ROAD SAFETY INDICATORS IN THE MEXICAN FEDERAL HIGHWAY NETWORK

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ABSTRACT

This article shows the definition of the safety road indexes based on characteristics such as: number of lanes, length, transit and traffic accidents with victims in the sections of the Mexican federal highway network through a model which uses three parameters, exposure, risk of a collision happening and the consequences thereof [1]. To measure the exposure, we used transit, length and vehicles per kilometer; for the second and third parameters, the traffic accidents with victims from three consecutive years are used to avoid the effects of returning to the average and accident migration. By linking these elements, we obtained numeric values that are representative of the risk: hazard, mortality and morbidity rates; and the inverse value of weighing these three indicators resulted in different road safety indicators. Subsequently, the highway sections were grouped according to their function (primary, secondary and local) and type of highway, and comparisons were made between several road safety indexes in order to present a proposal of what the limits of this indicator for different types of highways would be.

1. BACKGROUND

For more than ten years, the Communications and Transportation Secretariat (SCT– *Secretaría de Comunicaciones y Transportes*) has registered the records of all the accidents that take place in the highways patrolled by the Federal Police (PF – *Policía Federal*), based on the Acquisition and Administration of Accident Data System (SAADA – *Sistema para la Adquisición y Administración de Datos de Accidentes*), created by this Institute and from which a statistical annual of accidents in federal highways is created. This annual collects and organizes the most relevant statistics and helps to guide all actions for the prevention and mitigation of its sequels. In addition, the SAADA allows a systematical combination and exploitation of all the information collected using a software program set.

For the annual, apart from obtaining the most important statistics, the accident, mortality and morbidity rates per vehicles-kilometer are also calculated. These last figures are national, and even though graphics for the 10 sections and 10 segments of 500 meters for each of the 32 federal entities with the highest number of accidents per kilometer are shown, it is understood that in this comparison the effect of the vehicular flow is not taken into consideration. Because of this, the need of generating road safety indicators that allow comparisons and define limiting values for the different types of highway sections according to their function and vehicular transit arises, thus allowing future annuals to show the sections and segments that exceed these values.

2. METHODOLOGICAL FRAMEWORK

2.1. Platform

The Federal Highway Network (RCF – *Red Carretera Federal*) in our country is 56,780 kilometers long, divided into 145 routes that are formed by 876 highways divided into 2,756 sections, which are in turn formed by 114,000 segments of 500 meters. A database for each level of aggregation and an identifier system based on the nomenclature of the Technical Services General Management (DGST - *Dirección General de Servicios Técnicos*) of the SCT was generated.

It was determined that for the analysis of this first approach, all data should fall into the level of 500-meter segments, since some of the information sources show data per each kilometer.

2.2. Incorporation of physical and operational data

There is a Regulation [2] and an Official Standard [3] regarding the weight, dimensions and capacity of transport vehicles traveling on the roads and bridges under federal jurisdiction. These documents classify all roads according to their geometrical and structural characteristics, dividing them into: Main roads (ET – *Ejes Troncales*), type A, B, C, and D. In this categorization the ET and type A roads allow circulation of all authorized vehicles with the maximum dimensions, capacity and weight, while for the rest of the roads restrictions related to the length and weight of the vehicles apply. Type D roads are the ones with the strongest restrictions since they do not allow the circulation of articulated vehicles. It is worth mentioning that only 73.3% of the RCF (41,645 km) is classified according to the previously mentioned regulation.

On the other hand, the General Highway Conservation Office (DGCC - *Dirección General de Conservación de Carreteras*) of the SCT uses a classification which has more to do with the road’s functionality, dividing the network into: Corridor, Basic and Secondary; as an addition to the type of network, it also provides information about the number of lanes [4]. Just as in the previous case, the DGCC has only classified 73.8% (41,877 km) of the RCF.

Additionally, the capacity and vehicular configuration that the DGST of the SCT registered from 2006 to 2008 were also incorporated to the segment platform [5 to 7].

Summarizing, a RCF segmented into 500-meter elements was obtained and the following were added to it: the regulation’s classification (ET, A, B, C, and D) and all data provided by the DGCC (type of network, number of lanes and physical condition) obtaining as a result a network of almost 34,000 kilometers with all the information available. This represents 59.8% of the RCF’s total; this is due to the fact that the network classified under the regulation is not necessarily the same one used by the DGCC.

It should be mentioned that since the DGCC only has jurisdiction over toll-free roads, all toll roads that represent about 13% of the RCF are not considered in this analysis.

2.3. Incorporation of accident data

With the purpose of minimizing the effects of returning to the average and accident migration that are common in accident analysis, the accidents occurred from 2006 to 2008 were considered [8]. The compilation of accident data for this period was satisfactory since a database which comprises 88,431 accidents was incorporated. This represents 97.9% of the total for the three years reported by the PF that is 90,340 [9 to 11]. Due to the fact that a procedure that guarantees the recording of the totality of the accidents is lacking, only the accidents with reported victims —i.e. only those accidents which reported dead and/or injured victims— were selected, thus obtaining a database of 48,087 accidents with a balance of 14,985 people dead and 94,050 people injured. Accident data was incorporated to each 500-meter segment in the same way that physical and operational data were added.

