Computer Fraud and Security
ISSN (online): 1361-3723

Determination of Geometric and Signaling Hazards on Interurban Roads: Critical Perspective for Optimizing Safety on Route 2502

Jorge Luis Argoty Burbano.

jlargoty@udenar.edu.co

https://orcid.org/0000-0001-6661-1398

Universidad de Nariño, Colombia.

Abstract

Route 2502, between PR 5+000 and PR 28+000, is a high-traffic road corridor on the Pan-American Highway, with a high risk of accidents due to the interaction of different road actors. This study identifies critical accident areas, analysing geometric and signalling factors to propose corrective measures to improve road safety. Through the analysis of statistical data, signage inventories and road safety audits, the main risk points and their causes were determined. The results show the need for interventions in signage, road geometry and speed control to reduce the vulnerability of drivers and pedestrians. This work provides key tools for the planning of mitigation strategies in road infrastructure.

Keywords: Road Accidents, Road Safety, Road Infrastructure, Accident Analysis, Road Signage, Road Safety Audit, Road Geometry, Traffic Management.

1. Introduction

Road safety is a determining factor in the planning and operation of transport infrastructure, as it has a direct impact on mobility, quality of life and economic development of a region. Worldwide, road accidents represent one of the main causes of mortality, generating impacts both in terms of public health and in economic costs associated with the care of victims and material damage. In this context, the identification of risk factors and the implementation of mitigation strategies have become priority objectives within mobility and sustainable development policies.

In Colombia, road safety management has gained relevance in recent decades due to the growth of the vehicle fleet and the increase in accidents, particularly in strategic corridors with high vehicular flow. One of these corridors is **Route 2502**, specifically in the section between **PR 5+000 and PR 28+000**, which connects the city of **Pasto** with the municipality of **Chachagüí**. This road is part of the **Pan-American Highway**, a fundamental artery for the connectivity of southwestern Colombia, used for both passenger and cargo transport. However, the geometric conditions of the road, the deficiency in signage and the coexistence of different types of users (pedestrians, motorcyclists and heavy vehicles) have favoured the occurrence of accidents in this section.

Given this panorama, the objective of this study is to analyze the main factors that influence the accident rate of Route 2502, with the purpose of proposing improvements in infrastructure and road safety management. To this end, a comprehensive analysis was carried out that includes:

- **Accident data collection**: Road accident reports provided by the **Pasto Traffic and Transport Secretariat** and the **Highway Police were used**, with detailed information on the location, date, type of accident and severity of the event.
- **Inventory of road signage and demarcation**: The current state of the vertical and horizontal signage along the study section was evaluated, identifying deficiencies that could have an impact on accidents.
- **Road Safety Audit (ASV):** An audit methodology was applied to detect critical points on the road, considering aspects such as visibility, geometric alignment, pavement condition, and traffic operating conditions.

- **Geometric analysis of the corridor**: Elements such as curve radii, slopes and visibility distances were evaluated, comparing them with the regulatory standards in force in Colombia for interurban roads.

The results obtained in this study will make it possible to establish a precise diagnosis of the factors that influence the accident rate of this road section and to formulate recommendations aimed at reducing the occurrence of accidents. It is expected that this analysis will contribute to decision-making in terms of planning and management of road infrastructure, promoting the implementation of corrective measures such as the optimization of signage, the redesign of geometric elements in high-danger curves and speed control strategies.

In general terms, this work not only provides technical inputs to improve road safety in the study section, but can also serve as a reference for future research and intervention projects in other road corridors with similar problems.

2. General objective

Determine the magnitude of the accident rate on Route 2502, section PR 5+000 to PR 28+000, through the analysis of statistical data, the evaluation of road signage and the study of geometric factors, in order to identify critical points of accident and propose mitigation strategies to improve road safety.

3. Accidents and road safety in Colombia

Road safety is an essential component in transport planning and management, as it has a direct impact on the reduction of accidents and the protection of the lives of road users. Worldwide, traffic accidents are one of the main causes of mortality, being a public health problem with significant economic effects. In countries such as Colombia, road accidents have become a critical problem due to the combination of factors such as the growth of the vehicle fleet, the insufficiency of road infrastructure and the lack of compliance with traffic regulations.

To address this situation, strategic initiatives have been implemented, including Road Safety Audits (ASV), whose purpose is to systematically assess safety conditions in road infrastructure and formulate corrective measures before accidents occur. These audits have been adopted in several countries with positive results in reducing the accident rate. In Colombia, its application has allowed the identification of critical points in strategic corridors, facilitating the design of mitigation and optimization plans for road infrastructure.

