ROAD SAFETY AUDIT IN BRAZIL

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ABSTRACT

Road accidents are one of the biggest causes of deaths in Brazil. However there are few technical works about the subject. One efficient solution to reduce accidents is investments in engineering, but the resources are limited. The road audit, developed in this work, is a good way to prioritize engineering actions. It consists on a survey, with independent character, in which component attributes of the security are analyzed with its eventual deficiencies, assisting the choice of solutions. In this study, each one of the used attributes are clarified as well as its scales, its form, and the calculation method of the Index of Potential Security (IPS). From the assessment of a highway, the potential security and its degree of homogeneity are evaluated. Considering one attribute, the performance of several roads (benchmarking) are compared, showing which ones have better performance. Finally, we evaluate the gap between the priority of improvement of this attribute in different roads to the amount of resources invested in it by checking the effectiveness of financial effort.

Keywords: Audit; Road Safety; Potential Safety Index.

RÉSUMÉ

Accidents de la route sont l'une des principales causes de décès au Brésil. Cependant, il existe peu d'ouvrages techniques sur le sujet. Une solution efficace pour réduire les accidents sont les investissements dans l'ingénierie, mais les ressources sont limitées. La vérification de route, développé dans ce travail, est une bonne façon de prioriser les actions d'ingénierie. Il se compose d'une enquête, avec un caractère indépendant, dans lequel le composant attributs de la sécurité sont analysés avec ses défauts éventuels, en aidant le choix des solutions. Dans cette étude, chacun des attributs utilisés sont précisés ainsi que ses écailles, sa forme, et la méthode de calcul de l'indice du potentiel de sécurité (IPS). De l'évaluation d'une route, le potentiel de sécurité et son degré d'homogénéité sont évalués. Considérant un attribut, la performance de plusieurs routes (benchmarking) sont comparés, montrant quels sont ceux qui ont un meilleur rendement. Enfin, nous évaluons l'écart entre la priorité de l'amélioration de cet attribut dans différentes voies à la quantité de ressources dont il est investi en vérifiant l'efficacité de l'effort financier.

Mots-clés: Audit; Sécurité Routière; Indice du Potentiel de Sécurité.

1. INTRODUCTION

Traffic accidents are one of the biggest problems in Brazilian urban systems and roads.In 2005, there were 385,000 accidents with casualties in the country, accounting for the injury or death of 549,000 people [1]. This picture shows only a portion of the actual numbers of accidents in Brazil, as there is a high rate of underreporting in statistics, with 30 to 60% higher than the official figures [1].

In this scenario, road safety issue becomes highly reviewed, but the technical studies are still incipient in the country. This road safety is basically composed of three major elements that are supervision, education and engineering. Among these three elements, engineering is the one in which actions are faster and more efficient, but with a high cost. Currently, due to limited resources for investment even by public agencies, the detection of investment priorities is essential for the proper administration of the highways [2].

One of the best ways to prioritize investments in road infrastructure is through road safety audit. It consists of a preventive action to survey potential vulnerable points where engineering aspects should be improved. Therefore, this paper aims to develop, implement and describe the results of a road safety audit in a case study conducted in Brazil.

2. ROAD AUDIT

Road Safety Audit aims to identify deficiencies in the conditions of a project or of a road in operation, raising measures for preventing accidents or reducing their severity [3]. This survey has an independent character and is audited impartially and by a different team and not the one that carried out the design and improvement works. In turn, the design team is capable of finding solutions to problems identified by the audit team.

Audits in roads in operation include inspections by day and night and should consider climatic variations in the area. Carrying out regular surveys allows the identification of new risk situations and their correction before they result in accidents. The audit at the stage of operation seeks to identify and resolve safety deficiencies still not known and not revealed by accident data, giving it a status of pro-active [3].

In England, the Department for Transport has made road safety audit mandatory since 1991 [3]. In Australia, the audit road was inserted in 1994 by the Road Safety Audit Guide [3], emphasizing the issue of reducing fatalities. In New Zealand, a set of audit procedures highway was implemented in 1993 [3]. Other countries like Denmark, United States and Canada have included in their routine the practice of auditing.

