A METHODOLOGY TO ALLOCATE INVESTMENTS IN ROAD SAFETY IN DEVELOPING CITIES USING RISK MAPS

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ABSTRACT

This paper addresses the urban traffic accident problematic in developing cities through a methodology to prioritise the investments in road safety based on GIS tools. Within Colombian context, this issue has become relevant. In 2010, 92% of the traffic accidents occurred in urban zones, which is a significant percentage compared to the limited funds assigned to road safety. The procedure proposed allows identifying zones or road segments with high potential of accident reduction and economic savings with low investments. The methodology was implemented on a case study in Bogotá.

Keywords: Risk map, black spot, road safety, developing cities

1. INTRODUCTION

Colombian cities are experiencing high economic growth rates, which in turn, have led to growing private vehicle ownership and traffic flows. Similarly to what happens in the developing world, this situation has created an increasing number of transport-related problems, from congestion, insufficient transit systems, high noise levels, low air quality to poor road safety (Puchera et al., 2005), (Walters, 2008).

During 2010, 17% of accidents involving deaths and 21% of the accidents involving serious injuries were located within four Colombian main cities (CFPV and Universidad de los Andes, 2012a). These accidents cost to society USD 510 million (Source: Authors based on results from CFPV and Universidad de los Andes, 2011), while the investments on road safety in these cities were USD 8.4 million. For this reason, it becomes a priority for Colombian cities to develop tools to achieve casualties' reductions with limited budgets.

The paper addresses one of the challenges faced by Colombian cities, providing tools that enhance the policy-making processes in the road safety field. These tools are based on the transit police registers that include the localisation of each accident, which is quite useful with the Geographic Information System (GIS). The accident localisation through GIS allows creating maps in order to show which areas or road segments are most prone to serious accidents. Furthermore, a systematic application was developed to allow clever filtering of the accident and victims information, making possible to identify vulnerable users and potentially dangerous situations.

2. THEORETICAL BASES

2.1 GIS spatial analysis

The GIS platform is becoming a useful road safety tool. It permits to achieve a new level of analysis through spatial information. Location of the accident is enhanced by the characteristics of the place where it occurs such as road information, socio-economical variables, traffic flows, among others. This link between spatial data and characteristics of the place allows to "identifying contextual associations that conventional studies of individual road sections would miss" (Jones et al., 2008).

It is important to point out that the advantages of GIS technology not only remains on the new information, but also on how this information is being used. GIS based systems permits "quick access for obtaining information, data storage, output and integrity" (Erdogan et al., 2008).

The link made by GIS between spatial data and characteristics of the place allows to know how invest the resources efficiently in terms of road safety, as shown in (Vandenbulcke et al., 2009), where the risk of people who use cycle to work in Belgium was analysed, concluding that "there are strong spatial differences (regional and between different types of towns) in bicycle use and the risk of an accident. This suggests that cycling policies should be spatially differentiated." Likewise, GIS tools allow identifying where are the accidents concentrated for "determining effective strategies for the reduction of high density areas of accidents" (Tessa, 2009).

GIS platform is not only an efficient tool for road safety research, but also useful to decision-making process. It allows that decision makers and transit agencies can “retrieve, analyse and display the accident data and spatial characteristics of this data” (Erdogan et al., 2008). Furthermore, this tool permits that the decision makers can analyse the road safety situation from general to specific scale (Liang et al., 2005).

2.2 Risk maps and black spots

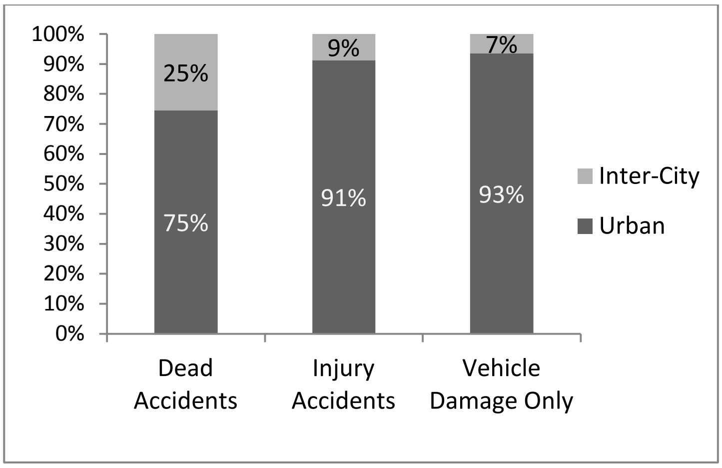
The use of GIS applications to geo-referenced accidents in road sections (or zones) allows identifying specific points with greater risk, known as black spots. In concordance with the classical definition, this term refers to a road location of limited area with a high concentration of accidents (PIARC, 2004). Identifying black spots through risk maps is a convenient tool for developing countries with high rates of road accidents such as Colombia. Intervene a black spot is usually seen as a highly profitable action in terms of accident reduction and cost-effectiveness (PIARC, 2004). Many countries have successfully implemented programs based on the black spot treatment, like the Black Spot Programs in Western Australia with a benefit-cost ratio of 4.9 (Meuleners et al., 2008).