This study focuses on the analysis of road accidents on Route 2502, section PR 5+000 to PR 28+000, evaluating its impact and proposing solutions from a comprehensive perspective. Variables such as signage, geometric conditions and the interaction between the different road actors (pedestrians, motorcyclists and drivers of light and heavy vehicles) are considered.

3.1 Information on Road Safety in Colombia

In the Colombian context, road safety has been the subject of study by various government entities and international organizations. One of the tools used for road infrastructure assessment is the International Road Assessment Programme (iRAP), which employs a scoring system based on road safety. The results obtained in these evaluations have shown that several regions of the country present high levels of risk for road users.

Image 1. IRAP score
Source: Road Prevention Fund Corporation
In original language Spanish

Image 2. IRAT department of Nariño
Source: Road Prevention Fund Corporation
In original language Spanish

According to the Road Prevention Fund, the department of Nariño obtained one of the worst scores in road safety, with an index of 18.7 points on a scale where a lower value indicates greater safety. This result reflects significant deficiencies in the design, maintenance and signaling of the roads in this region.

To address these issues, several intervention strategies have been identified, such as:

- Elimination of fixed obstacles located less than 10 meters from the road.
- Construction of berms and containment elements to improve safety on the roadsides.
- Segregated infrastructure for motorcyclists, cyclists and pedestrians.
- Installation of speed reduction systems, such as warning strips and improved signalling at critical curves.

The increase in the number of vehicles in Colombia, especially the increase in motorcycles, has led to an increase in road accidents. The absence of control measures and the lack of regulation in driver training have contributed to this phenomenon. For this reason, it has been recommended to strengthen the training of motorcyclists and improve the supervision in the issuance of driver's licenses.

3.2 Road Safety Statistics in Colombia

Statistics on road safety in Colombia have been compiled by various institutions, including the National Institute of Legal Medicine and Forensic Sciences, which records mortality data in traffic accidents considering victims who die up to 30 days after the accident, in accordance with international standards.

The report of the Pan American Health Organization (PAHO, 2013) establishes that Colombia has a rate of 11.7 deaths per 100,000 inhabitants, a figure that, although lower than the regional average of 16 deaths per 100,000 inhabitants, continues to represent a significant public health problem.

The historical analysis of accidents in the country indicates that between 2003 and 2010, deaths in road accidents have remained relatively stable, with an annual average of 5,490 deaths. However, the National Road Safety Plan 2011-2016 has pointed out the need to adopt stricter measures in traffic regulation, infrastructure improvement and road safety education to reduce these figures.

The main causes of accidents include:

- Speeding.
- Lack of adequate signage.
- Alcohol and drug use by drivers.
- Shortcomings in road infrastructure, especially in curves and steep slopes.

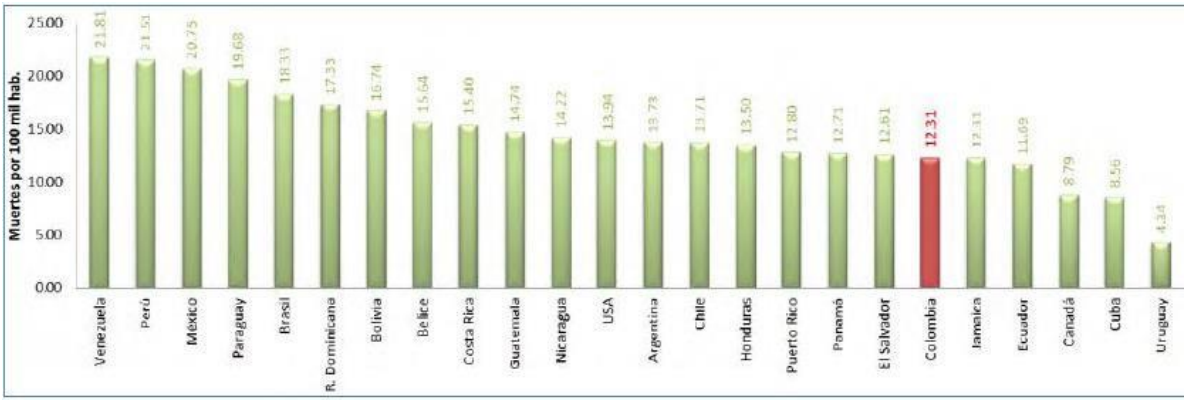

Figure 1. Rate per 100,000 inhabitants region of the Americas data 2007
Source: National Road Safety Plan Colombia 2011-2016 (WHO Report 2009)
In original language Spanish