3. GENERAL ANALYSIS

Once the data was incorporated to the 500-meter segment platform, the first general analysis was made and the following graphics resulted from it: first, Table 1 shows the distribution of length (41,887 km with network type data) in percentages for each type of network based on the number of lanes and the classification of the weight and dimensions regulation. We can observe that 26% of the network is registered as a corridor, 34% as basic, and 40% as secondary. The corridor network is the most important one since it has a larger proportion of four-lane highways (33.58%), as well as roads classified as ET (72%), compared to the basic and the secondary networks in which two-lane roads represent more than 90%. The second to last line is labeled S/C (without classification); these segments correspond to those that have information about the type of network, but that are not classified in the regulation, and in this regard we can see that 2.01, 11.5 and 35.85% of the corridor, basic and secondary type network, respectively, are in that situation.

Table 1. The length road distribution, in percentage

LENGTH										
Type of Network		Corridor			Basic			Secondary		
Number of lanes		> 4	4	2	> 4	4	2	> 4	4	2
Road classification	ET	1.06	30.69	**40.49**	0.22	0.74	3.63	-	-	0.21
	A	0.02	0.64	8.37	0.01	0.69	5.08	-	-	2.48
	B	0.01	1.59	11.82	0.58	2.71	**34.96**	0.17	1.08	20.01
	C	-	0.30	2.99	0.05	1.30	27.75	-	0.13	12.87
	D	-	-	0.01	-	0.48	10.29	0.01	0.26	**26.93**
	S/C	-	0.37	1.64	0.21	1.48	9.81	0.02	0.79	35.04
Total		1.09	33.58	65.33	1.07	7.40	91.53	0.20	2.26	97.54
		25.53			***34.35***			***40.12***		

As a part of this general analysis, tables similar to the previous one were created with all data about accidents, deaths, injuries and vehicles-kilometer, and they are shown herein below. Out of the 48,087 accidents with victims selected from the database, 37,397 happened in 500-meter segments with information about the type of network, and their results show 11,451 deaths and 71,656 injuries. The rates shown in Tables 2, 3, 4, and 5 were obtained from these figures.

Table 2 shows percentages for the accidents with victims occurred from 2006 to 2008; in this table we can see that the concentration of accidents per type of network is 37, 41, and 22% for corridor, basic and secondary, respectively. In the particular case of corridors, four-lane highways, classified as ET, are the ones that concentrate the highest number of accidents with 47.33%; for the basic network, two-lane highways classified as C account for 26.95%; and for the secondary network, two-lane highways classified as D agglutinate 26.75% of collisions.

Table 2. The accidents with victims' distribution from 2006 to 2008, in percentages

ACCIDENTS										
Type of network		Corridor			Basic			Secondary		
Number of lanes		> 4	4	2	> 4	4	2	> 4	4	2
Road classification	ET	3.78	**47.33**	23.13	0.60	1.94	2.95	-	-	0.43
	A	0.04	0.42	6.93	0.01	1.66	5.82	-	-	2.38
	B	-	2.49	12.16	1.81	6.21	25.48	1.91	2.38	19.04
	C	-	0.74	1.10	0.03	3.98	**26.95**	-	0.89	14.45
	D	-	-	-	-	0.83	11.63	0.07	0.66	**26.75**
	S/C	-	0.97	0.91	1.29	2.08	6.72	-	2.15	28.88
Total		3.81	51.95	44.23	3.74	16.70	79.56	1.98	6.08	91.94
		36.67			***41.08***			***22.25***		

Tables 3 and 4 show the distribution of dead and injured people; they both show a behavior similar to the accident distribution.

Table 3. The death distribution from 2006 to 2008, in percentages

DEATH										
Type of network		Corridor			Basic			Secondary		
Number of lanes		> 4	4	2	> 4	4	2	> 4	4	2
Road classification	ET	2.80	**44.99**	26.52	0.63	1.68	3.50	-	-	0.46
	A	-	0.59	8.09	-	1.48	6.03	-	-	2.65
	B	-	2.56	11.51	0.98	4.77	**29.97**	1.27	1.65	21.67
	C	-	0.45	1.41	0.07	2.26	28.06	-	0.81	16.03
	D	-	-	-	-	0.63	11.80	0.04	0.73	**26.31**
	S/C	-	0.59	0.49	0.70	1.59	5.86	-	1.23	27.16
Total		2.80	49.18	48.02	2.37	12.41	85.22	1.30	4.41	94.28
		37.11			***40.12***			***22.77***		

The vehicle-kilometer distribution per type of networks is also determined based on the number of lanes and according to the classification in the weight and dimensions regulation; we can see that the vehicular flow shows the same behavior as the accidents (see Table 5).

Table 4. The injured distribution from 2006 to 2008, in percentages

INJURED										
Type of network		Corridor			Basic			Secondary		
Number of lanes		> 4	4	2	> 4	4	2	> 4	4	2
Road classification	ET	3.80	**46.71**	22.85	0.66	1.91	3.07	-	-	0.35
	A	0.03	0.39	7.41	0.003	1.71	5.50	-	-	2.35
	B	-	2.45	12.91	1.95	5.66	25.34	1.91	2.26	19.99
	C	-	0.59	0.95	0.02	4.41	**27.21**	-	0.71	13.97
	D	-	-	-	-	0.71	12.13	0.09	0.56	**26.67**
	S/C	-	0.94	0.98	1.31	2.07	6.34	-	2.31	28.85
Total		3.83	51.08	45.09	3.95	16.47	79.58	1.99	5.83	92.17
		36.22			***41.24***			***22.54***		

Table 5. The vehicle-kilometer distribution per type of networks from 2006 to 2008