As shown earlier, risk maps can be seen as an effective tool of channelling resources to specific points with higher possibilities of considerable accident reductions. Nevertheless, this is not the only advantage; risk maps can also show what kinds of investments are required in each black spot (or black spot group).

In the current study, as stated earlier, a computer application was created to generate risk maps, which permits analyse the accidents' localisation based on the information taken from National Transit Police reports. This data includes important variables such as accident conditions, involved actors, time of occurrence, vehicle features, and victim's characteristics. Based on the maps results, a methodology to help the decision makers about where and how to invest the resources was developed, as explained further in Chapter 4.

3. CONTEXT

Most of the traffic accidents in Latin America occur in cities. Despite this being a problem of public health, social and economic impact, there is no substantial experience in urban areas. Inter-American Development Bank (IDB) has proposed citywide strategies to decrease number of accidents (IDB & Universidad de los Andes, 2011). Focusing on the analysis of road accidents as a major Colombian issue, the government has become aware of the need to intervene areas with greatest concentration of road accidents. In 2010, most of the accidents occurred in Colombia took place in urban areas (approximately 68,862 road accidents with at least one injured, which represent the 91% of the total).



Analysing the number of accidents in the year 2010 by its severity, it can be seen that this phenomenon is concentrated in the urban area, representing 75%, 91% and 93% for accidents with dead, injured and vehicle damage only, respectively.

Figure 1 – Accidents in urban and non-urban areas
Source. Based on (CFPV & Universidad de los Andes, 2012a)

The number of victims is another aspect analysed within risk maps. In 2010, victims were concentrated in urban areas, accounting for 61% of deaths and 87% of the injured (CFPV & Universidad de los Andes, 2012a).

A recent analysis shows some of the weaknesses of local institutions to tackle road accidents: lack of prioritising, poor intersectoral cooperation, scarce technical and financial resources, and no clear targets or investment strategies (CFPV & Universidad de los Andes, 2012b).

Keeping in mind the problem described above, for the current study we choose four main Colombian cities where the 17% of the national deaths in traffic accidents and the 21% of serious injuries are located (CFPV & Universidad de los Andes, 2012a). The main indicators of these cities are shown in Table 1.

Table 1 – Main road safety indicators of four Colombian cities in 2010

City	Population[a]	Deaths in Traffic Accidents[b]	Serious Injuries in Traffic Accidents[b]	Deaths per 100,000 inhabitants	Serious Injuries per 100,000 inhabitants
Bogotá	7,363,782	522	3,162	7	43
Medellín	2,343,049	278	2,527	12	108
Barranquilla	1,186,412	62	896	5	76
Bucaramanga	524,030	66	1,492	13	285

Source. [a] Based on (DANE, 2011)
[b] Based on (CFPV and Universidad de los Andes, 2012a)

Each city has its own road safety budget, which is managed by the local Transport Authority. As it is shown in Table 2 and Table 3, the investments on road safety are only a small share of the city budget. The cost of accidents involving deaths and serious injuries was around USD 510 million for these four main cities. This number is really significant and quite high compared with the part of the budget invested on road safety by these four cities, USD 8.4 million (CFPV & Universidad de los Andes, 2011, 2012b).