Morgan [3] comments that the achievement of road safety audit is an element of legal defense, stating that those responsible for the project have not neglected the issue of security. Furthermore, it is seen as a means of reducing processes, since it avoids the occurrence and severity of claims.

Finally it is possible to enumerate the benefits of conducting road safety audits: increased security, improved techniques and safety practices, improving standards and norms relevant to the needs of vulnerable road users, reducing costs related to accidents; road improvement project, encouragement of safety culture [3].

2.1. Attributes and their weights

To perform the kilometer-based Road Audit it is necessary the survey of the engineering characteristics to be evaluated by technical inspector. In this paper, the characteristics or attributes were selected from the study by Nodari[3] and authors' expertise. Thus, among the nine macro-attributes and 34 attributes proposed in the landmark study, 14 attributes were selected and the nine macro-unique attributes were maintained. When reducing the amount of aspects to be measured, the survey becomes more dynamic without losing their technical accuracy. The macro-attributes (letters) and attributes (numbers) were assessed as follows:

• A) Surface: This refers to the condition of the pavement. The problems in the roadway surface decrease the security of the site.

1) Holes in the Surface: It measures the existence of potholes and shoulder (Scale: grade 10= no holes; grade 7 = eventual holes; grade 3 = frequent holes; grade 1 = constant holes.
2) Gravel in the Roadway: It measures the occurrence of scattered debris on the roadway (Scale: grade 10 = clear roadway; grade 7 = possible existence of gravel; grade 3 = frequent existence of gravel; grade 1 = constant presence of gravel).

• B) Curves: It involves the evaluation of curves in the road stretch assessed.

3) Curves: The occurrence of curves decreases road safety (Scale: grade 10 = no curve; grade 7 = existence of curve without reducing speed; grade 3 = presence of the curve, with moderate speed; grade 1 = existence of the curve, with sharp reduction of speed).

• C) Intersection: This is the existence of intersections (crossings) measured in km.
4) Intersection Design: The intersections with other highways and trunk roads creates problems of road safety, so the quality of the design of intersections is essential (Scale: grade 10 = no intersection; grade 7 = the intersection exists, but it is well-designed, grade 3 = intersection with regular project; grade 1 = there is a poorly designed intersection.

• D) Signaling: it consists of the aspects of existing road signs. The better the signaling, the greater the safety of local roads is.

5) Horizontal Painting: It refers to the pavement paint (Scale: grade 10 = lines very visible; grade 7 = lines note faded lines; grade 3 = line visible in some areas and absent in others; grade 1 = no lines);
6) Reflective Tacks: It measures the condition of the existing tacks, and its reflective surfaces [4] (Range: grade 10 = tacks ever present and with good reflectivity, and/or bigger tacks in good condition and good reflectivity; grade 7 = tacks and existing bigger tacks in hazardous locations and in good condition and good reflectivity; grade 3 = tacks and bigger tacks barely visible; grade 1 = nonexistent tacks norbigger tacks).
7) Vertical Signaling: It evaluates the existence and condition of road signs (Scale: grade 10 = sings with correct messages, correct placement, quantity, conditions and premises; grade 7 = minor deficiencies in the messaging, positioning, quantity, condition and location of the signs; grade 3 = moderate disability in messaging, positioning,

quantity, condition and location of the signs; grade 1 = major deficiency in the messaging, positioning, quantity, condition and location of the signs.

• E) Longitudinal element: it assesses the degree of safety offered by a developed aspect of the axis.
8) Overtaking: It assesses the ability to overtake with the safety specified by the signs. The greater the possibility of overtaking, the greater the road safety is (Scale: grade 10 = constant opportunities for safe overtaking; grade 7 = frequent opportunities for overtaking; grade 3 = possible overtaking opportunities; grade 1 = no chance of overtaking).