VEHICLE–KILOMETER										
Type of network		Corridor			Basic			Secondary		
Number of lanes		> 4	4	2	> 4	4	2	> 4	4	2
Road classification	ET	4.48	**50.65**	22.82	0.84	1.68	2.87	-	-	0.33
	A	0.03	0.51	5.98	0.02	2.05	5.39	-	-	2.83
	B	0.01	2.60	9.95	3.50	5.88	**26.14**	1.56	3.15	18.97
	C	-	0.33	1.09	0.03	3.45	25.92	-	0.38	16.84
	D	-	-	0.01	0.00	0.73	10.62	0.02	0.65	**23.78**
	S/C	-	0.58	0.96	2.32	2.39	6.17	0.05	2.55	28.88
Total		4.52	54.67	40.81	6.71	16.18	77.11	1.63	6.74	91.63
		36.49			***40.88***			***22.63***		

From this overview, we find that although the secondary network represents 40% of the RCF analyzed in this article (see Table 1), its concentration as to the number of accidents and victims, and the transit flowing through them is lower (see Tables 2 to 5); while the corridor and basic networks are smaller in length, but move a larger number of vehicles and concentrate an important percentage of accidents and victims (see Figure 1).

Based on the balance of accidents and vehicle-kilometers, the hazard (accidents with victims), fatality and morbidity rates per million vehicle-kilometers were calculated; we can observe that the maximum values are reported for the two-lane roads, as shown in Figure 2.

Figure 3 shows the indicators based on the road classification, and we can see that type D roads have the highest gravity and morbidity rates, 0.159 and 0.310 respectively, while the highest fatality rate is in type A roads.