Table 2 – City general budget comparing with road safety investment budget

City	Bogotá	Medellín	Barranquilla	Bucaramanga
Population[a]	7,363,782	2,343,049	1,186,412	524,030
City general budget[b]	$ 6,075	$ 1,705	$ 882	$ 293
Budget on investment on road safety[b]	$ 5.7	$ 1.5	$ 1.1	$ 0.1
Proportion of the city budget spent on road safety[b]	0.1%	0.1%	0.1%	0.0%

Millions of U.S. dollars on 2010
Source. [a] Based on (DANE, 2011)
[b] Based on official city budget

Table 3 – Transport Authority budget comparing with road safety investment budget

City	Bogotá	Medellín	Barranquilla	Bucaramanga
Transport Authority budget[a]	$ 176	$ 38	$ 17	$ 9
Proportion of the Transport Authority budget spent on road safety investment	3.2%	4.0%	6.4%	0.7%

Millions of U.S. dollars on 2010
Source. [a] Based on official city budget

As shown on Table 2, the mean proportion spent by these four cities on road safety is 0.1% of the city budget. This could be seen as evidence of the lack of importance given to traffic accident situation.

4. METHODOLOGY

Based on traffic accident information provided by the Colombian Transit Police, maps were created to show the problematic on road safety through serious accident risk in the four cities previously selected. These maps were developed on three spatial scales. First scale involves districts, which are the main city political divisions. Second one is the zone scale called UPZ´s, which are districts subdivisions. Finally, is the road network scale, where the unit of measure is a road section of 100 meters on average. In UPZ's and districts, accidents were standardised by each 10,000 inhabitants.

4.1 Risk concept

Within the spatial information provided by the maps a risk concept was developed, defining which zones or road sections are more vulnerable for a serious accident to occur. The definition of risk used on this project is: the probability that a road section or zone will have a greater number of accidents than a reference value (Nr). The case of study took into account only accidents with victims, seriously injured and/or death. In this kind of events is intuitive to suppose that every accident is independent from each other, and occur at instants of time randomly. Having regarded the previous supposition, a probability model was chosen, which uses the Accumulated Poisson Function for predicting the risk level as shown in Equation 1.

$$P(N > Nr, t) = 1 - P(N \leq Nr, t) \quad (1)$$

$$= 1 - \sum_{i=1}^{Nr} P(N = i, t) = 1 - \sum_{i=1}^{Nr} \left[\frac{1}{i!} (\mathrm{Nt})^i \exp(-\mathrm{Nt})\right]$$

Where:

N = Number of accidents in a period of time.
Nr = Reference number of accidents.
t = Period of time (in this case is equal to 1 year).

This probability was divided in five ranges that are represented in a scale of five colors, as shown on Table 4.

Table 4 – Risk ranges

Level of Risk	**Probability**	**Color**
Very Low	0 % < X ≤ 20 %	Green
Low	20 % < X ≤ 40 %	Yellow
Medium	40 % < X ≤ 60 %	Orange
High	60 % < X ≤ 80 %	Red
Very High	80 % < X ≤ 100 %	Black

Reference value (Nr) is a critical variable that determines the proportion of road sections or areas in each probability range. The current study guarantees the minimum dispersion using the least squares method as shown in Equation 2. This calculus shows that the optimal Nr for road sections is 2 accidents, and for zones are 5 accidents for each 10,000 inhabitants.

$$\min(d_i) = \min\left(\sqrt{(f_{0i} - pc_i)^2 + (f_{1i} - pc_i)^2 + (f_{2i} - pc_i)^2 + (f_{3i} - pc_i)^2 + (f_{4i} - pc_i)^2 + (f_{5i} - pc_i)^2}\right) \quad (2)$$

Where:

di = Dispersion value for a Nr = i

f0i = Number of road sections or zones which have 0% of probability to show Nr = i accidents.

f1i = Number of road sections or zones which have 0 % < X ≤ 20 % probability of showing greater than Nr = i accidents.

f2i = Number of road sections or zones which have 20 % < X ≤ 40 % probability of showing greater than Nr = i accidents.

f3i = Number of road sections or zones which have 40 % < X ≤ 60 % probability of showing greater than Nr = i accidents.

f4i = Number of road sections or zones which have 60 % < X ≤ 80 % probability of showing greater than Nr = i accidents.

f5i = Number of road sections or zones which have 80 % < X ≤ 100 % probability of showing greater than Nr = i accidents.

pci = Average value between f0i, f1i, f2i, f3i, f4i and f5i.

