DETERMINATION OF CERTAIN OPERATIONAL CHARACTERISTICS OF TRAFFIC ON THE TRACKS FOR PURPOSES OF MODELING USING GPS

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ABSTRACT

The accelerated development in the field of instrumentation and the popularization of its use is permeating all fields. This global trend consists in the instrumentation of vehicles and also the road infrastructure, through the installation of equipment in public and private vehicles, as well as the installation of different types of sensors on the road infrastructure. At international levels this system is used to improve traffic circulation in the cities, public transport services through the modeling of new routes, and control system for vehicles.

This phenomenon is also taking place in Colombia regarding alarm systems, and recovery and vehicle tracking in taxis, bus transportation in Bogotá, the state security vehicles throughout the country, and in some public urban transport vehicles in various cities, among them Manizales.

It is noticeable the popularization of these systems with their implementation in new technologies such as cellular phones, that provide the user with the ability to have a people locating system, especially when these include global positioning services.

The *Avantrack GPS* system, implemented a few years ago in Colombia is providing vehicle monitoring services, with applications that include control of speed limits, positioning access, and location tables in real time via Internet. In Colombia there are more than 10 operators offering this service.

There are multiple applications of vehicle instrumentation, where vehicle monitoring clearly stands out, and provides vehicle information in real time regarding on – off detection, open – closed door sensing, amount of cargo or amount of product, among other data. Work is also being done on the monitoring of people for academic, operational and security purposes. However an application aimed at determining operational characteristics of road networks has not been done. It can have great applications in processes of network calibration and modelling.

This paper presents the result of the analysis of over 12 million records of this kind that allowed the identification of the real conditions of traffic operation and its comparison to the parameters used in the various traffic studies conducted by standard methodologies and the subsequent traffic models proposed for the city of Manizales (Colombia), obtaining significant differences with respect to them. Due to the large amount of information involved and the availability of its variation in time, the results thus obtained allow the generation of a more realistic model, with a positive effect to future analysis of predictions through the creation of scenarios increasingly more trustworthy.

Keywords: Monitoring, GPS, modeling, vehicles, traffic.

BACKGROUND

Technological development has brought about many applications to vehicle and road instrumentation with direct applications to the traffic network, which is an evident worldwide trend that can be used to improve traffic circulation in the cities, public transport services through the modeling of new routes and also as a control system for vehicles.

The satellite monitoring system, created for military purposes, is widely used in many fields, among them the traffic and transport fields. It is important to highlight the popularization of these systems with their implementation of new technologies such as cellular phones, which provide the user with the ability to have a people locating system, especially when these include global positioning services.

Today it is very common the usage of Internet for vehicle monitoring services with applications to maximum speed control, positioning access, and location tables in real-time. Vehicle monitoring in real time stands out from the multiple applications of instrumentation in vehicles. This monitoring provides vehicle information regarding on – off status, open – closed door sensing, amount of cargo or amount of product, among others, and it is used by industry, by common people, and by State offices for security purposes [*Ministry of Transport. Republic of Colombia. 2008*]. It is also used to monitor people for academic, operational and security purposes (inmates in house arrest).

The use of information from traffic sensor systems has been a logical consequence of the technological development, due to its availability and the great value of its results. There are already several publications regarding the various applications such as traffic estimated forecast using the nearest nonparametric regression [*R. K. Oswald, W. T. Scherer, and B. L. Smith. 2000*], which is an approach based on the processing of historical data using a nonparametric regression for traffic prediction of future movement in specific sites, analyzed at the level of each individual, which prevents the determination of traffic density at the level of each link. Similarly, in [*S. Shekhar, C.-T. Lu, S. Chawla, and P. Zhang. 2000*] the mining of traffic data from multiple sensors in the network is used to predict potential bottlenecks based on historical information of very long periods of time.

As time passes, it is more common to find large amounts of available real-time information stored in databases, such as sensors which provide information of the position, speed and direction of each object. This has allowed the development of applications such as the one presented in [*M. Hadjieleftheriou, G. Kollios, D. Gunopulos, and V. Tsotras. 2003*], where the highest densities for short periods of time can be predicted based on information using a uniform dense grid of cells.

An increasingly common application, is that of monitoring public transport vehicles [*Bullock, Ph. et al.. 2005*]. This has permitted the systematization of data acquisition, and definitely the improvement of the control and operation of large fleets of vehicle to unprecedented levels of detail, such as determining the number of stops, duration of each stop, trajectory, speed of operation among others. Finally, in [*Michael D Fontaine, Brian L. Smith. 2007*] it is reported an alternative for vehicle monitoring, since the cost of using networks to transmit real time data can be significant when using General Packet Radio Service (GPRS) associated with cellular phone networks.

METHODOLOGY

The research reported in this paper was carried out during the second half of 2009. This research involved the installation of high-precision GPS, simultaneously in different types of vehicles for long periods of time (one month), with continuous equipment operation obtaining a database (more than 12 million records) of real vehicle movement on the road network of the city of Manizales (Colombia), which can be used for multiple purposes.

Overview

The city of Manizales is located in the central western region of Colombia, with an altitude of 2150 meters above sea level, and a latitude between 5.4º north and 75.3 º Greenwich, on the Andes mountain chain. It lies at the center of the triangle constituted by three major cities of Colombia (Bogotá, Medellín and Cali). It has a population of about 370,000 inhabitants.

The urban shape of the city reflects the adaptation to a very broken and rugged topography with very particular characteristics due to its geographical location. Located on the edge of the hill, Manizales allows a permanent opening to the landscape throughout its length. Thus, the urban growth has been organically adapting to this topographic condition, and thus the city is characterized by a non-continuous urban structure, with a road infrastructure network used by both private and public transport with slopes greater than 18%.

Processing

The GPS equipment, featuring an accuracy of ± 3 meters, recorded for every second the date, time, event, speed and coordinates of each of the vehicles where the systems were installed. A database was obtained with the itinerary of the different vehicles on the road network of the city, achieving coverage of more than 95% with multiple passes through the different links and at different times of the day, allowing the perfection of the obtained statistical analysis.