• F) Cross Section: It measures the degree of safety offered by items related to the cross design (cutting section).

9) Track width and shoulder: It measures the adequacy of the track width and shoulders. The larger the width, the safer the highway (Scale: grade 10 = width of the track and shoulder appropriate according to the class of the road – usually track with 3.5 m or more and shoulder at 2.5 m or more; grade 7 = good track and narrow shoulder in accordance with the class of the highway; grade 3 = narrow track and shoulder; grade 1 = narrow track and no shoulder.

• G) Vulnerable Users: Ir records the presence of unprotected transients in the area of the roadway.

10) Cyclist and Pedestrian: It evaluates the existence of vulnerable servers on the highway. The greater the presence of cyclists and pedestrians, the less safety on the highway (Scale: grade 10 = no presence of pedestrians nor cyclists in the vicinity of the area; grade 7 = existence of pedestrians and cyclists in the vicinity, but there is a shoulder or a way in good conditions for circulation; grade 3 = it shows pedestrians and cyclists in the vicinity, but there's the conditions of moving are bad; grade 1 = there are pedestrians and cyclists, yet there is no suitable way or shoulder for traffic).

• H) Highway edges: It assesses the safety conditions offered by the elements present in the highway edges.

11) Hazardous Elements: It indicates the occurrence of physical barriers in the right-of-way near the roadway that may exacerbate the consequences of accidents and off-track excursions, such as vegetation, poles, walls, billboards and homes. The greater the amount of these dangerous elements, less road safety in the area (range: grade 10 = 9 m free after the end of the shoulder; grade 7 = dangerous elements less than 9 m from the roadside, but they are protected by elements of containment (fenders); grade 3 = presence of elements unprotected less than 9 m from the right-of-way, but in small numbers; grade 1 = large number of unprotected elements less than 9 m from the sideroad).
12) Accesses: It shows the number of accesses (local streets, entrances to homes and businesses) along the right-of-way. The existence of accesses is a major cause of traffic accidents on highways (Scale: grade note = no access; grade 7 = sparse existence accesses; grade 3 = frequent existence of accesses; grade 1 = constant existence of access).

• I) General Elements: It refers to the existence of other items that influence the traffic safety that were not covered by

other macro-attributes.
13) Compatible Speed: It measures the adequacy of the permitted speed and the speed made. When speed is held above the permitted speed accidents end up happening (Scale: grade 10 = velocity done is appropriate with regard to the speed limit; grade 7 = the velocity is almost done properly at the speed allowed (up to 20% higher); grade 3 = speed is not compatible with the permitted speed (from 21% to 40% higher); grade 1 = speed is held incompatible with the permitted speed (above 40% up)).

14) Large Animals: It records the existence of large animals (cattle, horses, goats, sheep, capybara, etc.) in the right-of-way. The existence of animals circling near the road greatly increases the risk of claims (Scale: grade 10 = no animals near the road; grade 7: there are animals nearby, but all the land is surrounded; grade 3 = presence of animals nearby, and not all land is surrounded; grade 1 = loose animals are circling around the track or field).

After setting all the attributes to be measured and their ranges, it is necessary to define the weights of importance of each of these attributes. For assignment of weights, we used the survey conducted by Nodari[3] in which weights were assigned to four classes of professionals involved in the issue of road safety (National Expert, International Experts, Designers of Highways and Road Police). The average of these grades was made from the weight given by each of them (see Table 1).

Table 1 – Measured Attribute and Weights of Importance Assigned (Source: Nodari, 2003).