4.2 Building risk maps

Maps were developed for each city based on risk definition, showing the zones or road sections that require priority intervention. A summary of the building risk maps procedure is shown below.

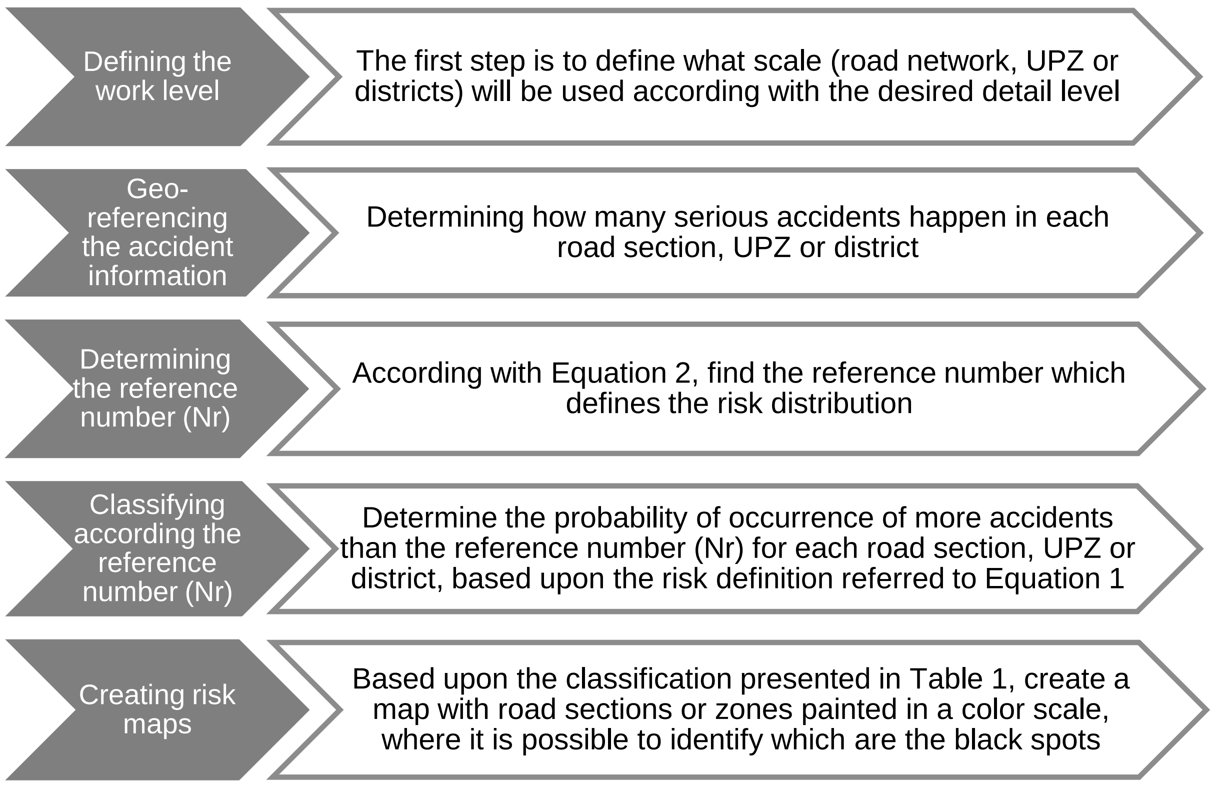


Figure 2 – Methodology for creating risk maps

4.3 Prioritising and treatment recommendations

The whole process of building risk maps was automated in a computer application, which contains the entire geographic data and the accident reports information. This application allows that the decision maker could see where the black spots are located and their main characteristics.

From the perspective of the previous ideas, a methodology was created to facilitate the decision making process as it is shown on Figure 3. It begins with the selection of the road sections that are going to be intervened; the decision makers have to choose a target, for instance the number of road sections to intervene or the acceptable level of risk for these road sections. Based upon the target, the computer application provides the information needed to estimate the reduction of accidents and the economic benefits. Afterwards, it is possible to create indicators providing enough information of areas (UPZ or districts) needing priority intervention.

After specifying the road sections, the following step is to determine which of the possible interventions are adequate for each segment. The computer application provides the user all the accident information about a particular road section. Furthermore, it is possible to create maps with specific filters showing how the accidents are distributed according to time periods, actors involved and victims' characteristics.