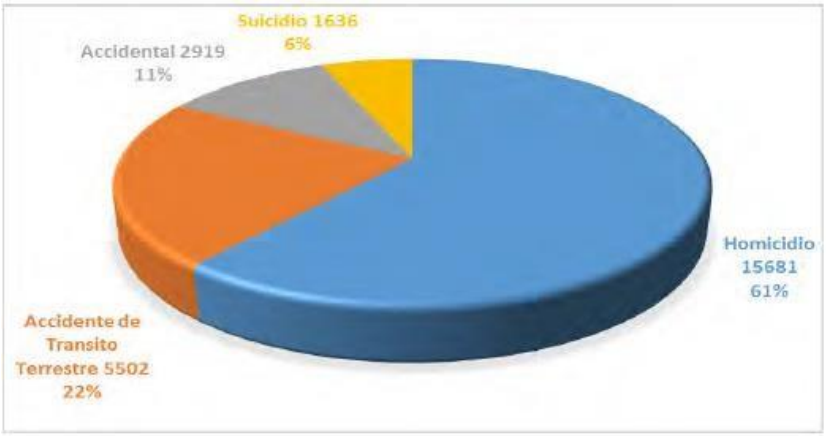

Figure 2. Violent deaths in Colombia
Source: National Road Safety Plan Colombia 2011-2016 (Report on Legal Medicine Data and Forensic Data, Yearbook 2010, UNIANDES)
In original language Spanish

3.3 Road Safety Audit

Road Safety Audits (ASV) have been implemented in Colombia as a prevention mechanism that allows the evaluation of road conditions and the detection of risk factors before accidents occur. These audits can be applied at different stages of a road project, including the design, construction and operation of the infrastructure.
The analysis of accident factors on Colombian roads reveals that the main determinants of road accidents can be grouped into three categories:

1. Human factor: It accounts for 93% of accidents and includes driving errors, distractions, driving under the influence of alcohol or drugs, and disobedience to traffic rules.
2. Vehicle factor: Responsible for 13% of accidents, associated with mechanical failures, problems in brake systems and tires in poor condition.
3. Infrastructure and environment factor: It impacts in 34% of cases, related to deficiencies in the geometric design of the road, inadequate signage and adverse weather conditions

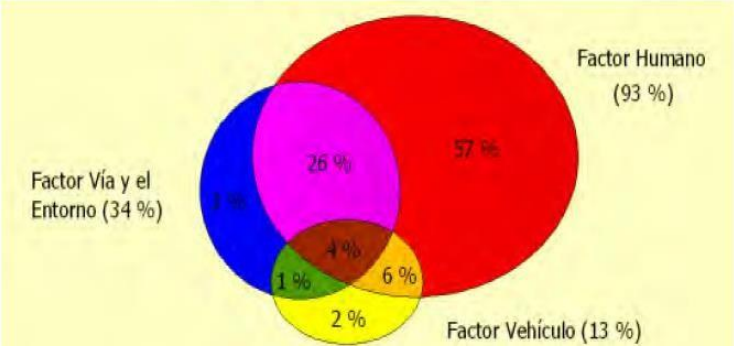

Figure 3. Factors that contribute to the occurrence of an accident.
Source: The problem of road insecurity (Eng. Juan Carlos Dextre)
In original language Spanish

Studies have shown that the implementation of road audits contributes significantly to the reduction of accidents, since it allows the identification of critical areas and the formulation of appropriate intervention strategies. In this sense, ASVs are fundamental tools for decision-making in the planning and maintenance of road infrastructure in Colombia.

