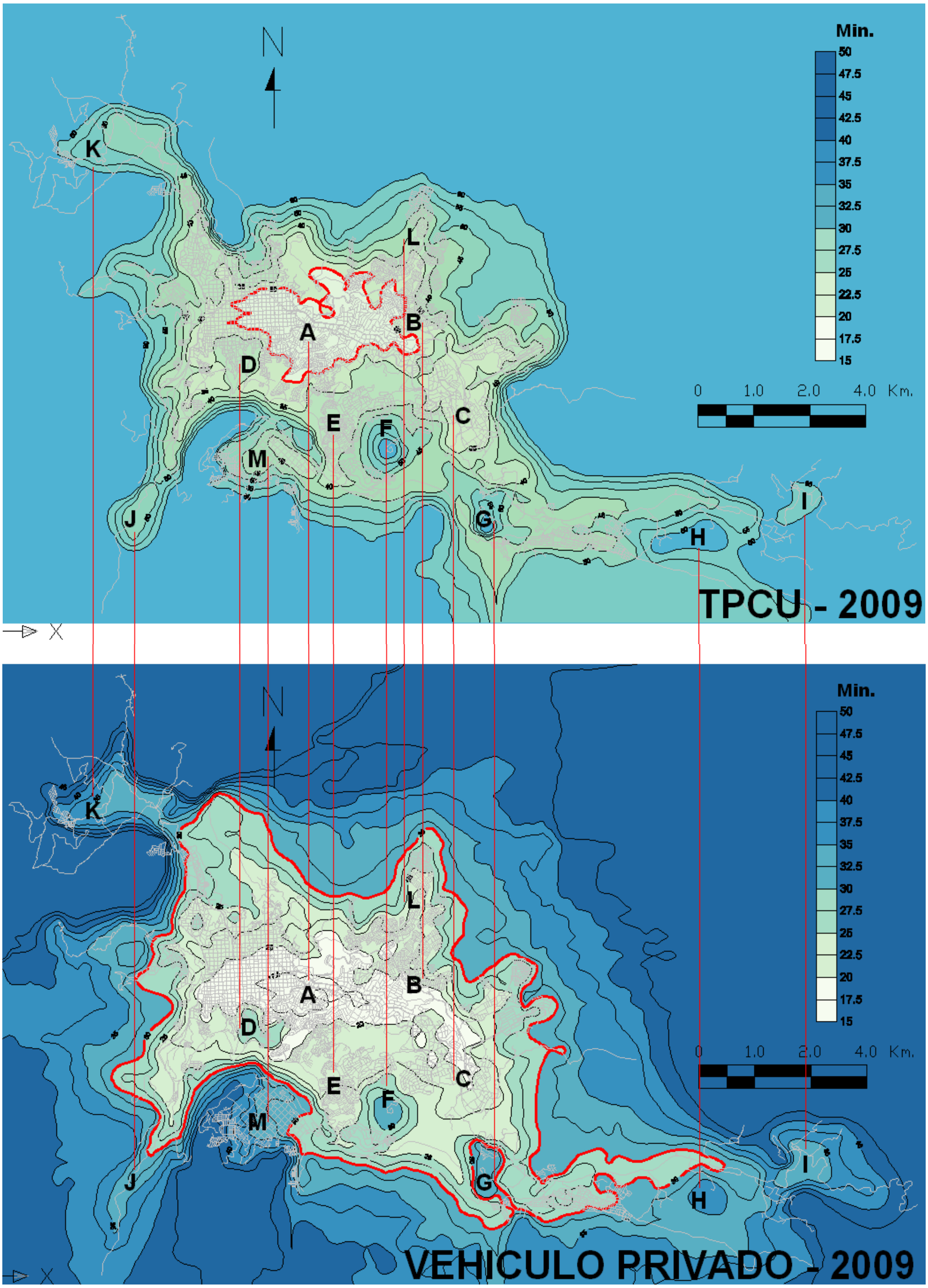

Figure 9 – Isochronous curves of Global Mean Accessibility offered by public transit (TPCU) and private vehicles for the year 2009 (ordinary Kriging with spherical semivariogram model)

All the peripheral areas of the city are within an average time of travel up to 60 minutes (Points H, I, J, K, L and M), i.e., that normally one could go to these areas from any geographical point of the city, in about of one hour in public transport.