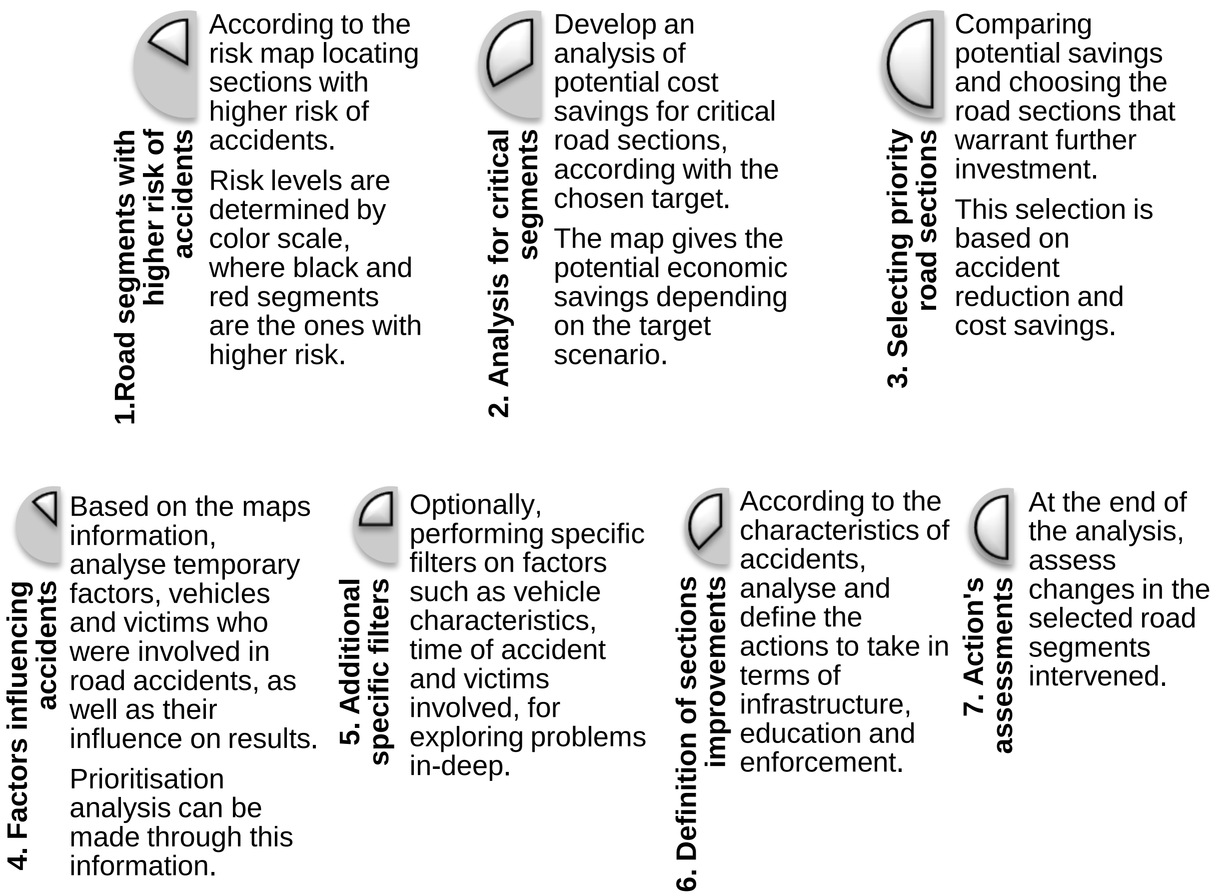


Figure 3 – Prioritising treatments methodology

In addition to the methodology described above, it is possible to emphasise actions by vulnerable road users. It means the same procedure can be performed only on accidents involving only pedestrians, cyclists or motorcyclists.

5. RESULTS AND ANALYSIS

The process described in Figure 3 was applied to the Bogotá case, where the probability calculus overall showed that the reference number (Nr) is 2 accidents per road section. Figure 4 shows the map generated for a specific district of Bogotá, where is possible to observe the risk for each road section.