4. Location via Pasto – Chachagui

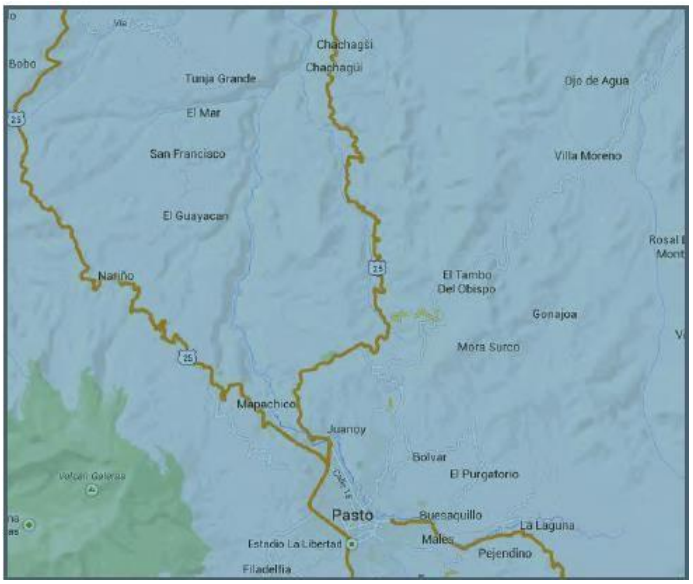

Image 3. General location of the section of Pasto – Chachagui road
Source: google earth

Image 4. Geographical features of the section of vista road towards Pasto-Chachagui
Source: google earth

5. Study Methodology

This study was developed using a methodology structured in several stages, with the aim of analyzing the accident rate on Route 2502, section PR 5+000 to PR 28+000. To this end, data collection and analysis techniques, road safety audits and evaluation of the existing infrastructure were applied.

5.1 Collection of Information

The collection of available information on the road under study was carried out, including plans, previous studies, accident reports and other relevant documents. This phase allowed the problem to be contextualized and an initial database for analysis to be established.

5.2 Updating Road Signage Information

A visual inspection and photographic documentation of the road section was carried out in order to record the current state of the signage. Both vertical and horizontal signs were evaluated, identifying deficiencies and omissions in the existing signage. This information was organized in a systematized inventory.

5.3 Checklist Generation

Structured checklists were developed based on road safety audits (ASV), with the purpose of identifying failures in the infrastructure and road conditions that may represent a risk to road users. These lists were filled out in the field, compiling detailed information on the state of the road and its safety elements.

5.4 Analysis of Accident Information

Statistical data on road accidents registered in the Secretariat of Traffic and Transport of Pasto and the Highway Police were processed, in order to establish trends in the accident rate. Accidents were classified by type, severity, location and possible causes, allowing the identification of critical points and predominant risk factors.

5.5 Analysis of Geometric Factors of the Track

Geometric characteristics of the road section were evaluated, including curve radii, slopes, visibility and alignment of the road. These parameters were compared with the road design regulations in force in Colombia, in order to detect conditions that may influence the occurrence of accidents.

5.6 Preparation of Recommendations and Conclusions

Finally, based on the analysis of the data collected, recommendations were made to improve road safety in the evaluated section. Corrective measures were proposed in signage, road geometry and speed control strategies. The conclusions of the study provide a guide for decision-making in the planning and optimization of road infrastructure in the region.

6. Analysis of the results

In the preparation of the checklist, sixteen items were taken for each kilometer, taking a total of 5888 data of the general conditions of the road, visually an average of almost 256 data per kilometer, enough to determine patterns

of insecurity, from these data can be determined; the 23 km have berms less than 1.5 m; none of the curves have an overwidth; 139 curves in a very short section approximately 6 curves per kilometer, 1 curve every 150 m with very small radii, 139 between tangents of which 81 (58.28%) are less than 50 m in length, and only 15 (10.8%) are longer than 150 m; throughout the section there is no good lighting of the road at night, nor reflective horizontal signage; there are no suitable sections for parking vehicles in case of incidents; almost all the vertical signs are in good condition, but the poor condition of some is beginning to be noticed, and there is also a deficit of them due to speeding, pedestrian areas; there are no efficient structures for pedestrians, and there are no systems for motorcyclists, cyclists and pedestrians; the condition of the pavement is good due to its rehabilitation; there are fixed objects on the road such as retaining walls, sewer heads that do not have adequate signage and protrude too much, approaching centimeters from the lane; the canals are inadequate throughout the section, generating lethal risks in the event of an accident; throughout the section, the visibility distance in horizontal curves is a problem; there are several areas of landslides and detachment of material; throughout the section there are no clear side areas for the braking of vehicles in case of getting out of control; 100% of the barriers have inadequate finishes that generate more danger to users.