It was necessary the development of different algorithms to collect, adjust and filter the information of each GPS for the generation and subsequent processing of the database. This was done in a dynamic manner useful to the intended purpose, since the data files from the GPS usually come in XML, CSV or TXT formats, and contain large amounts of information, more than 40,000 records, and around 300,000 data a day.

A database of defined attributes, collected day by day, was built using the data gathered, day by day, from the GPS. Thus, an algorithm was used to open each file and extract the itineraries of vehicles where the GPS equipment was installed. In addition, when the data base is generated the coordinates are changed to the same system where all the geographic information is found. Once the database was complete the information was filtered thus obtaining only the relevant information.

The node field, which is the union of links of the network or the equivalent of an intersection, common to the cartographic and the generated base, was used. Because the interest is to trace the record that crossed a node in a particular trip, it is not necessary to add this field to all records. It is done only for those records that are at some distance *x* from the nearest node (the distance is a function of the GPS precision).

At this point the information is more useful to the goal of tracing the itinerary of each vehicle on a given network. However, due especially to low speeds or vehicle stops, there may be many points within the margin of *x* that correspond to the same itinerary. This is an undesirable situation because it is only required a point to establish that a given vehicle effectively crossed a given network node. Thus, it was necessary a new filter with an algorithm to determine the nearest assigned node for the points within the set range.

Besides the precision of the GPS, which for moving elements is normally slightly less than the theoretical one, it was necessary to make a final check to verify whether the sequence of the itinerary taken by each vehicle corresponded to a real sequence, with no jump discontinuity for loss of signal or information attributable to other aspects. This work was done following the itinerary node by node in the database and inconsistencies were corrected, thus obtaining a very reliable information on the real itinerary of each vehicle.

Multiple analysis were done using the obtained database, since the road network data combined with the itinerary information for different vehicles was available at the same time, thus allowing the calculation, for instance, of the driving speed in each link for each time a vehicle went through.

It was possible to obtain the relationship between the operation speed and the category of the road with such speed value using the categorization traffic data according to the Territory Management Plan of the city.

The algorithm so developed yields very valuable graphical results from the point of view of functionality vs. real operation speeds, due to the use of the database obtained by satellite monitoring. The research summarized herein analyzes the operating characteristics of the traffic network of Manizales, in variables such as operation speed, stop rates, parking and application to the modeling of traffic networks.

Calculations

The processing of the information required different calculations according to the development stage, with special focus on the analysis of the speed and on the assignment models.

Speeds

The speed was determined for each time interval and also for each link using the information obtained at every second by the GPS. Three parameters were obtained: (1) the vehicle speed at every second during in the *i* –th link; (2) the average speed of the *i* –th link, and (3) the average speed of each link *i* for 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 in km/h
x_1, y_1 = coordinates of point 1
x_2, y_2 = coordinates of point 2.

This parameter is useful for examining the speed variations within a particular link, 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 link, was determined as the ratio of the length of the link 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 = Speed *i* in the link *a* (km/h)

l_a = length of the link *a* in meters

t_1 = Passing time for through the first node

t_2 = Passing time through the second node

Finally the average speed in the link is calculated by

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

where

$\overline{V_a}$ = Speed average of *a* link

n = Number of times a vehicles passes in the link

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

Assignment model

The road network of Manizales city was used with a schedule matrix to determine the applicability to modeling processes. The stochastic user equilibrium was the assignment model used, since this was the one with the best correlations according to the Mobility Plan [*National University of Colombia (2005)*] designed by the Universidad Nacional de Colombia for this city. The TransCAD ® software was used for the assignment process. It takes into consideration the effect of traffic flow on travel time, assigning each trip in such way that there is consistency between the flow and travel time, and iterating the assignment of flows for each link, implying a capacity constraint and a new travel time, by means of the following expression:

$$t^a = t^a{}_{fl} \left[1 + \alpha \left(\frac{V}{c} \right)^{\beta} \right] \qquad (4)$$

where,

t^a: time travel in the *a* link in congestion conditions
t_{fl}: time travel in the *a* link under free flow conditions
α y β: calibration parameters
V: volume of *a* link
c: capacity of *a* link

ANALYSIS OF OPERATION SPEED

Figure 1 shows the categorization of the road network in the city of Manizales in 2009. The main network forms a ring road traveling east, west and vice versa. Between Center and East, there is densification of main roads, with three main branches.

Table I shows that the main network has the highest average speed, as expected. Also, the local network has the lowest speed of the system, while the secondary network has average speeds slightly lower than those normally provided by theory.

A descriptive statistical analysis of the real average speed variable was done based on the category of the network. Figure 2 shows the frequency histograms and the most representative statistical values of each road category, with a 90% of confidence that the value of the average speed on a main road in the city of Manizales is in the range of 25 to 55 km/h, while the value of the average speed of a road on the local network is between 6 and 30 km/h.