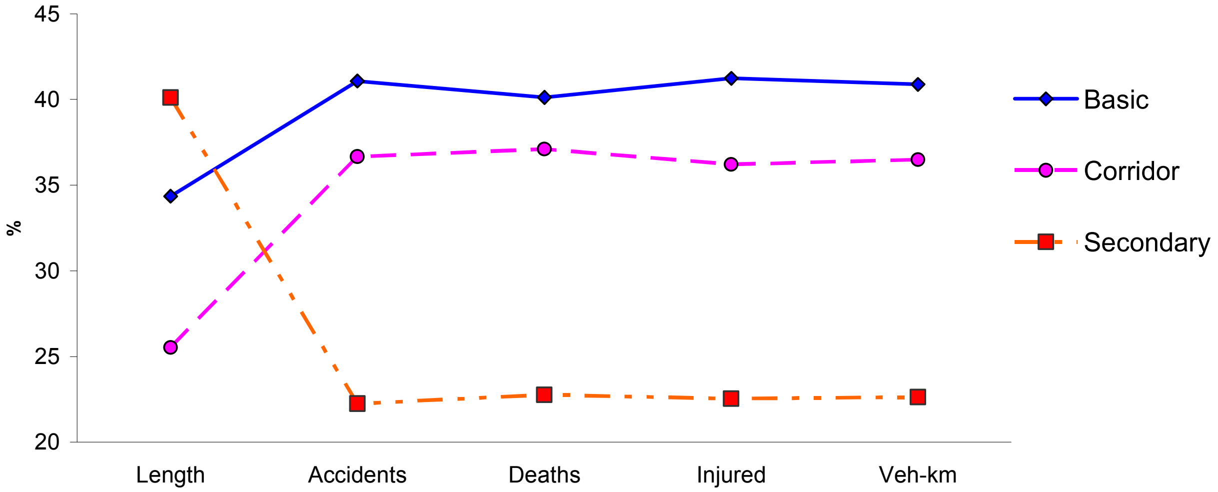

Figure 1. Distribution for the different types of networks

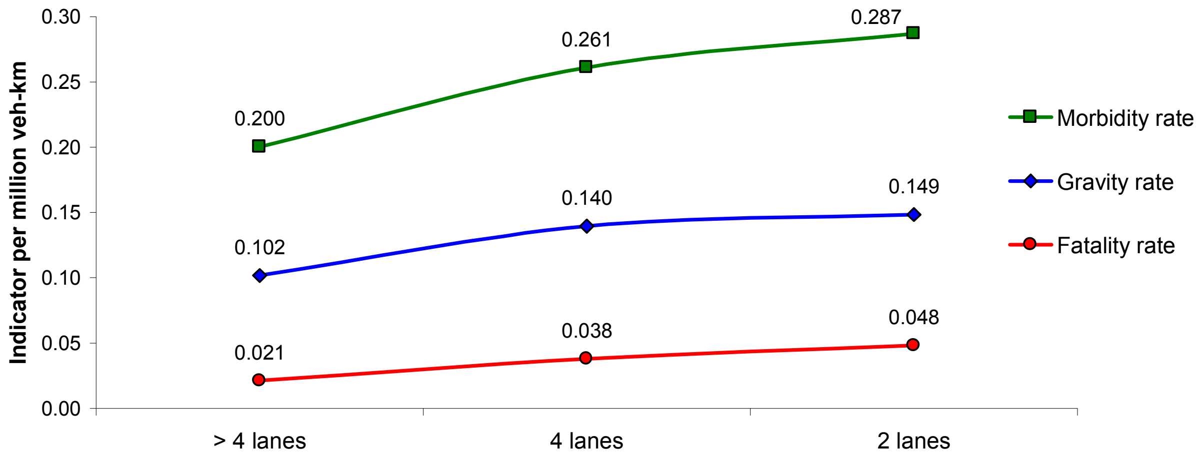

Figure 2. Indicators per million vehicles-kilometers, by number of lanes

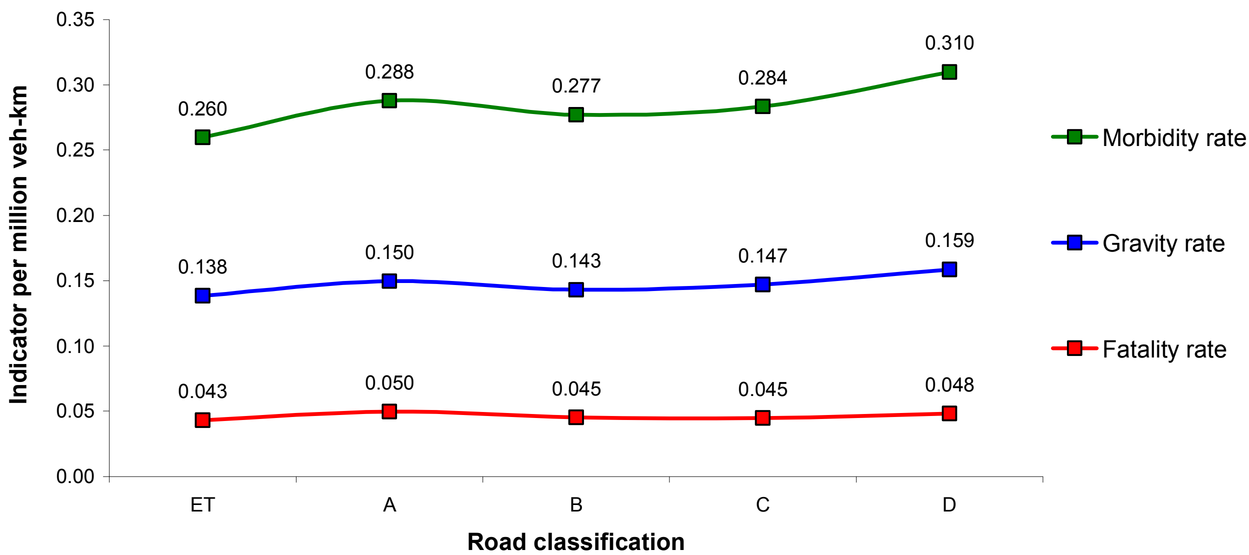

Figure 3. Indicators per million vehicles-kilometers, by the road classification

Indicators based on the type of network (corridor, basic and secondary) were also analyzed, obtaining very homogeneous values; for example, the gravity rate ranges from 0.141 to 0.145; the fatality rate ranges from 0.043 to 0.045, and the morbidity rate ranges from 0.274 to 0.278. These figures are very similar to those shown in Figure 3.

4. PARTICULAR ANALYSIS

In a first attempt to define a methodology for obtaining road safety indicators and taking into account the results obtained, we decided to limit the scope, taking into consideration the following aspects: two-lane roads are the ones with the highest indicators and from this group the ones classified as type B were chosen, since these roads are the longest (9,657.41 km).

First of all, an analysis of the distribution of the Average Daily Traffic (ADT) per type of network for the selected highways was made, obtaining the results reflected in Figure 4, which shows the accumulated frequency as a continuous line, and the normal distribution as a dashed line; values for the average of the secondary, basic and corridor line networks of 3,560, 6,410 and 8,280 vehicles, respectively, were obtained from the statistical analysis.