The Figure 9 also shows a comparison of isochronous curves of global mean accessibility offered by public transit private vehicles.

The comparison of the isochronous curves, offered by the two transportation modes, shows that the isochronous curve of 30 minutes covers more territory in a private vehicle than in public transit (red lines, Figure 9). This illustrates why the people find the use of private transport more attractive than public transit since, for a given period of time, a private vehicle can reach areas of the city in less time.

It is noted that the downtown (Point A, Figure 9) is reached in private vehicles in almost half the time than using public transit, a situation that is repeated in residential areas of middle and high income levels (Points B & C); however, there are residential areas of low income that show a great imbalance of times between the two modes (Points D, E & L), which leads to conclude that Manizales' new road infrastructure has disproportionately benefited the high income classes.

Industrial (Points H & I) and recreational sectors (Points F and G) also report a significant imbalance in time by comparing both modes of transport; however, there are peripheral areas of the city (Points J, K & M) where the difference of traveling in any mode is less important.

Doing the analysis of gradients of time between the isochronous curves of accessibility offered by the two modes, one can see in Figure 10 the ratio of travel time in private vehicle and public transit. This identifies the areas of the city where it is necessary to invest a higher percentage of travel time in public transit mode compared with private vehicle mode.

The sector that shows the less imbalance of relative travel time between modes of transport is located in Villamaría (blue line, Point A, Figure 10). To reach that area one have to spend up to 25.0% more time if the travel is in public transit that in a private vehicle.

There are parts of the city in which one must invest up to 50% more travel time when using the public transit (sectors enclosed by a red line in Figure 10); these sectors have a residential land use of middle and in some cases low income levels. Also, there are areas of the city where the population density is high, the socioeconomic level is low and its inhabitants are dependent on public transit; some of these areas show an imbalance in travel times between the two modes of transport up to 75% (Points B, C and north of the city, Figure 10). The same applies for a sector of industrial and educational uses (Point E, Figure 10).

The sector that shows the larger imbalance in travel times between the two modes of transport (Point D, Figure 10) has a residential land use of high income, a high rate of vehicle ownership and a public transit deficiency, since that area is served by only one route out of 64 existing ones.