6.1 Analysis of accident hotspots and critical areas

The critical accident areas according to statistical analysis of accidents based on data obtained from the Highway Police and STTP are:

8+000 – 9+000	10+000 – 11+000	13+000 – 14+000	27+000 – 28+000

Table 1. Critical accident areas (by statistical accident analysis)

To evaluate the consistency of the geometric design, different criteria and methodologies have been developed, strongly related to the level of accidents. The most commonly used are based on the analysis of the evolution of operating speeds. To do this, the operating speed profile is used. The greater the dispersion of operating speeds, the more likely it is that this section will be more dangerous. In addition, sudden reductions in operating speed mean a greater probability that accidents will be concentrated in that area
They established two consistency criteria related to operating speed, which include the difference between operating speed and design speed (criterion I) and the difference in operating speed between consecutive geometric elements (criterion II).

The abscissas taken below are from an assessment made by Lamm criteria I and II

From, Gómez Chamorro Jeisson Alexander - Paz Villota Diego Fernando, Study of operating speed and analysis of the speed profile of the Pasto – Chachagui (airport) km 19+000 – km 32+500 by using radar, the following critical sections were obtained:

19+272 -19+379	19+661 - 19+712	20+779 - 21+003	21+441 - 21+759
21+759 - 21+799	21+850 - 21+971	21+997 - 22+054	22+320 - 22+510
22+597 - 22+653	22+711 - 22+977	23+139 - 23+256	23+331 - 23+561
23+634 - 23+814	23+814 - 23+861	23+965 - 24+201	26+053 - 26+134
26+184 - 26+380	26+232 - 27+176		

Table 2. Accident Hotspots (by Thesis)

6.2 Analysis of accident hotspots

8+000 – 9+000:
Causes of accidents: the accident rates of this section are associated with causes related to collisions between vehicles due to overtaking curves or slopes, overtaking in the opposite direction, speeding, whose factors or deficiencies are related to the development of the speed of the vehicles due to the excessive longitudinal slopes of the road, especially in the descent lane and sudden changes in alignment, whose operating speed values far exceed the geometric design of the track.

10+000 – 11+000
Causes of accidents: the accident rates of this section are associated with causes related to collisions between vehicles due to overtaking curves or slopes, overtaking in the opposite direction, speeding, whose factors or deficiencies are related to the development of the speed of the vehicles due to the excessive longitudinal slopes of

the road, especially in the descent lane and sudden changes in alignment, whose operating speed values far exceed the geometric design of the track

13+000 – 14+000
Causes of accidents: the accident rates of this section are associated with causes related to collisions between vehicles due to overtaking curves or slopes, overtaking in the opposite direction, speeding, whose factors or deficiencies are related to the development of the speed of the vehicles due to the excessive longitudinal slopes of the road, especially in the descent lane and sudden changes in alignment, whose operating speed values far exceed the geometric design of the track.

27+000 – 28+000
Causes of accidents: the accident rates of this section are associated with causes related to collisions between vehicles due to overtaking curves or slopes, overtaking in the opposite direction, speeding, whose factors or deficiencies are related to the development of the speed of the vehicles due to the excessive longitudinal slopes of the road, especially in the descent lane and sudden changes in alignment, whose operating speed values far exceed the geometric design of the track.

19+272 -19+379	19+661 - 19+712	20+779 - 21+003	21+441 - 21+759
21+759 - 21+799	21+850 - 21+971	21+997 - 22+054	22+320 - 22+510
22+597 - 22+653	22+711 - 22+977	23+139 - 23+256	23+331 - 23+561
23+634 - 23+814	23+814 - 23+861	23+965 - 24+201	26+053 - 26+134
26+184 - 26+380	26+232 - 27+176		

These are the sections that are a potential risk of accidents according to the assessment made by Lamm's criterion I and II. This criterion is what makes it possible to compare the speed changes between consecutive elements and therefore determine the areas where drivers have to change speed abruptly, which gives the driver a feeling of insecurity and perceptible discomfort. Here an intervention must be carried out by modifying the geometric characteristics of the elements in order to homogenize the route and not have drastic changes in speeds, but rather that it has a fluid appearance, in addition to adapting the lateral areas to generate braking zones and better visibility.