Category	Attribute		Nacional Experts	International Experts	Designers	Road Police	Average	Calculated Weights
A-Surface	1	Holes	0,216	0,154	0,225	0,203	0,200	5,09%
	2	Gravel	0,183	0,187	0,184	0,201	0,189	4,81%
B-Curves	3	Curves	0,195	0,189	0,190	0,203	0,194	4,94%
C-Intersection	4	Intersection Design	0,51	0,54	0,53	0,49	0,519	13,22%
D-Signaling	5	Horizontal Painting	0,178	0,172	0,181	0,171	0,176	4,48%
	6	Tacks	0,163	0,163	0,166	0,167	0,165	4,20%
	7	Vertical Signs	0,165	0,158	0,164	0,163	0,163	4,14%
E-Longitudinal Element	8	Overtaking Opportunity	0,359	0,328	0,346	0,336	0,342	8,72%
F-Cross Section	9	Track/Coasting	0,282	0,282	0,291	0,256	0,278	7,08%
G-Vulnerable Users	10	Cyclist/Pedestrian	0,500	0,475	0,491	0,488	0,489	12,45%
H-Highway Edge	11	Hazardous Elements	0,330	0,377	0,336	0,331	0,343	8,75%
	12	Access	0,327	0,327	0,337	0,335	0,331	8,45%
I-General Elements	13	Compatible Speed	0,272	0,259	0,285	0,262	0,270	6,87%
	14	Animals	0,266	0,250	0,285	0,270	0,268	6,82%

Considering the average grade of the 14 attributes, the weights were normalized so that their sum equals to total 100% (see column "Calculated Weights" in Table 1). As you can see, the attributes considered most important for ensuring road safety (greatest "Calculated weights"), in order of influence are as follows: "Project of Intersection" (weight equal to to 13.22%);"Cyclists and Pedestrians" (weight equal to 12.45%), "Hazardous Elements on the roadway" (weight equal to 8.75%), "Overtaking" (weight equal to 8.72%)and "Accesses"(weight equal to 8 45%).

2.2. Form Used

After defining the attributes, a form was set to be applied in field, as shown in

Figure 1.The form consists of a header with the following information: road; initial and final km; segment, date, time; and weather conditions. In the figure, there a gap to be filled with the 14 attribute related to each km surveyed. Below the questionnaire there is a brief description of the numerical scales of each attribute in order to make easier the filling.

3 SAFETY ROAD INDEX

Here we try to calculate the Safety Index (IS_{km}) of the kilometers evaluated, as well as the Safety Index for the entire road (IS_{Road}). The first step is the calculation of the IS km.
The first step for the calculation of IS km is to evaluate all 14 the attributes for each road kilometer. After this evaluation, the IS km of each kilometer is calculated by Equation 1:

$$IS_{km} = \sum N_n * P_n \quad (1)$$

where IS_{km}: potential safety index of the km segment;
N_n: evaluated grade to the attribute [range from 1 to 10];
P_n: attribute weight n.
n: attribute 1 to 14.

After calculating the Security Index for each km, the Safety Index of the Road should be calculated. The calculation of this index is obtained by the geometric average of the Safety Index of each kilometer (see Equation 2). According to Nodari [3], the use of the geometric average to obtain the Safety Index of the Road aims to focus on road segments more homogeneous with regard to safety. It seeks to penalize the segments alternating good and poor safety.
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$$IS_{Road} = \sqrt[w]{IS_{km\,1} * IS_{km\,2} * IS_{km\,3} * \cdots * IS_{km\,w}} \quad (2)$$

where IS_{Road}: potential safety of the road index;
$IS_{km\ 1\ a\ w}$:index of potential safety of each of the "w" km;
w: total length of the road (in km).

Roads with a IS_{Road} lower than 5 points are considered unsafe; those with a score between 5 and 8 points are considered as reasonably safe, and roads with overall score above 8 are called safe (see Table 2).

Table 2 – Classification of Safety Level of the Road.

