Aggregate analysis of the effectiveness of road safety policies in Portugal

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ABSTRACT
In the last few decades, there have been significant improvements in terms of road accident decrease in Portugal. There are many causes identified as responsible for these improvements, however, the wide range of factors related to road accidents, increases the uncertainty about the effectiveness and efficiency of each adopted measure.

The purpose of this study is the analysis of road safety policies' effectiveness in Portugal, between 1987 and 2007, using multiple linear regression models. Variables related to infrastructure, the vehicle fleet, the social-economic factors and policies on road safety were taken into account. Six road accident indicators were analyzed: accidents with casualties (ACV); fatalities (MORT); accident severity index (IG); fatalities per volume of fuel sold (MC); fatalities on motorways per volume of fuel sold (MAEC); accidents with casualties per volume of fuel sold (ACVCOMB). It has been verified, from the obtained models, that the contribution of the produced legislation during the analyzed period, results on decreased road accident indicator values (considering all six indicators). Also, the reduction of indicators MORT, IG and MC benefited significantly from road infra-structure policies (specially the network of motorways). The average price per liter of fuel was another factor responsible for the reduction of accidents with casualties and fatalities (ACV and MORT). Despite the improvements that the legislation in force represents, the percentage of national fleet's vehicles increases the values of ACV and ACVCOMB.

Keywords: road traffic accidents, road safety policies, multiple linear regression analysis

1. Introduction

A major objective of road accidents' analysis is the identification of its causes and the factors that potentiate or reduce them. The correct identification of both, causes and factors, allows saving lives and provides authorities with the necessary information for better planning and analyzing the effectiveness of policy enforcement and road safety measures.

Considered as a growing public health issue, road traffic injuries are a major concern of governments and citizens. It is estimated that each year about 1 million people lose their life and between 30 to 50 million get injured (PIARC, 2003). In economic terms, the cost of road crash injuries is estimated, according to the World Bank (WB), between 1 and 3 percent of gross national product (GNP). In 2004, the estimated cost of road accidents exceeded 180 billion Euros in EU-15 (ETSC, 2007). In Portugal, according to the recommended values of the WB, estimated costs ranged, in 2007, between 1.6 and 4.8 billion Euros. Mortality and morbidity of road accidents and its economic and social impact, requires an active and effective intervention by the responsible authorities.

In recent years, in Portugal, special attention has been given by the authorities to road traffic accidents, leading to several prevention campaigns and amendments to the existing legislation and even to the infrastructure itself.

Widely publicized by the media, campaigns focus on prevention, awareness and education of both adults and children, either pedestrians or drivers.

Several changes were made to legislation, to both the Traffic Rules Code and the Penal Code. For example: the mandatory use of seat belts and effective protection for minor passengers' transport increased penalties, and criminalizing irresponsible acts and potentially inductors of accidents with victims, such as, the excessive consumption of alcohol by the driver. To these changes and their effectiveness, the efficient surveillance and mobilization of traffic police, ensuring compliance, is added.

Some infrastructures were, and still are, under several improvements like signaling changes, becoming more visible and complete, allowed speed limits and even layout or road type recasting.

Alongside these changes and despite the statutory approvals for vehicles, car technology developed towards safety, leading to safer cars that combine technology with active and passive safety: Air-bags, Anti-lock Breaking System (ABS), traction control, Electronic Stability Program (ESP), Electronic Stability Control (ESC), protection bars, among others.

From 1987 to 2007 Portugal's transport scenery deeply changed. Better and more infrastructures, car fleet improvements, the change of road users' risk behaviors and a set of implemented policies, all lead to a steady decline in accident rate, since the late twentieth century. This reduction puts Portugal amongst European countries with better results in the decrease of traffic accidents.

The great effect of all these improvements in the reduction of road accidents is very noticeable. However, the effectiveness and influence of each measure in reducing accidents, or even if any and which were completely superfluous in such decline, is not clear. Beside these, some unmanageable factors are often suggested as variable causes of road accident numbers, especially those related to economic factors (like fuel prices) or even weather factors.

Road safety is a complex interaction of road users, vehicles, infrastructure and environment. This complex interaction makes road safety's approach and implementation difficult (JAMROZ, K., 2008).

The wide range of road accident factors increases uncertainty to the effectiveness and efficiency of each adopted measure. Researchers as SIVAK and TSIMHONI (cited in Wilmots, B. et al., n/d) argue that simpler accident problems have already been overcome (implementing measures based on common sense). They also stand by the need of complex problems' treatment in order to achieve further reductions of road accident ratios (WILMOTS, B. et al.).