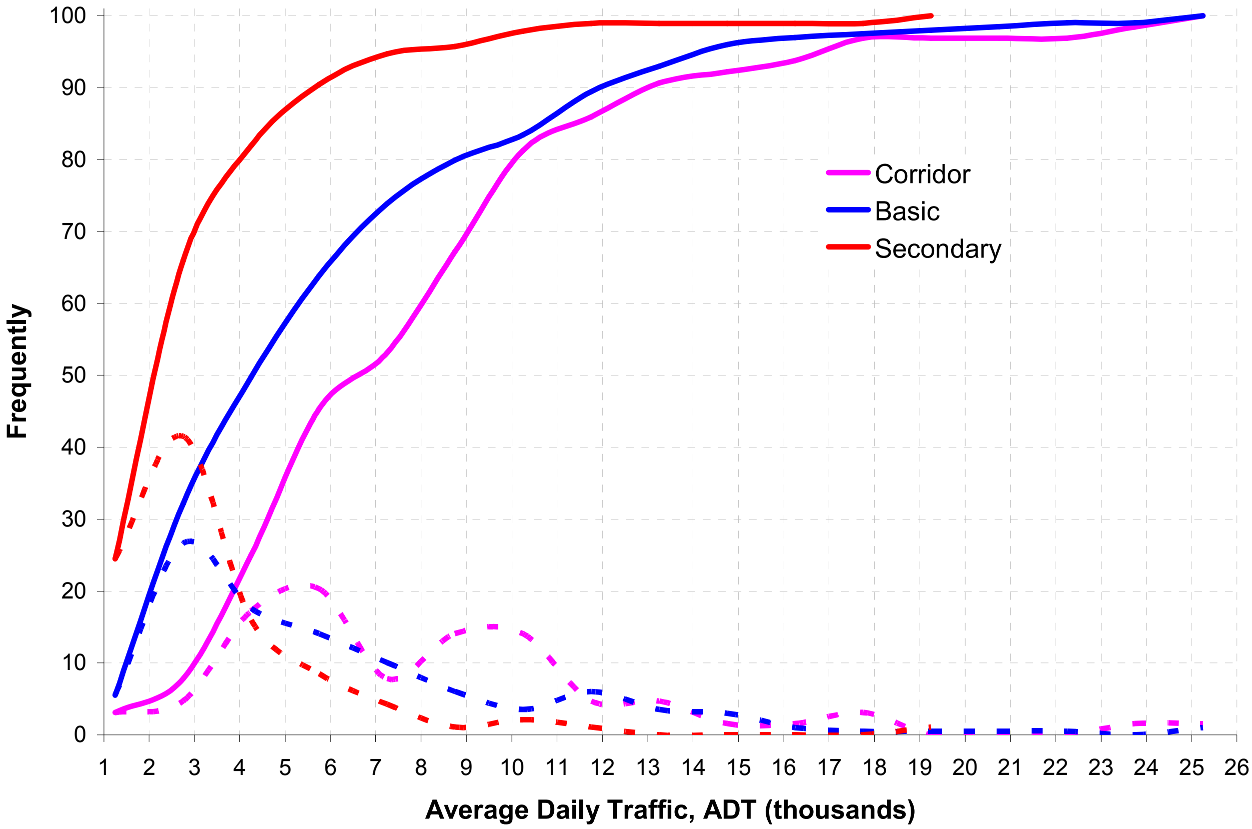

Figure 4. The ADT distribution, by type of network

This same analysis was made for the vehicle-kilometer values, obtaining the graphic in Figure 5 as a result. Since the length variable enters the analysis, the average values are not that scattered; thus, for the corridor network the average is 136.9; for the basic network, 132.2, and finally, for the secondary network, it is 112.8 millions of vehicles-kilometer.

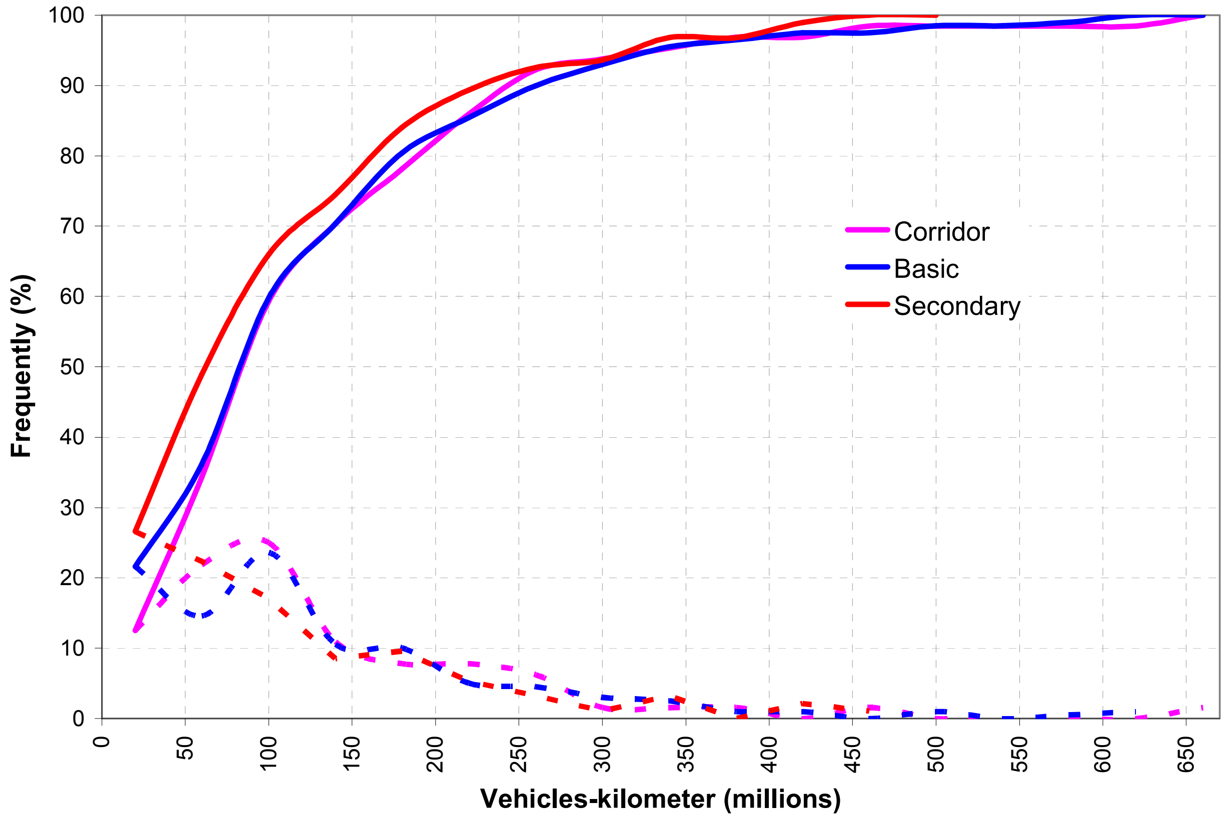

Figure 5. The vehicles-kilometer distribution, by type of network

Since the distribution of vehicle-kilometer shows a uniform behavior, the segments for all the networks were grouped together and six ranks based on the ADT were defined. In order to determine the average values, the distribution of the gravity, fatality and morbidity rates for each 100 million vehicle-kilometers, as well as that of the number of accidents, deaths and injuries per kilometer, was analyzed, finding the values reflected in Table 6. The figure in parenthesis in the first column represents the number of segments analyzed.