(red)	$0<PSI_{Roadway}<5$	Unsafe
(yellow)	$5<PSI_{Roadway}<8$	Reasonably Safe
(green)	$8<PSI_{Roadway}<10$	Safe

AUDIT ROAD SAFETY SPREADSHEET

Report:

Initial km: ____ Roadway: ____ Date: ____ Hour: ____

Final km: ____ Stretch: ____ Weather Conditions: ____

		stretch: (initial km / final km)																											
surface	1	Holes																											
	2	Gravel																											
curves	3	Curves																											
inters.	4	Intersection Design																											
signaling	5	Horizontal Painting																											
	6	Tacks																											
	7	Vertical Signs																											
long elem	8	Overtaking Opportunity																											
cross sect	9	Track/Coasting																											
vulner. users	10	Cyclist/Pedestrian																											
highway edge	11	Hazardous Elements																											
	12	Access																											
gen. Elem.	13	Compatible Speed																											
	14	Animals																											

10	**QUESTIONNAIRE ITEMS**	**1**
absent ←	1-Holes	→ constant
absent ←	2-Gravel	→ constant
absent ←	3-Curves	→ strong speed reduction
absent ←	4-Intersection Design	→ poorly designed
visible lines ←	5-Horizontal Painting	→ absent
always present ←	6-Tacks	→ absent
appropriate ←	7-Vertical Signs	→ very deficient
const. opportunities ←	8-Overtaking Opportunity	→ absent
appropriate ←	9-Track/Coasting	→ narow, no coasting
absent ←	10-Cyclist /Pedestrian	→ no coasting
9m free ←	11-Hazardous Elements	→ many unprotected
absent ←	12-Access	→ constant
appropriate ←	13-Compatible Speed	→ incompatible
absent ←	14-Animals	→ on the road

Figure 1 – Form to Data Survey (adapted from Nodari, 2003).

The level of homogeneity of the Potential Safety Index along a roadway determines its level of consistency with regard to safety. The greater the degree of homogeneity, the safer the road becomes once it does not require abrupt changes in behavior of its drives. Homogeneity level can be measured by the Standard Deviation of Potential Safety Index of the kilometers that make up the segment evaluated according to Table 3.

Table 3 – Level of Homogeneity of Potential Safety of a Road.

Classification	**Standard Deviation**
Very Homogeneous	≤ 0,5 points
Homogeneous	From 0,51 to1 point
Heterogeneous	From 1,01 to 1,99 points
Very Heterogeneous	≥ 2 points

The field survey was conducted by road technicians, specialists in transportation area and outside project and area works, so that they had advanced know-how about traffic engineering and kinematics. The auditor traveled in the passenger seat, aided by a driver. In the first days of data collection it was more difficult to fill the sheets, but after some practice, the work became more productive. Because of the fatigue, it was found that one single auditor can collect data in a proper way of no more than 100 km per day. Therefore, the audit average is 18-20 km per hour (totaling 5-6 hours of work per day).

We evaluated seven real roads identified by letters once their identifications were preserved. The first road to be audited was the Road X because it involves rural and urban areas, serving as a good model for any adjustments to the form. The survey began on April 24, 2009. The second road to be audited was the Road Y (on the same day of the Road X). The third road was the Road Z, on May 13, 2009. The fourth road evaluated was Road K on May 20, 2009. The fifth segment road was Road V on June 3, 2009. The penultimate evaluated assessed road was Road W, traveled in two days (August 4 and September 5, 2009). The closing of the road safety audit took place on Road Q, also on September 5, 2009.

4 FIELD SURVEY AND ANALYSIS

4.1. Analysis by Roadway

As an example of analysis, the Roadway Q will be used because of it is basically rural and has low traffic flow.The attributes detected with better performance were (see Figure 2): “Intersections" (100% of the possibilities), "Horizontal Painting" (100%),“Track Width and Shoulders” (99%) and “Presence of Cyclists and Pedestrians” (99%). The parameters with lower grades are only “Overtaking"(39%) and "Hazardous Elements on the road” (51%). The actions to improve the conditions of overtaking have a high cost and are not possible because of the low traffic road; however actions to clear the right-of-way are prudent.