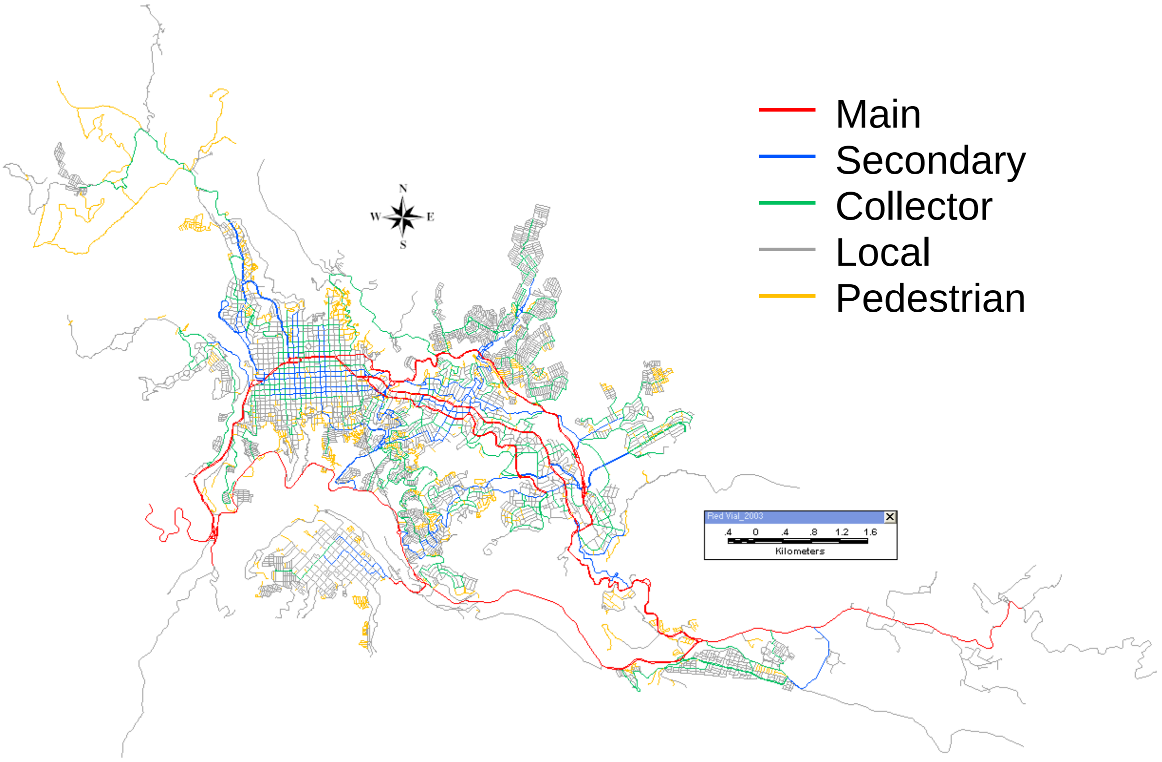


Figure 1 – Categorization of the Road Network

Table I – Categorization of the road network and its relationship with the real average speed and the length of the covered network

Road Category	Average Speed (km/h)	Average speed weighted by the length (km/h)	Standard Deviation (km/h)	Length	
				Km.	**%**
Main	37.92	39.85	9.07	68.8	10.0%
Secondary	27.24	28.43	9.52	56.3	8.2%
Collector	24.14	25.22	8.07	100.0	14.5%
Local	17.66	17.96	7.36	372.8	54.0%
Pedestrian	2.00	2.00	0.00	91.6	13.3%
Total Length				689.5	100.00%

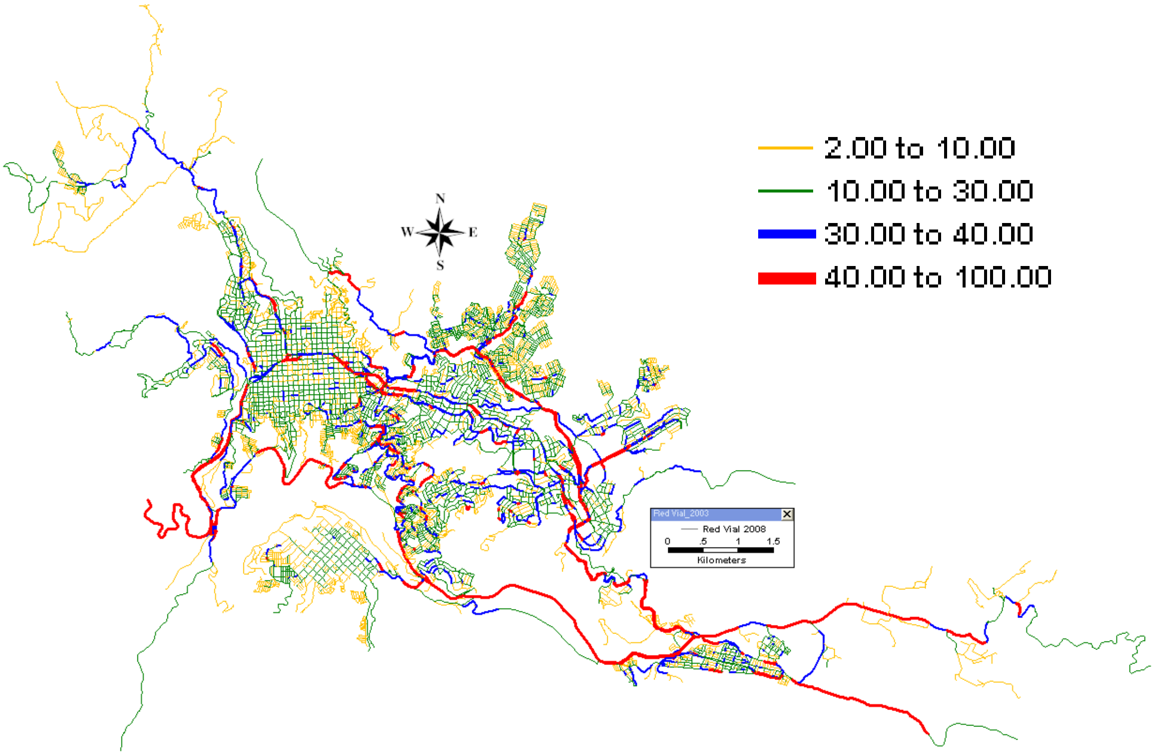
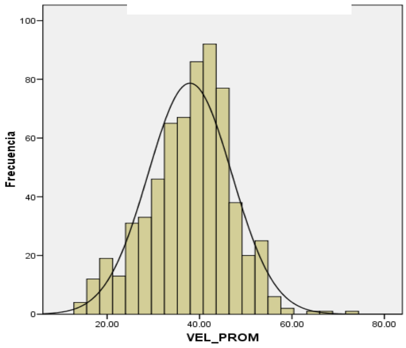