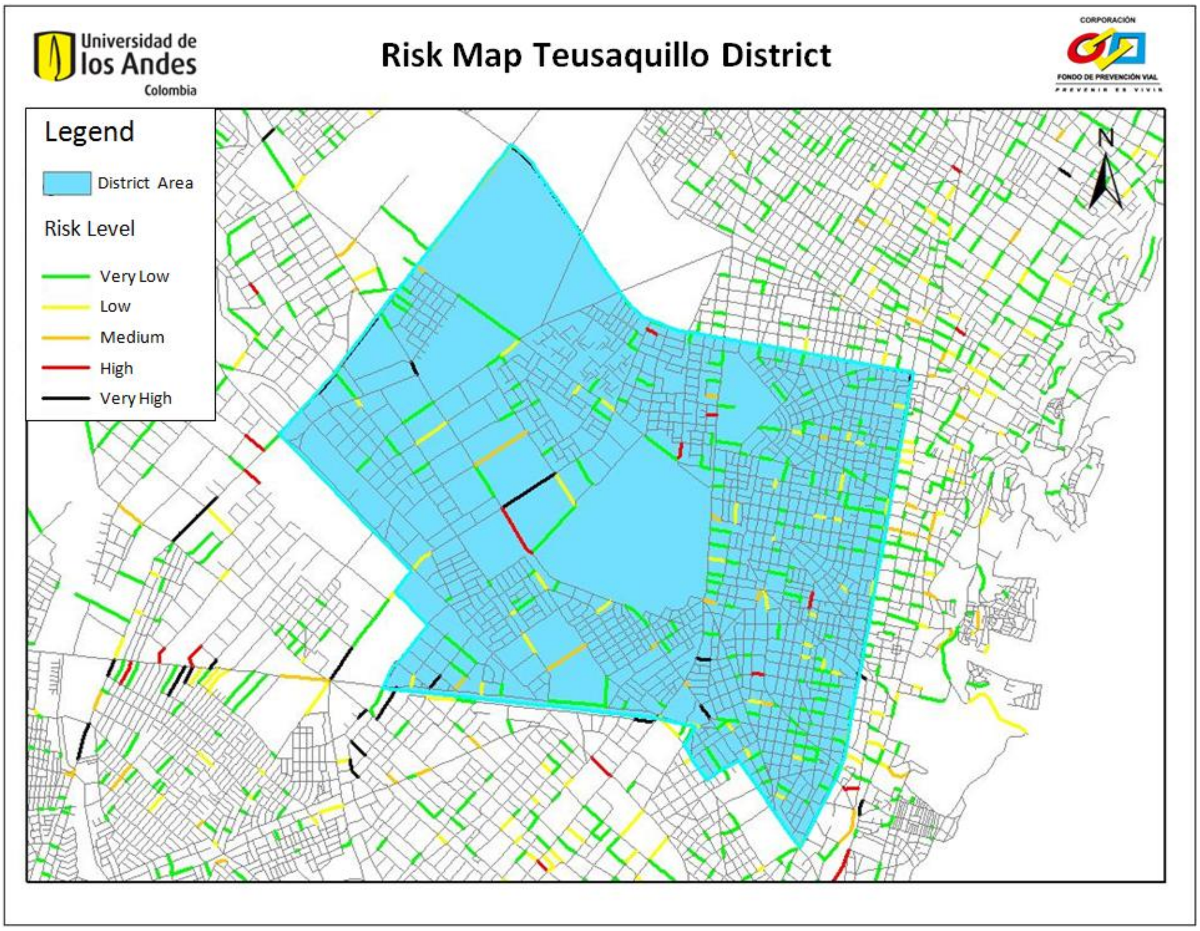


Figure 4 – Risk Map - Teusaquillo District (Bogotá)

On this case, it was proposed that the road sections that should be intervened were the ones with high (red) and very high (black) risk of accident, and the target scenario was to become them into low risk (green). According to the previous statement, the following results were generated.