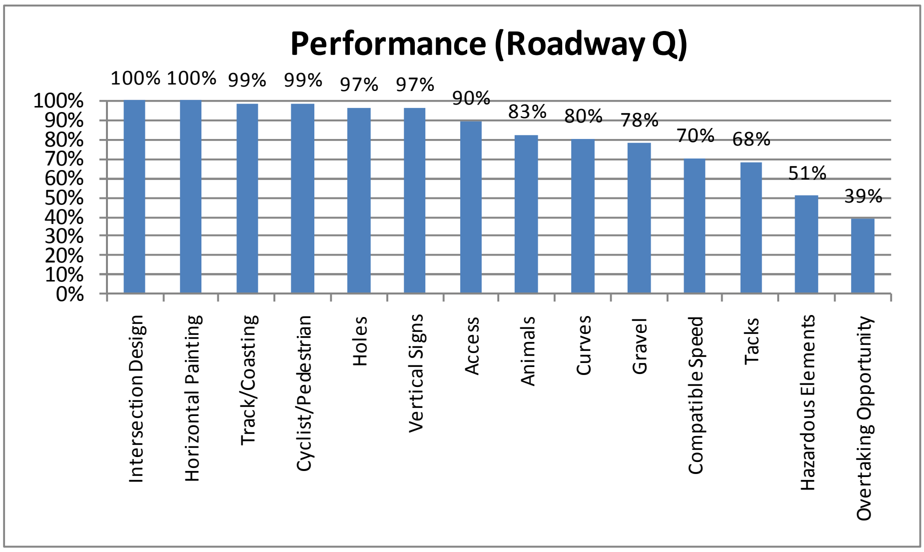

Figure 2 – Performance of the Attributes Evaluated in the Roadway Q.

This roadway is characterized as "safe" with a Potential Safety Index of the Road (IS_{Road}) equal to 8.22 (as the scale of Table 2). The distribution of the Safety Index over the kilometers is considered "homogeneous" (see scale in Table 3) with a standard deviation of 0.53 points and values ranging from 7 to 9 points (see Figure 3).

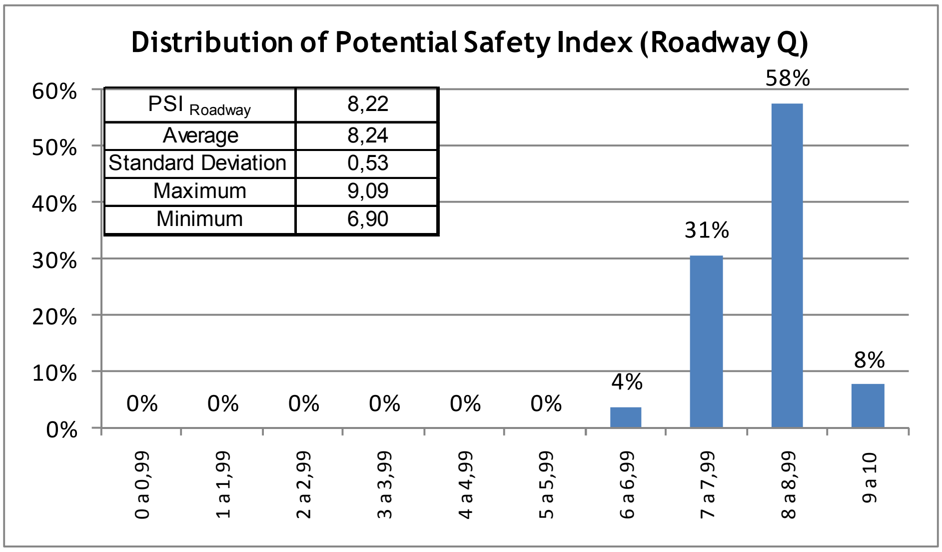

Figure 3 – Distribution of Potential Safety Index of Roadway Q.

Evaluating the Table 4, there is an inconsistency in the correlation between the amount of accidents and attributes, which results in positive values. This fact can be justified by the negligible number of accidents that occurred on this road, those arising from the randomness and human and environmental factors not measured by the audit.

Table 4 – Correlation between Accidents and Evaluated Attributes (Q Roadway).