Table 6. The average values for several indicators

ADT Ranks (Number of segments)	**Indicators per each 100 millions vehicles-kilometer**			**Indicators per kilometer**		
	Gravity	Fatality	Morbidity	Accidents	Deaths	Injured
< 3000 *(94)*	16.320	7.130	34.150	0.130	0.054	0.278
3000 – 6000 *(132)*	18.350	5.850	36.900	0.288	0.091	0.584
6000 – 9000 *(61)*	15.540	5.560	29.840	0.420	0.149	0.809
9000 – 12000 *(35)*	19.210	6.810	36.600	0.744	0.265	1.419
12000 – 15000 *(20)*	14.480	5.720	24.700	0.687	0.280	1.171
> 15000 *(15)*	12.250	2.790	23.410	0.885	0.203	1.679

As can be seen, the indicators for vehicle-kilometer show an unsteady behavior up to the range between 9,000 and 12,000 vehicles, and from that point on, they show a downward trend. While the indicators per kilometer show a performance directly proportional to ADT up to the range mentioned herein before, and from then on, the behavior becomes unsteady (see Figures 6 and 7).

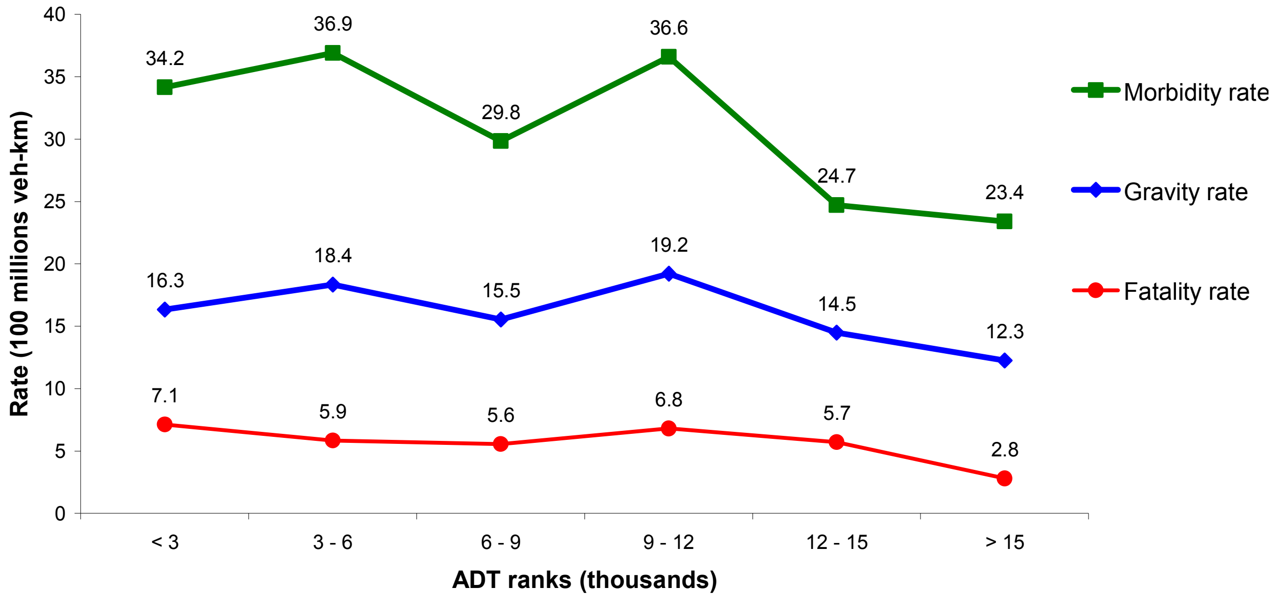

Figure 6. Performance of the indicators per vehicles-kilometer

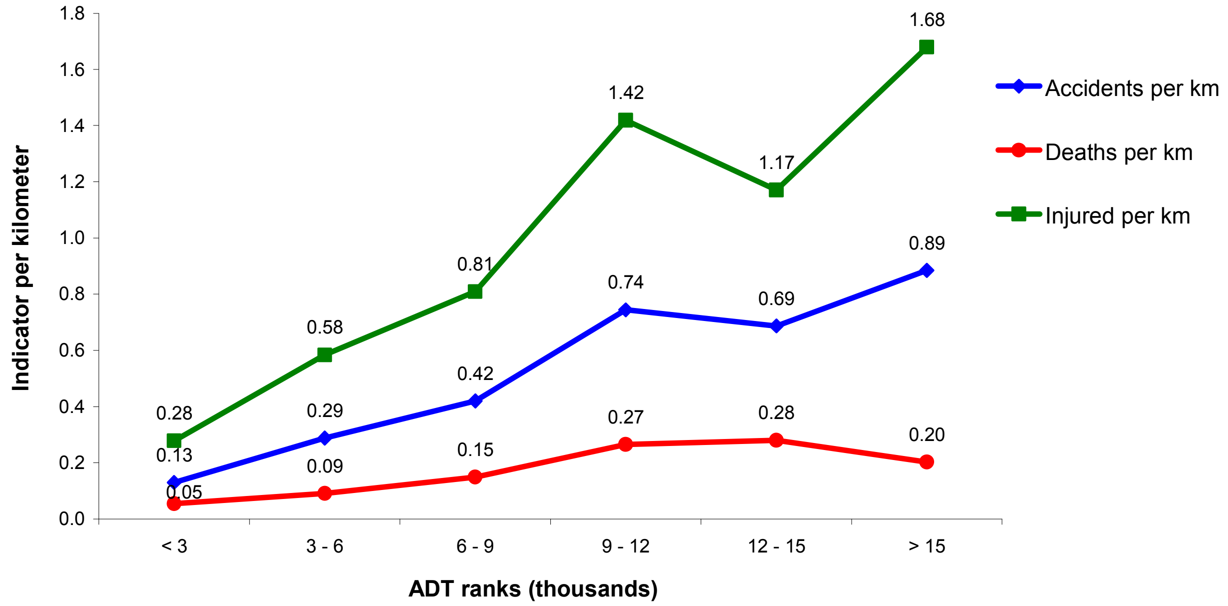

Figure 7. Performance of the indicators per kilometer

Based on the fact that indicators per vehicle-kilometer show an unsteady behavior, the indicators per kilometer were used to obtain a more detailed analysis. This analysis observes only the segments with an ADT lower than 13,000 vehicles (more than 90% of the segments analyzed), since as shown in previous figures in segments with a greater transit, behavior for these indicators is unsteady. In this final analysis, the maximum, minimum and average values for accidents, deaths and injuries per kilometer were determined for ADT ranks with 1000 increments. Figures 8, 9, and 10 show the results of these values in graphics; numbers in red and blue represent the maximum and minimum values detected for each of the ranks, respectively, and are represented by the gray bars; the green circle is the average value and the line represents the trend.