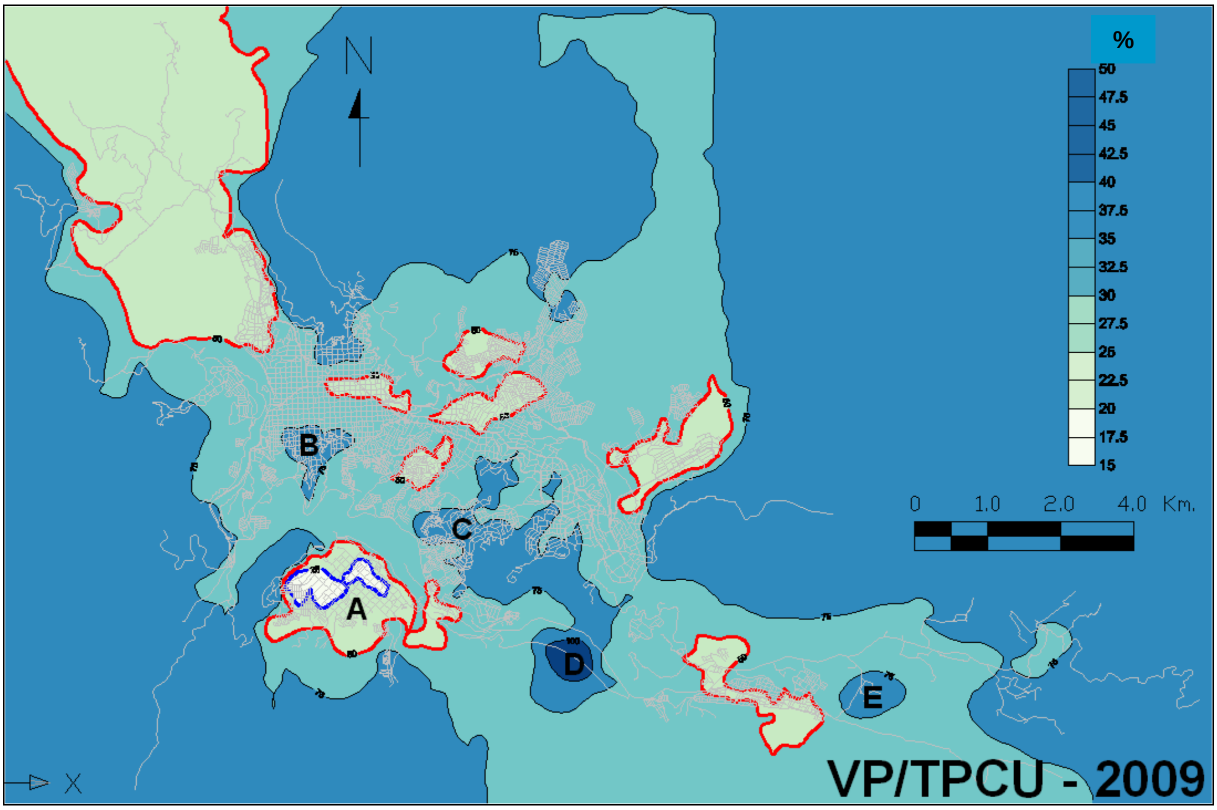

Figure 10 – Curves of Global Mean Accessibility gradients between public transit and private vehicles for the year 2009 (ordinary Kriging with spherical semivariogram model).

CONCLUSIONS

Currently, Manizales is covered between isochronous curves of 15 to 45 minutes to travels made by private vehicle. In the period 2000 – 2009, the expansion of the curves for greater accessibility is evident in a easterly direction (towards the new economic center of the city), which coincides exactly with the location of Manizales' main corridor (an imaginary eastbound line joining the Points C'A'B'D' in Figure 6) that communicates the main centers of economic activities (Points A ' & D' in Figure 6).

The road works carried out between 2000 and 2009 produce more impacts to the peripheral areas of the southwest and north, while the peripheral areas of the northeast and south report a relatively small impact on their travel times by private vehicle.

There are numerous local roads that could be used to operate public transit; also it would be possible to prioritize the use of certain road corridors, which are currently mixed, to specialize in one mode of transport.

It is concluded that over 50.0% of the length of the road network where public transit operates belongs to streets categorized as primary and secondary, finding that a high percentage of the length of the main network has operating speeds above 20 kilometers per hour, while for other road categories, most of its length has operating speeds under 15 kilometers per hour

It was found that not only the main network plays a pivotal role in the operation of public transit, but there is also the need for better vehicle management in secondary, collector and local streets in order to increase the operating speed at least to 18 kilometers per hour.

It was found that areas of the city that have a higher travel time imbalance between the two modes of transport, are residential zones with lower income and a population that depends largely on the public transit; consequently, the road infrastructure works carried out between 2000 and 2009, have only benefited users of private vehicles, their impact on public transit is minor and will be less until there is a real management of this mode of transport.

It is vital to improve the operation and start public transit policies that discourage private car use, which will result in more humane living conditions and a more equitable right to mobility.

This type of analyses are technical support at any time for decision making about changes to the road network and, above all, to establish what areas of the city needs better accessibility and enhancement of the quality of life for residents.

Future research should be aimed to the application of this methodology for assessing the accessibility for other intermediate Colombian cities, for example, joining efforts to rigorously analyze Armenia, Ibagué and Pereira with the purpose of comparison with Manizales' results and to conclude about the current situation between the two modes.

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