Correlation Between Attributes	Holes	Gravel	Curves	Tacks	Vertical Signs	Overtaking Opportunity	Track/Coasting	Cyclist/Pedestrian	Hazardous Elements	Access	Animals	PSI km
Accidents (2007 - 1st Sem. 2009)	0,13	0,1	0,1	-0,2	-0,2	0,00	0,13	0,1	0	0,2	0,2	0,1

4.2. Analysis by Attribute (Benchmarking of the Roadways)

After analyzing all the attributes of a roadway (as item 4.1), it is possible to compare the performance of the seven roads which generates a ranking (benchmarking).The following is an example of comparison of performance using as example the attribute of "Vertical Signs". It is noted that the Roadway Q has the best performance (97% of 100%possible). The second-best behavior is of the Roadway W – 90%. The worst performance were of Roadway Z (66% of 100% possible) and the Roadway V (74%) (see Figure 4).

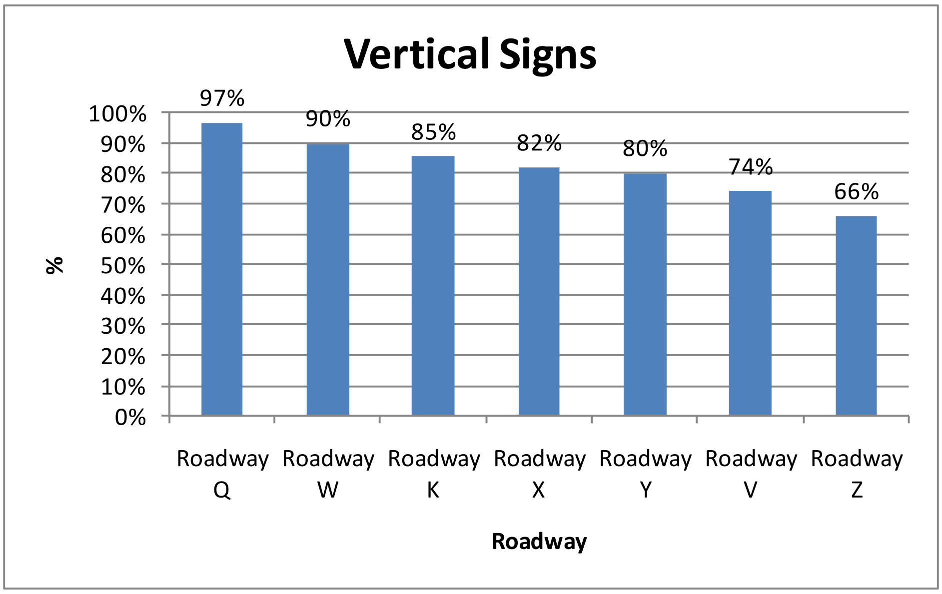

Figure 4 – Performance of Vertical Signaling.

Now, it will be conducted an analysis (gap) that crosses the priority of improving the attribute with the amount of investment made in the different roadways. To calculate this level of priority, the required percentage to achieve a 100% performance of the roadway is taken and is multiplied by the% extension of the same in relation to the total roads studied. Thus, the priority is given to places that need improvement and, at the same time, have greater extent. After, this result is normalized in a sum equal to 100% to make the analysis easier. To calculate the amount of investment, the money invested is simply distributes in percentage terms (in this case on road signs) for each roadway.

Figure 5 shows the analysis of the percentage of investment versus the need for investment in each roadway (assuming the attribute of vertical signs, so the *gap* (percentage difference between the two). Itis observed that the largest negative gaps (where the need is greater than the amount invested) are the Roadway Z (gap equal to -10%) and the Roadway V (gap equal to -7%). There are gaps where the positive percentage invested is greater than necessary, as in the Roadway W (equal to +14%) and Roadway Q (equal to 4%). Roadway X has only a percentage of investment in road signs consistent with their need (nil gap). This analysis shows that it is recommended to reassess the division of investment so that the gaps decrease.