Table 5 – Current situation

Risk Level	Road Sections	Number of Serious Accidents	Average Serious Accidents per Road Section	Accident Cost per Road Section	Total Cost
-	102,749	-	-	-	-
Very Low	3,634	3,634	1.0	$ 0.02	$ 83
Low	919	1,838	2.0	$ 0.05	$ 47
Medium	363	1,089	3.0	$ 0.08	$ 28
High	141	564	4.0	$ 0.11	$ 15
Very High	219	1,570	7.2	$ 0.18	$ 40

Millions of U.S. dollars on 2010
Source. Authors' calculations based on (CFPV and Universidad de los Andes, 2011, 2012a)

Table 6 – Target scenario

Risk Level	Road Sections	Number of Serious Accidents	Average Serious Accidents per Road Section	Accident Cost per Road Section	Total Cost
-	102,749	-	-	-	-
Very Low	3,634	3,634	1.00	$ 0.02	$ 83
Low	919	1,838	2.00	$ 0.05	$ 47
Medium	363	1,089	3.00	$ 0.08	$ 28
High	141	141	1.00	$ 0.02	$ 3
Very High	219	219	1.00	$ 0.02	$ 5

Millions of U.S. dollars on 2010
Source. Authors' calculations based on (CFPV and Universidad de los Andes, 2011, 2012a)

Table 7 shows how, in the Bogotá case, the target scenario could produce economic savings of USD 47 million only with intervention of 360 road sections that generates a substantial accident reduction (20%).

Table 7 – Target scenario results

Number of serious accidents - current situation	8,695
Number of serious accidents - target scenario	6,921
Reduction percentage	20%
Economic savings	$ 47
Road sections intervened	360
Economic savings per road section	$ 0.13

Millions of U.S. dollars on 2010
Source. Authors' calculations based on (CFPV and Universidad de los Andes, 2011, 2012a)

As a result from all districts of Bogotá, information shown on Table 7 shows the economic benefits of the intervention. Next step is to define which districts should be prioritised, using the previous analysis for each district with the same target scenario.

Figure 5 shows that accident distribution is not uniform. The same target scenario produces an average reduction of 20% with a standard deviation of 9%. Based upon these results, it is possible to observe that some districts would have accident reductions over 30%, while others districts would have a reduction less than 10%.

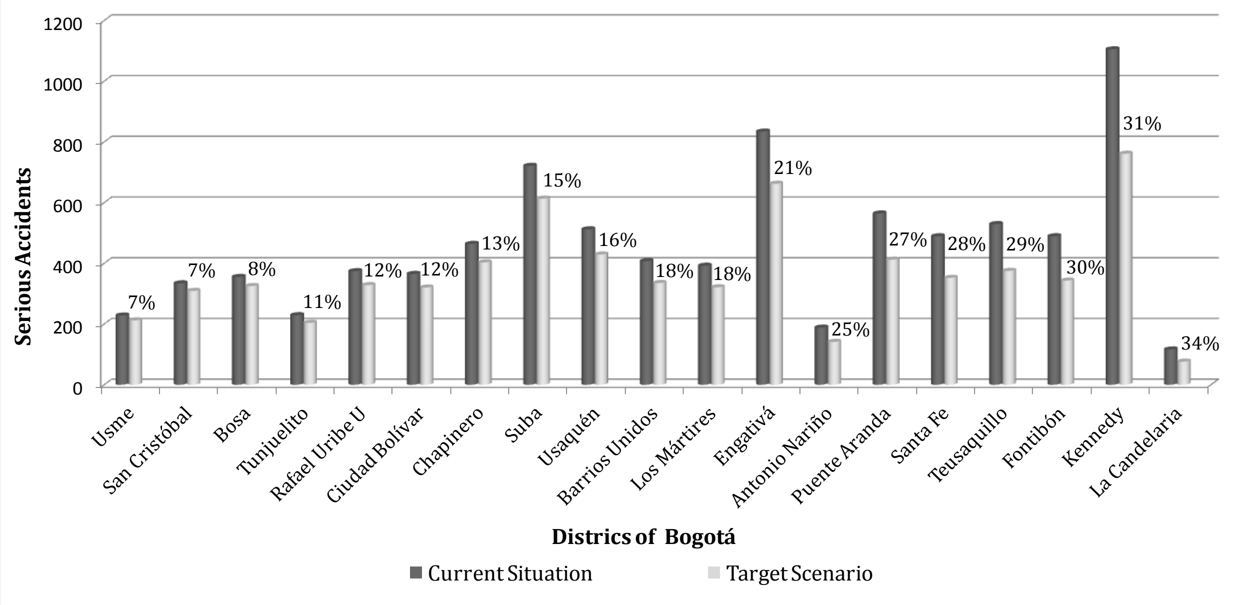


Figure 5 – Districts accident reduction
Source. Authors' calculations based on CFPV and Universidad de los Andes 2012a

Finally, according with the serious accidents cost (CFPV & Universidad de los Andes, 2011), a ranking was made with the economic savings generated by the target scenario. Figure 6 shows that road segments with higher accident risk are concentrated in few districts that generate economic savings far above average.