Figure 2 - Ranges of operation speeds on the road network

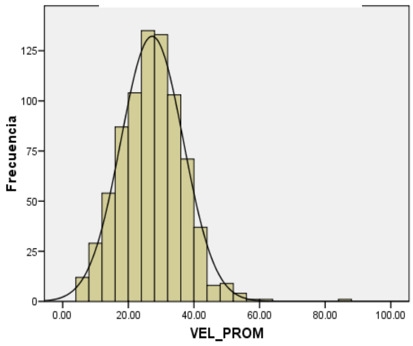
Figure 3 and Table II illustrate the results for the real average speeds, showing that the main network offers operation speeds above 40 km/h in most of its length (58%) and that approximately 82% of the road network have real operation speeds below 30 km/h, while about 8% of the road network have real operation speeds above 40 km/h. It is shown that when analyzing the length of the network covered by each category, each of these fall within the values referenced as appropriate by the AASHTO [*ASSHTO, 2001*].

Main network

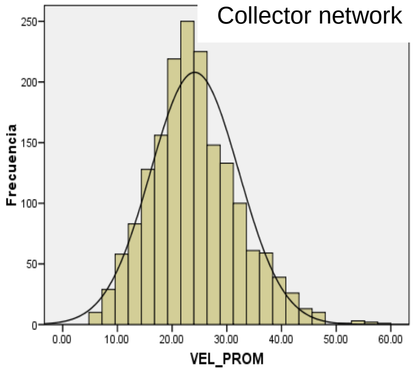


N	639
Averange	37.9244
Standard Deviation	9.07089
Minimum	13.96
Maximum	72.52

Secondary network

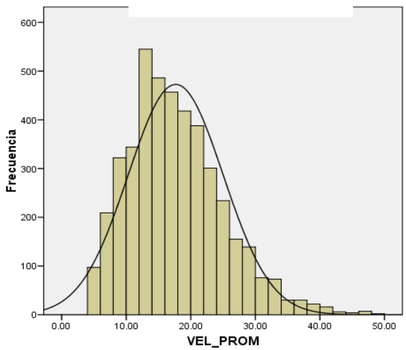


N	789
Averange	27.2423
Standard Deviation	9.5212
Minimum	5.58
Maximum	86.87



N	1754
Averange	24.1356
Standard Deviation	8.07431
Minimum	5.13
Maximum	59.25

Local network



N	4361
Averange	17.6596
Standard Deviation	7.36151
Minimum	5.01
Maximum	48.72

Figure 3 – Descriptive statistics for each category of the road Network

Table II – Categorization of the network and its relationship to real speed ranges and the length of the covered network

Category of the road	**Real average speed**					
	< 10	**10 - 30**	**30 - 40**	**> 40**		
	Length (Kph)				**Total**	**% of Total**
Main	0.0	8.8	20.5	39.5	68.9	10.0%
	0.0%	12.8%	29.8%	57.4%		
Secondary	1.7	30.2	18.7	5.7	56.3	8.2%
	3.0%	53.7%	33.1%	10.1%		
Collector	2.8	68.3	23.7	5.1	99.9	14.5%
	2.8%	68.4%	23.7%	5.1%		
Local	91.2	264.2	13.7	3.8	372.8	54.1%
	24.5%	70.9%	3.7%	1.0%		
Pedestrian	91.6	0.0	0.0	0.0	91.6	13.3%
	100.0%	0.0%	0.0%	0.0%		
Total	188.6	373.6	77.4	54.8	689.5	
% of Total	27.4%	54.2%	11.2%	7.9%		

On the other hand, it is worth noting that virtually the entire downtown sector has real operation speeds under 30 Kph. (See Figure 4). This shows lack of vehicular management of the downtown sector of the city, which has no road corridors of a common functionality regarding its operation speed.

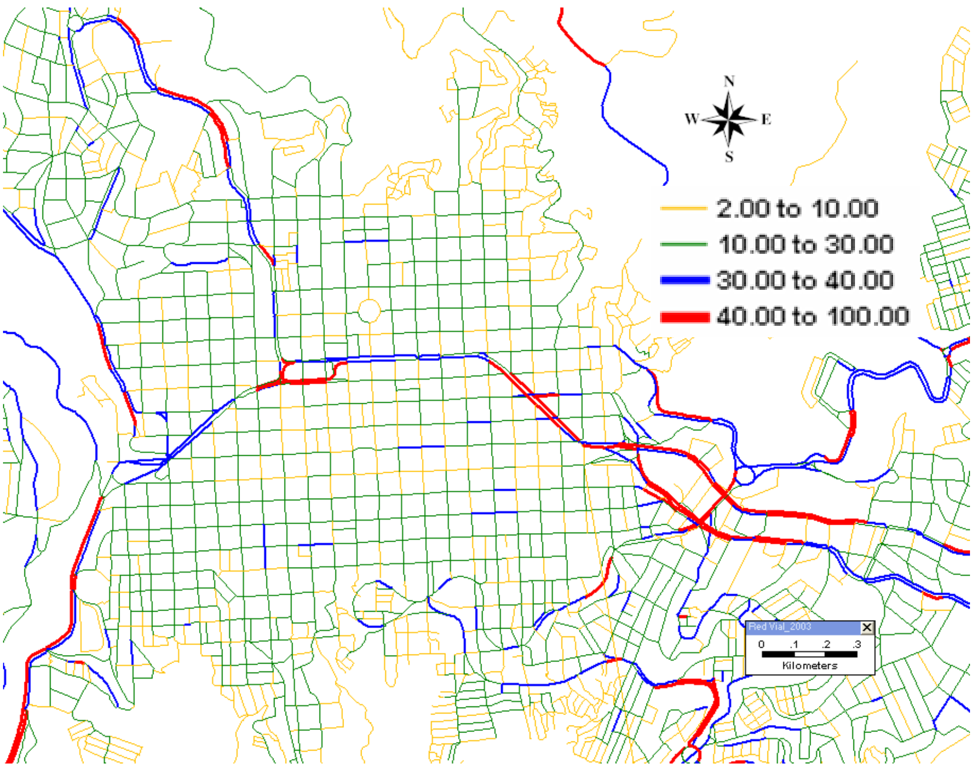


Figure 4 – Ranges of operation speeds in the Center of the city.