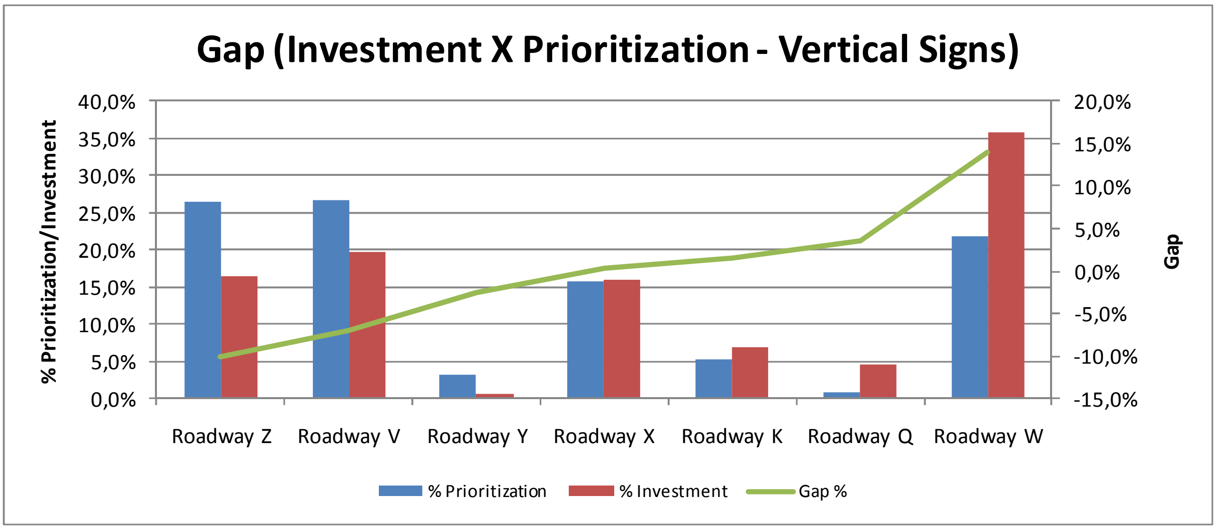

Figure 5 – Gap between Level of Improvement Priority and Investments Made.

5. FINAL REMARKS

The road audit is mandatory in several developed countries, but technical studies are still rare in Brazil. It has a proactive status in detecting problems before the occurrence of accidents. This is a strong element of defense in legal and regulatory issues, and an efficient tool to avoid costs with traffic accidents.

In this study, some aspects regarding the practical application of auditing road were found:
• The 14 attributes evaluated taken from Nodari's landmark study [3] were pertinent for the detection of road safety conditions;

• The attributes of greatest weight in the evaluation of the methodology in order of importance are: intersection design; presence of cyclists and pedestrians; hazardous elements on the road; places to overtake, and, availability of access;

• The model form used proved to be very practical and suitable for field surveys;

• The potential security indexes used (to kilometers and roadways) were effective, easy to calculate, and with scales consistent with reality;

• The degree of homogeneity of the potential safety created in this work can reveal problems of inconsistency in the safety of the roadways;

• The service of field audit is fairly productive, being held from 18 to 20 km per hour of survey work;

• The small number of road accidents with no correlation between the amount of accidents and potential safety index, is probably due to the influence of randomness and of human and environmental factors not measured by the audit. However, on roadways with higher number of accidents, there was a negative correlation between the number of accidents and potential safety index. That is, in this case, where there is a greater number of accidents, the potential safety index is lower;

• The audit method allows you to compare and rank the performance of several roads, or segments of road, as shown in the practical example developed;

• Analysis of gaps between the needs for improvement for each attribute and the percentage of resources invested in it helps managers to better distribute the costs, which benefits local inhabitants most deprived.

It was also found that the method has a high capacity for replication in other localities. However, we warn that the field survey, tabulate of the data and reporting expend considerable energy. Thus, for the Brazilian scenario, it is advisable to perform the audit practice at intervals of at least two years also because the necessary interventions that were detected require long-term to be made.

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