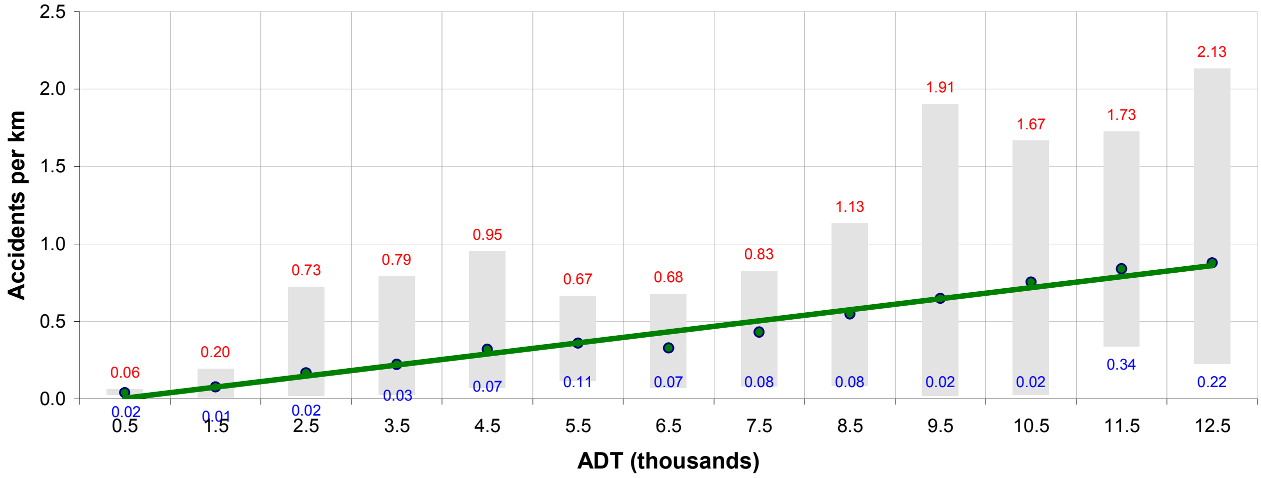

Figure 8. The maximum, minimum and average values for accidents per kilometer

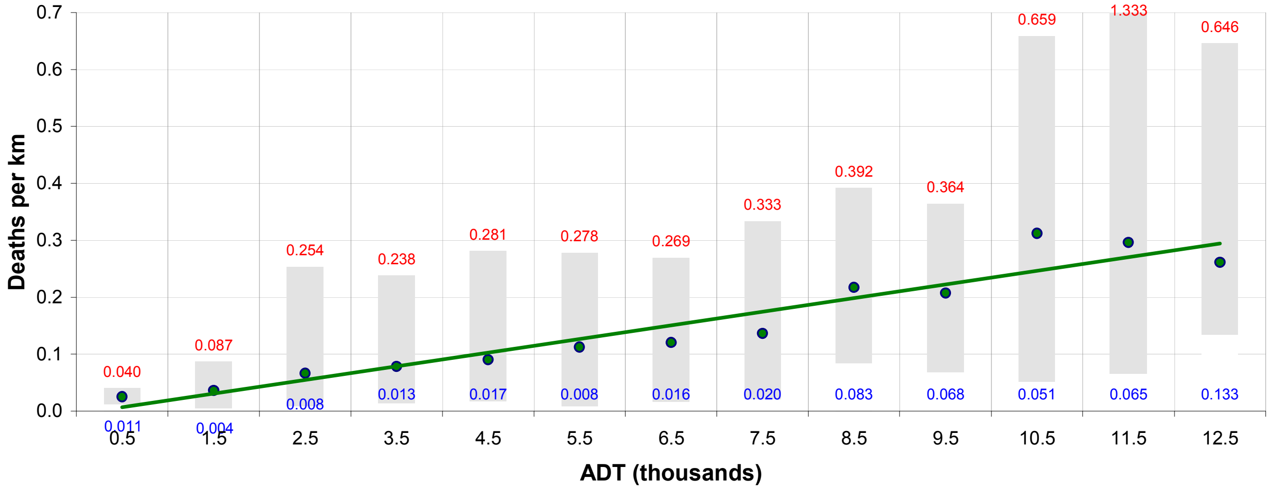

Figure 9. The maximum, minimum and average values for deaths per kilometer

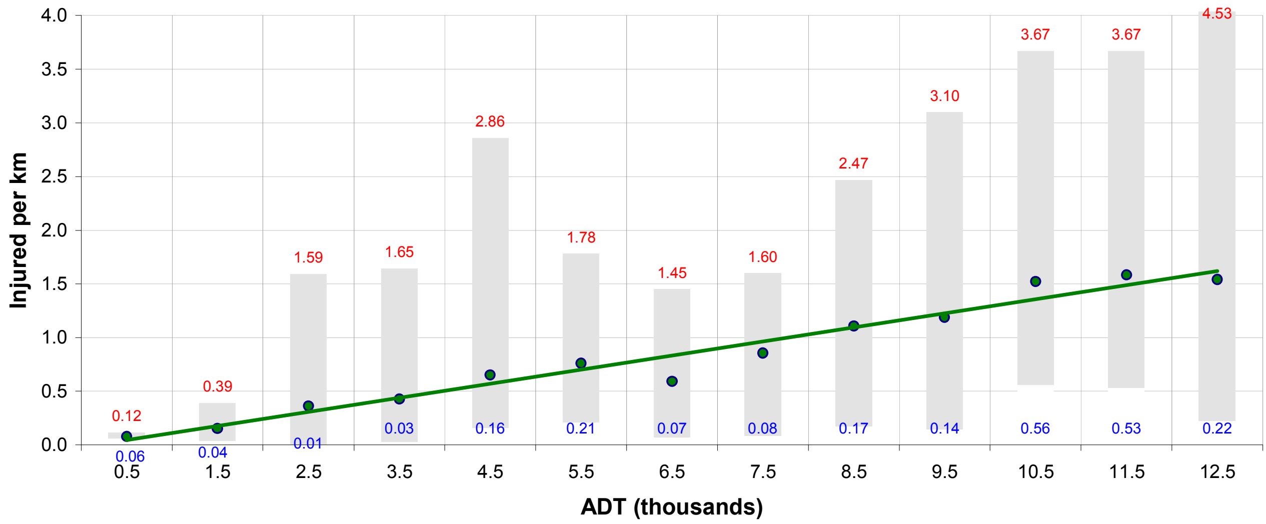

Figure 10. The maximum, minimum and average values for injured per kilometer

If someone has the ADT value and the indicators per kilometer for a two-lane B-classified highway segment, it could be integrated to these graphics and thus determine which accident conditions are reported in regard to the average values obtained for these segments.

Finally, with the purpose of finding one value that reflects the security in one segment, a security index *(Is)* that weighs the indicators in Figures 8, 9, and 10 was generated.

$$Is = \frac{1}{[(N°of\,accidents/km)(0.1)]+[(N°of\,deaths/km)(0.6)]+[(N°of\,injured/km)(0.3)]}$$

Figure 11 shows the values in the security index based on the ADT ranks. The green line outlines the average value, and the dots are the security index of each of the 327 segments analyzed, so we could say that the dots in the white area (174), which are over the average value, present mild accident problems. The ones that fall inside the green area (84) have a moderate problem, while the ones inside the red area (68) have serious problems, since they report a rate that is below the 60%, which is the average.