Conclusions
The analysis of the accident rate on Route 2502, section PR 5+000 to PR 28+000, has made it possible to identify the main causes of accidents on this road and establish strategies to mitigate their effects. The findings show that deficiencies in infrastructure, inadequate signage and geometric road conditions play a determining role in the occurrence of accidents. It was determined that 72.9% of the registered accidents correspond to collisions between vehicles, followed by collisions and overturns, which reflects the need to implement measures that improve road safety and reduce the exposure to risk of users. In addition, the lack of adequate vertical and horizontal signage, together with the absence of night lighting and speed reduction devices, compromises drivers' perception of the road environment, increasing the likelihood of collisions and road departures.
The study also revealed that inadequate road geometry is one of the most critical factors in the accident rate of this section, since 89.93% of the curves analyzed have radii of curvature lower than the values recommended by current regulations. The high density of curves, with an average of six per kilometre, reduces visibility and forces drivers to make sudden manoeuvres to maintain the stability of their vehicles, which increases the risk of accidents. The lack of overwidths in these sections prevents cargo vehicles and public transport from circulating safely, increasing the likelihood of head-on collisions.
Another worrying aspect identified is the absence of adequate infrastructure for pedestrians, cyclists and motorcyclists, who represent one of the most vulnerable groups on the road. The lack of pedestrian crossings, bicycle lanes and protection barriers increases their exposure to the risk of being run over and accidents with larger vehicles. The data reflect an increase in accidents with motorcyclists in recent years, which suggests the need to strengthen traffic regulation and design road spaces that safely integrate these actors.
The analysis of the distribution of claims allowed the identification of several critical points along the evaluated section, particularly in the segments between PR 8+000 and PR 9+000, PR 10+000 and PR 11+000, PR 13+000 and PR 14+000, and PR 27+000 and PR 28+000. These sectors present a combination of risk factors, such as reduced curve radii, absence of adequate signage and abrupt changes in operating speed, which makes them highly dangerous areas.
In view of this problem, the implementation of corrective strategies focused on improving road safety of the evaluated section is proposed. Among the priority measures are the optimisation of signage and horizontal demarcation through the use of reflective materials, the geometric redesign of critical curves to improve their radius of curvature and the enabling of overwidths in the most dangerous sections. It also recommends the

installation of speed reduction devices in urban accesses and segments with a high accident rate, the implementation of side protection barriers to avoid collisions with fixed obstacles, the creation of emergency bays and braking zones for cargo vehicles and the construction of safe infrastructure for pedestrians and cyclists.
The study highlights the importance of road safety audits as key tools for the identification of accident hotspots and the formulation of mitigation strategies. The application of these audits in the planning and maintenance phase of the infrastructure makes it possible to proactively assess the risks associated with the road and establish preventive measures before accidents occur. Its implementation would contribute significantly to the reduction of accidents and the improvement of mobility in strategic corridors with high vehicular flow.
In conclusion, Route 2502 presents a series of structural and operational deficiencies that affect road safety and require immediate intervention. The implementation of the proposed measures will not only reduce the occurrence of accidents, but also improve the mobility and quality of life of road users. This study provides a technical basis for the formulation of intervention projects in road infrastructure and sets a precedent for future research in the management of road safety in strategic corridors of the country.

Bibliographic references

FEDERAL HIGHWAY ADMINISTRATION, Manual of Uniform Traffic Control Devices, United States of America.

ANDREW, P O. Brien and Deborah Donald Road Safety Audit “Nitti Gritty” – Design Stage Audit.

COMMISSION OF ROADS AND URBAN TRANSPORT, Manual of Devices for the Control of Traffic in Urban and Suburban Areas, Mexico City.

DOURTHÉ CASTRILLÓN, Antonio. Jaime Salamanca Candia, Guide to Conducting a Road Safety Audit.

MERINO, Luis Armando. Proposal of the Evaluation Model for the visual inspection of Road Safety devices and their incidence in the accident rate in the Route 2501 Road section of the Western trunk from PR 5+00 to PR 83+00 Sector Ipiales Pasto, Civil Engineering - University of Nariño – 2010.

MINISTRY OF TRANSPORT, Road Prevention Fund, Road Accidents in Colombia 2007.

MINISTRY OF TRANSPORT. Manual of Geometric Design of Roads Bogotá D.C.2008. 277 p.

MINISTRY OF TRANSPORT, Road Signage Manual, Devices for the Regulation of Traffic in Streets, Highways and Cycle Routes of Colombia May 2004.

MINISTRY OF TRANSPORT. National Road Safety Plan Colombia 2011-2016. 72 p.

ORGANIZATION OF AMERICAN STATES AND MINISTRY OF TRANSPORTATION
AND COMUNICACIONES (Venezuela). Inter-American Manual of Devices for Traffic Control in Streets and Highways 2nd Edition