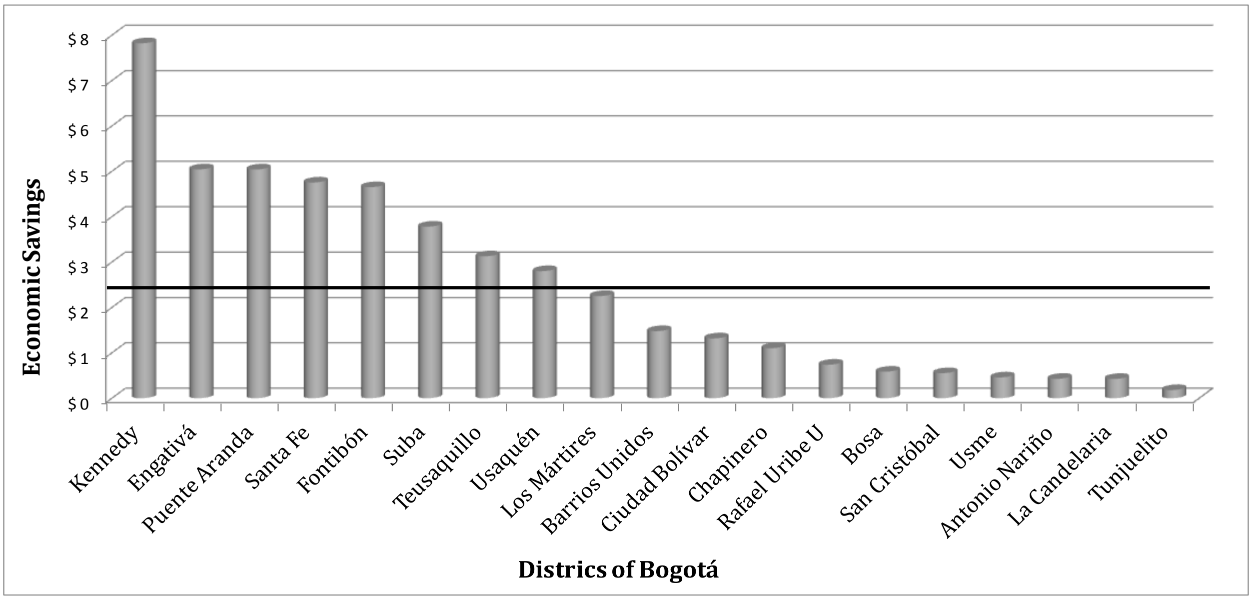


Figure 6 – Districts economic savings
Millions of U.S. dollars on 2010
Source. Authors' calculations based on CFPV and Universidad de los Andes (2011, 2012a)

Next steps would depend on a deeper analysis, based on the specific road segments that the decision maker chooses to improve. This kind of analysis can help the decision makers to optimise, from a technical perspective, the distribution of road safety investments on the cities.

6. CONCLUSIONS

This paper provides a valid and comprehensive conceptual framework about the phenomenon of traffic accidents, supported by tools that make it applicable to any city. The set of analyses and maps developed are useful to establish investment priorities.

Risk maps show the places that should be studied, but does not describe, necessarily, the whole phenomenon or its causes. Therefore, the maps should not be taken as the only source of information for policy making of traffic accidents' issues.

This project provides a tool to enhance the decision-making processes of road safety investments in Colombia. It is responsibility of the decision makers to establish a target in order to identify priority zones or road sections, through a process of interaction between accident risk maps, the application of specific filters and the analysis of potential economic savings.

Risk maps, by itself, do not offer a solution to the problem of traffic accidents in an urban area; however it is a useful tool for decision makers who are in charge of distributing the investments to identify and focus on critical zones or road sections in order to obtain the maximum benefit. Furthermore, is important to have accurate information in order to obtain factual results of the analysis, helpful to explain and describe the phenomenon correctly.

ACKNOWLEDGEMENTS

This research paper is the result of a project funded by "Corporación Fondo de Prevención Vial" in Colombia, aimed at developing new tools to improve road safety investment decisions in Colombia. The authors express their gratitude to them.

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