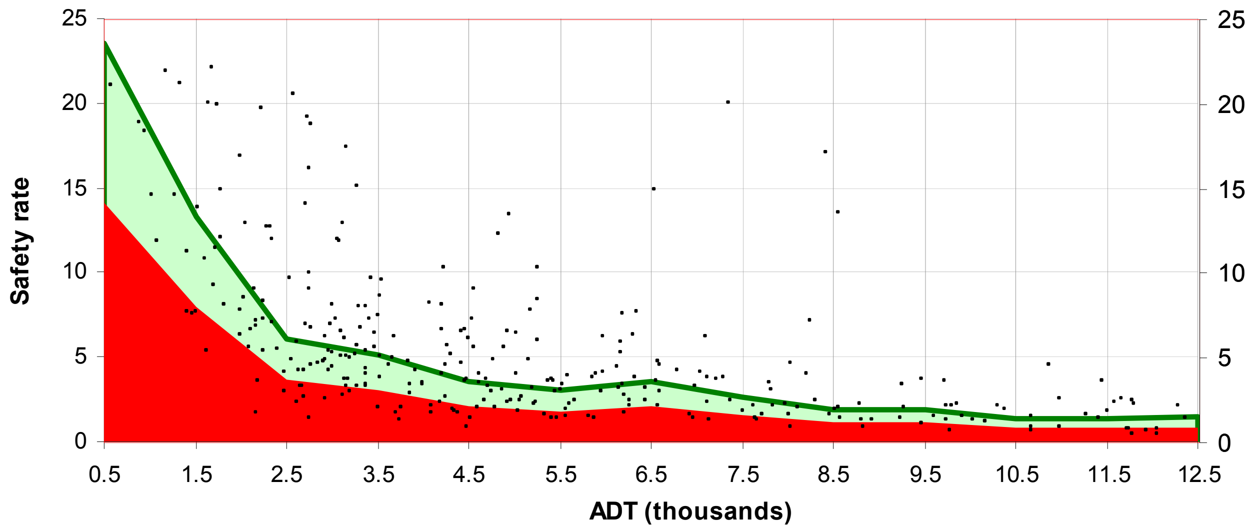

Figure 11. The security index based on the ADT ranks

CONCLUSIONS

With this article, we obtain the first indicators for road safety for a part of the RCF, that is, two-lane type B roads, in another effort to understand the performance of these indicators. This initial approach allows us to relate accidents to the ADT in a simple manner, since they have a lower incidence in the other parameters. Besides, we have the first graphics for determining the accident conditions for the roads mentioned herein before.

One of the next tasks will be to obtain the accident data from 2009 and 2010 in order to perform an in-depth analysis, as well as to evaluate the performance of the rest of the segments in the network according to their classification (ET, A, C, and D), and the number of lanes. And with the results of this first analysis and those of the next task, the information will be linked to a geographical information system, in order to obtain a clearer image of the results.

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