Similarly, when zooming in the east side of the city, it is possible to see that the main road corridors (see Figure 5), have real operation speeds between 30 to 40 km/h nearly along its length. Likewise, it is observed the lack of a uniform functionality corridor connecting the East sector to West sector.

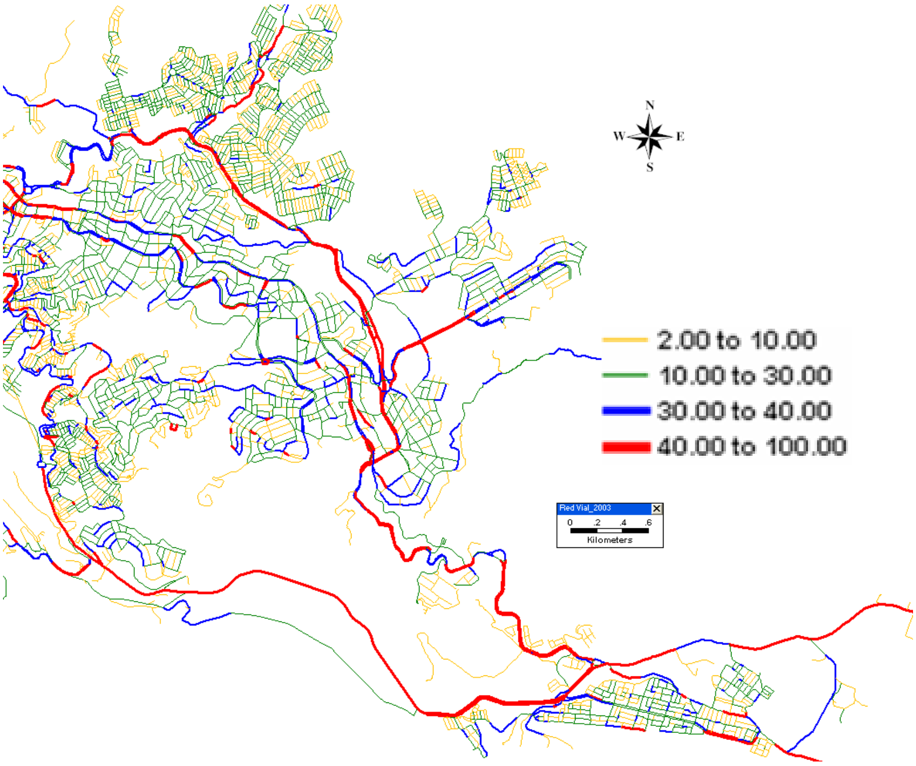


Figure 5 – Ranges of operation speeds in the east sector of the city

Figure 6, highlights the part of the road network that provides the highest speeds (above 50 Km/h, located in the northeastern and southeastern sector of the city, respectively, which are part of the main road network.

Comparative analysis between the operating speeds of the (2005) Mobility Plan and the (2009) real average speeds.

A multiplier factor that shows the relationship between real and theoretical values is obtained using the average operation speed (real speeds), obtained through the analysis of the database from the GPS system, and the average speed data from the Mobility Plan of the city of Manizales [*National University of Colombia (2005)*] (theoretical speeds).
Using the theoretical speed / real speed relation, it is possible to obtain a multiplier factor that explains the overvaluation or undervaluation of the speed data of the Mobility Plan [*National University of Colombia (2005)*]. The links that refer a multiplier factor lower than 1.0, have values of average operation speed overvalued in the Mobility Plan data base when

compared to the real speed data from the GPS system. Similarly, the links that refer a multiplier factor greater than 1.0, have values of average operation speed undervalued in the Mobility Plan data base when compared to the values of real average speed from the GPS system.

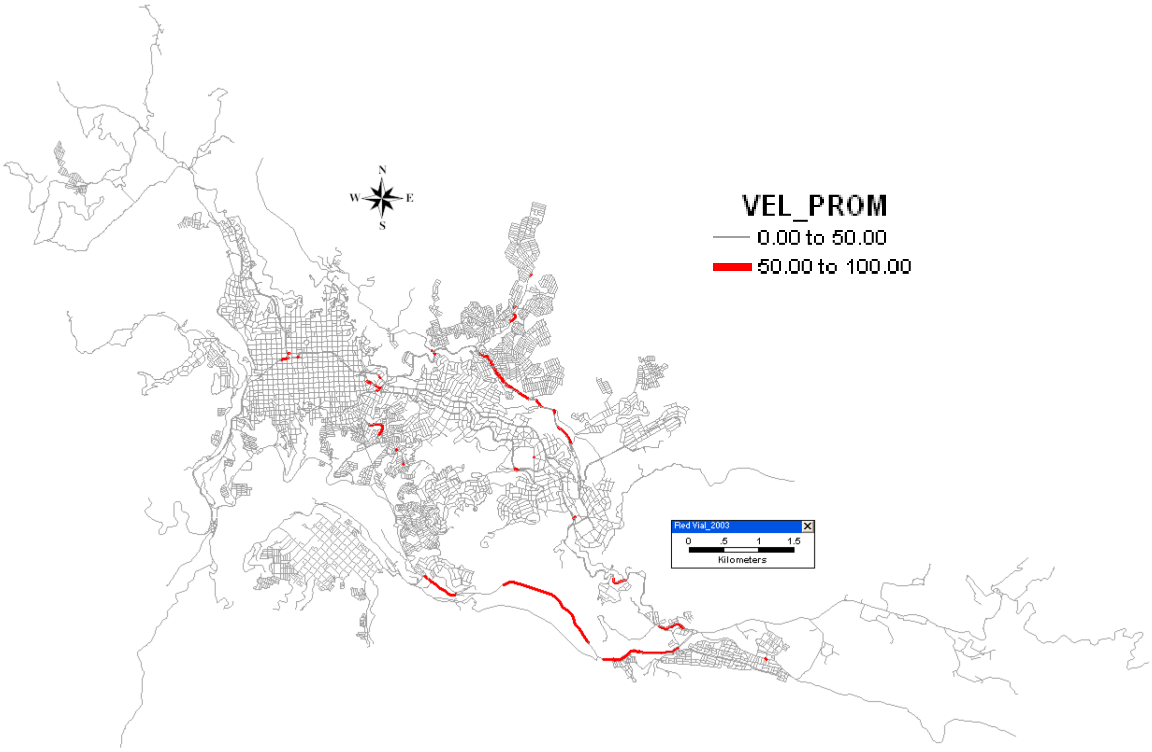


Figure 6 – Road network with real average speeds above 50 km/h.

It was shown that approximately 84% of the length of the road network has overvalued speed values in the Mobility Plan database [*National University of Colombia (2005)*] (theoretical data), while 16.5% of the length of the road network has operation speed values undervalued in the same study (see Table III).

Figure 7 shows the links of the road network that refer a multiplier factor greater than 1 and also the links that refer a multiplier factor lower than 1, thus the links highlighted in gray are those with overvalued operation speeds, while the links highlighted in red are those with undervalued operation speed as a result of the theoretical estimation methodology and the sampling used in the Mobility Plan [*National University of Colombia (2005)*].

Table III – Categorization of the road network and its relationship to the real average speed and the length of the covered network.

Multiplier Factor	**Length**	
	Km.	**%**
< 1	575.76	83.5%
= 1	3.32	0.50%
> 1	110.42	16.0%
Total	689.5	

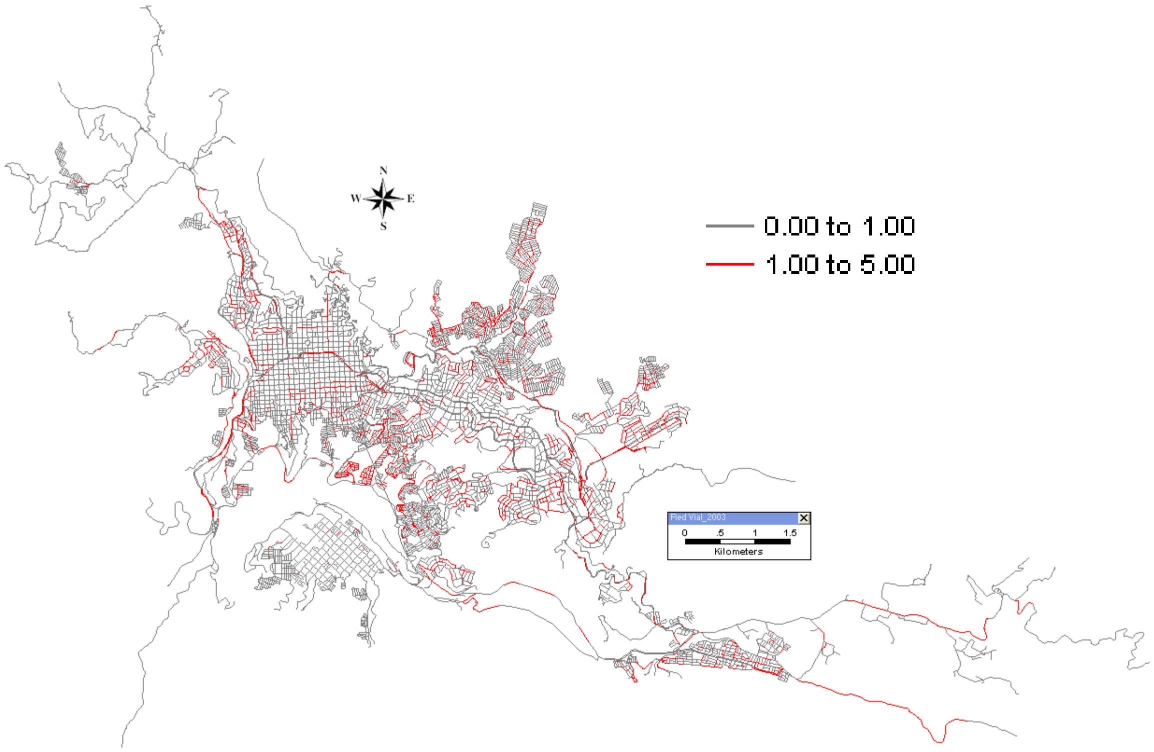


Figure 7 – Multiplier Factors between the average speed of the theoretical operation and the average speed of the real operation.

However, it is possible to establish the need for a thorough analysis of the functionality of certain road corridors in order to find a functional categorization of the road network that provides more continuous channels of communication throughout the city, taking into account the different land usages. This type of research is fundamental to detect the parts of the city that would benefit most from a better traffic management based on more real values, and also the parts of the city that can be potentially intervened in order to improve their connectivity. In other words the obtained information provides a real spectrum of the operation of the entire city, which is crucial for proper planning by the responsible authorities.

STOP RATES

Figure 8 shows an analysis of the stop rates. It can be seen that there are values superior to 50%, which means that for every 10 vehicles that go through a link, 5 will have to stop for a few seconds.

These values are consistent with the presence of control devices to stop, traffic light, high values of vehicular and pedestrian traffic, lack of coordination between the existing traffic lights, usage of driving lanes, existence of permanent parking maneuvers and public transport system stops, among others.

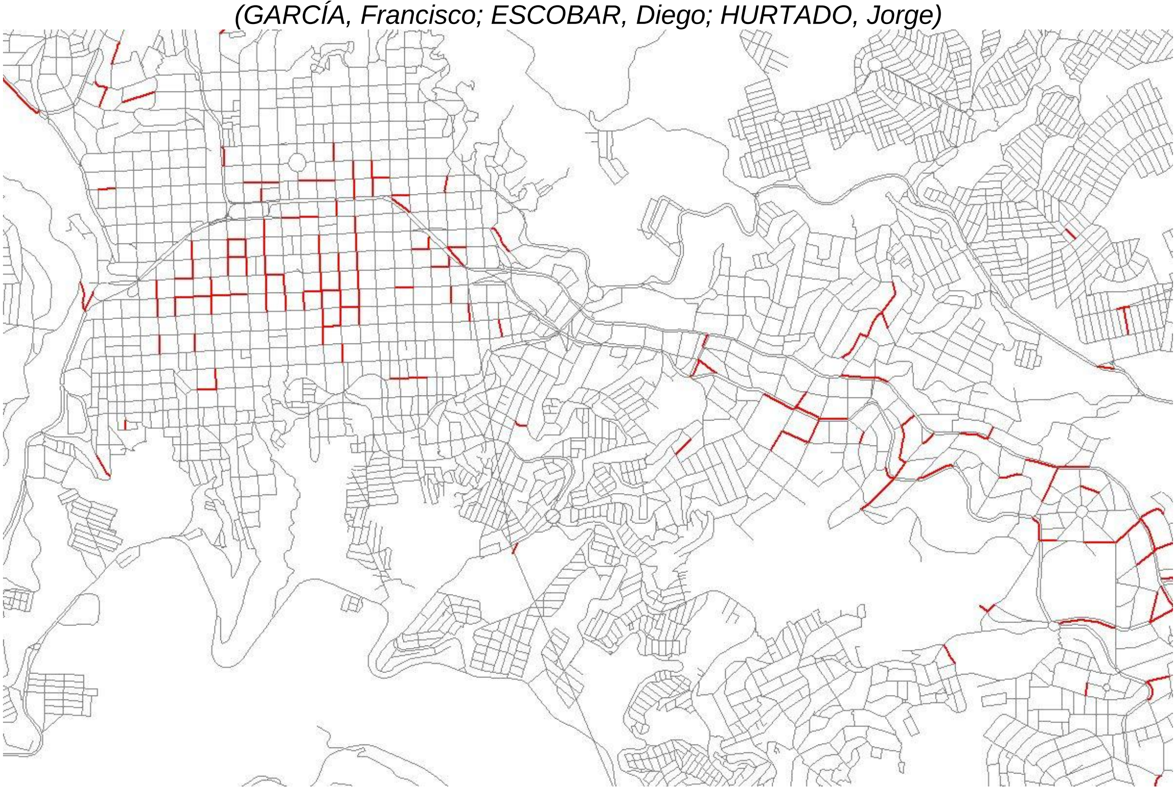


Figure 8 – Vehicle stop rates superior to 50%

SPECIFIC APPLICATION

The satellite monitoring of vehicles can be applied to the study of traffic variables and provide information regarding speed, traffic volumes, stop rates, parking, trajectories and schedules, among many others, which in turn can be applied to solve specific practical problems, such as the programming of traffic lights, adjustment of these lights in real time, help for the user in the selection of a more efficient path in real time, evaluation of corridors with traffic lights, modeling of network in real-time or by batches, modeling for the evaluation of projects and in general a broad range of private and public transport aspects.

A specific application related to network traffic modeling is presented below for the case of an intermediate city such as Manizales (with a population of approx. 370,000 inhabitants). This example is done primarily as a practical application of the data obtained to determine its applicability to modeling practical problems and to solve any inconsistencies.

As expected, these results differ from those obtained in Mobility Plan [*National University of Colombia (2005)*] as it is modeled with a different version of a software tool, using speeds which are different in most cases from those used herein, as already stated, since the speeds used in 2005 were the result of a theoretical calculation and of sampling processes of the most important corridors. In contrast, in our case the values are the result of 4000 hour monitoring of different vehicles obtained in approximately four months, which provided several speed data for each link in the network. In other words the values obtained from the average of several field data for each road segment is real.

It should also be considered that the speed measure today correspond to the actual network conditions, and for this case, important changes have been made to the road network affecting its operational characteristics, particularly because of construction of new infrastructures. In any case, as 2005 parameters are used (schedule matrix, road network, and number of vehicles), the places of high impact are excluded with the aim to make data usable and to determine the correlation coefficient of the model.

The road network

The road network of Manizales consists of about 690 km. (see Table I), of main, secondary, collecting, local and pedestrian roads represented by links (road segments) and nodes (intersections or road crossings), and in turn these have a number of characteristics that define their behavior and/or function in the system. These links are closely related to their physical properties such as road name, nomenclature, length, slope, and cross section (width, separator, sidewalk, green areas), among others.

These links are also related to their operational characteristics such as category, direction, operation speed for private vehicles, and operation speed for public transport, free flow speed, and public transport routes, among others.

The above characteristics make up the road network to be modeled, which has been systematized using TransCAD software and has been refined over time by the municipal administration and by the various consultants with whom specific work has been done such as the Mobility Plan developed in 2005 by the Universidad Nacional de Colombia. Figures 1, 3, 5, 6 and 7 show different aspects of the network.

Traffic Assignment process

In this application, private transport is modeled using the results obtained from satellite monitoring, mentioned above, especially in terms of the operation speed variable and applying these results specifically to the type of monitored vehicles which in this case are light private vehicles.

Thus, trips of the private transport system are modeled, assigning traffic on the different links of the network, based on the road network and taking into account the properties already mentioned and also the schedule matrix obtained for the private transport system. In this case, the matrix corresponds to individual trips, so it must be converted to vehicle trips using occupancy values from studies of vehicle occupancy rate, obtaining a matrix for each zone during peak hours, in this case morning rush hour.

The results of this matrix include 14,000 trips in rush hour distributed into 57 sectors (57 x 57 matrix) in which the city was divided. Then, the values of the network preload from public transport, passing routes to the intermunicipal transport terminals, and freight distribution companies, are calculated. This research used the existent information related to the network and the schedule matrix already produced in the formulation of the Mobility Plan in 2005 [*National University of Colombia (2005)*].

The allocation of the schedule matrix is done based on the parameters already presented, which in brief, and as minimum include: link length, link capacity, travel time (calculated from the speed), link type (vehicular or pedestrian), direction, one or two ways, preload and parameters α and β (calibration parameters) as a function of congestion.

Accordingly, the allocation is done following these parameters:

- Method: Stochastic user equilibrium
- Impedance: Travel time (obtained from the GPS real operation speeds)
- Link capacity: Same values used in the Mobility Plan 2005.
- Alpha and Beta parameters: Same used in the Mobility Plan 2005. (0.50 and 5.00, respectively)

Main Results

The modeling was done using the software tool described above, obtaining vehicle loads on different links of the network, validated by 18 control points, from which the value measured in the field of traffic volumes was known. These sites are shown in Figure 9, and correspond to those used in Mobility Plan (2005), having dismissed two of the sites used in that year as it was an influence zone of major projects affecting the variable of vehicular volumes and speed.

Table IV shows the values of the real number of vehicles and the value obtained applying the model. Using these values, a linear regression to calculate the value of the R^2 correlation, and the equation of the tendency line is performed (see Figure 10). The result is a correlation coefficient of 0.7825 and a slope of the line close to 1.0, which is considered good and therefore the obtained model represents the behavior of the city.

CONCLUSIONS

Although the future is always uncertain, it is logical to think that the use of technology related to satellite monitoring will become more and more frequent, and of general usage. Undoubtedly, the benefits are very high and this research provides information and promising results. Information could become free when using information already stored from companies that nowadays use monitoring for purposes other than traffic applications, such as fleet control for operational purposes, taxi services, security systems, and public transport systems. This information is stored for several months or even years.

Figure 9 –Location of control links with real number of vehicles in the field.

Table IV – Real number of vehicles measured in the field vs number of vehicles obtained with the model using speed parameters.

LINK_ID	STATION	Real number of vehicles	Assigned
8793	1	572	786
4419	2	657	865
6657	3	317	397
10077	4	247	545
5963	5	385	543
6782	6	1269	1573
5280	7	726	1243
7210	8	1333	1366
6764	9	841	789
8794	10	1048	1225
10527	11	854	1150
8345	12	435	604
254	13	81	32
6858	14	966	1519
6954	15	844	1381
9177	16	638	1022
869	17	1021	1117
7456	18	226	757

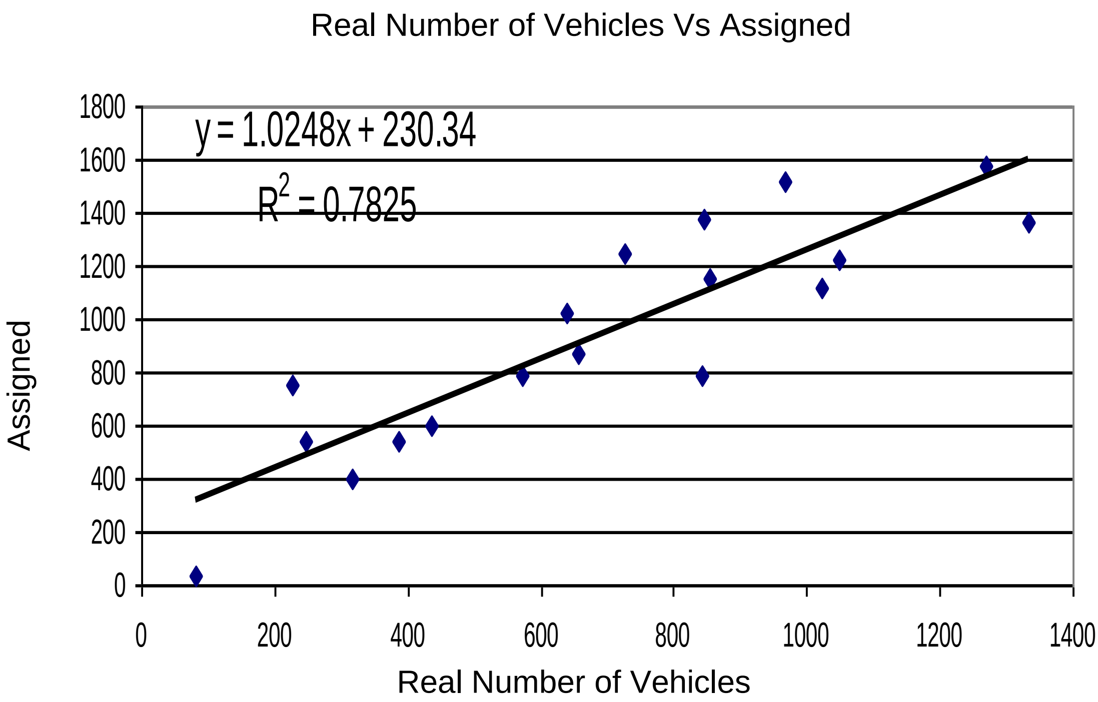


Figure 10 – Dispersion of the modeling results using speeds obtained by satellite monitoring

The possibility of its application to practical cases is high, allowing a level of detail previously unimaginable, such as the determination of vehicle operation speeds for each hour of the day. Take into account that nowadays it is common to use only one value for network modeling.

It is also possible to discriminate variables at the level of vehicles increasingly more specific such as private car, trucks, jeeps, motorcycles, and taxis that are usually labeled as private or particular. This level of detail would redound in better results when seeking to create and evaluate very specific scenarios, even at the level of micro simulation of specific problems.

Finally, the results presented in this paper might be important in terms of the differences found regarding the theoretical estimated speed values for different links and those found in this research. These differences are superior to 100% especially, when considering that most of the factors used to calculate speed theoretically have not changed over the past five years because these are physical characteristics that have changed only in very specific locations in the city. It is necessary to study this topic in depth and to evaluate thoroughly the applicability of the different methodologies or to carry out studies and proposals to better them.

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