The purpose of this study is the creation of models that explain the influence of several factors in the decline of some road accident indicators in Portugal between 1987 and 2007. Six road accident indicators were selected as dependent variables: accidents with casualties (ACV); fatalities (MORT); accident severity index (IG); fatalities per volume of fuel sold (MC); fatalities on motorways per volume of fuel sold (MAEC); accidents with casualties per volume of fuel sold (ACVCOMB). It were considered as explanatory variables those relating to infrastructure, transport, socio-economic factors and legislation in force. The Multiple Linear Regression Analysis method and software SPSS for Windows (v.16.0) were used.

2. Road Accidents Evolution in Portugal

Portugal's European Union (EU) accession in 1986, allowed the creation of economic, social and cultural conditions to join Europe's most developed countries group. Structural funds elevated the country to another level of expansion, inflicting profound changes on road transport. The road network typology was altered in line with other European countries, growing both in quantity and quality. Car fleets were updated and expanded and high segment vehicles gained market share. The ratio grew from 7.5 inhabitants per passenger car, to nearly two Portuguese citizens per passenger car (2.3 individuals per light vehicle) (ACAP; INE).

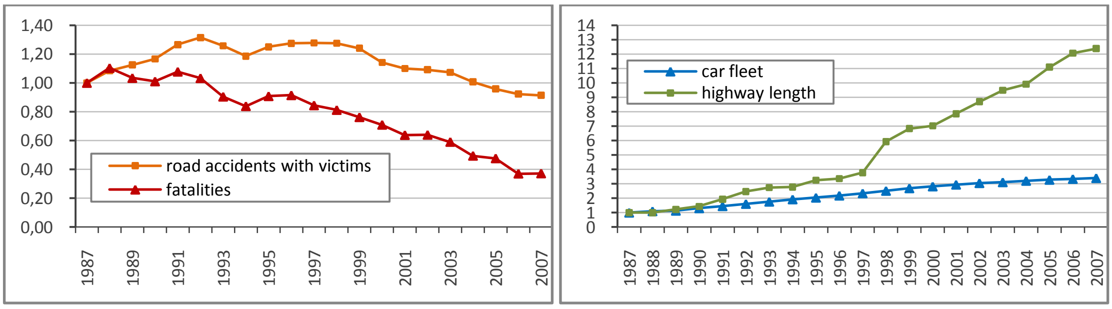

FIG. 1: YEARLY PORTUGAL ROAD ACCIDENTS WITH VICTIMS, FATALITIES, CAR FLEET AND HIGHWAY LENGTH (YEAR 1987 = 1) (SOURCE: INE, ACAP, ANSR)

Alongside these structural changes, serious road accidents decreased consistently and approached European average, since mid-1990 (BRANCO, 2003).

Despite the downward trend of fatalities in traffic accidents, in the beginning of this century, on average, four lives were lost every day, on Portuguese roads.

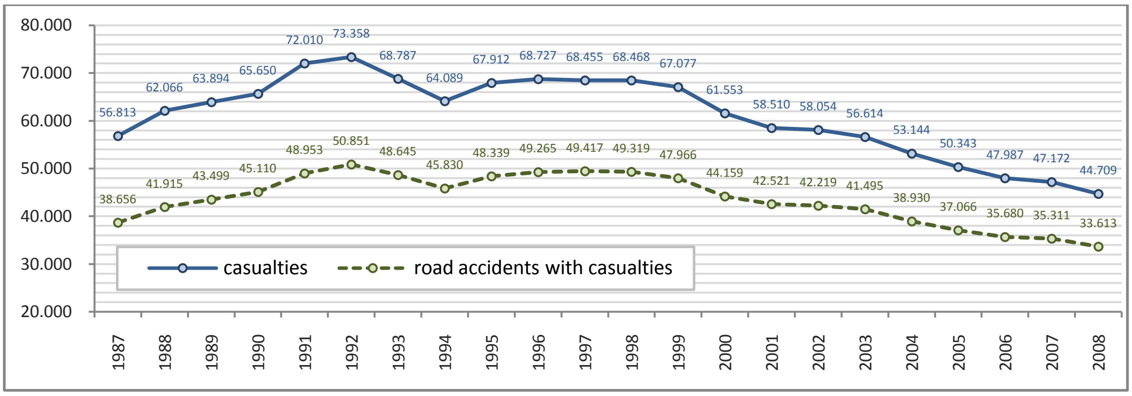

FIG. 2: ANNUAL EVOLUTION OF SOME INDICATORS OF ROAD ACCIDENTS IN THE PERIOD 1987-2007 (SOURCE: ANSR)

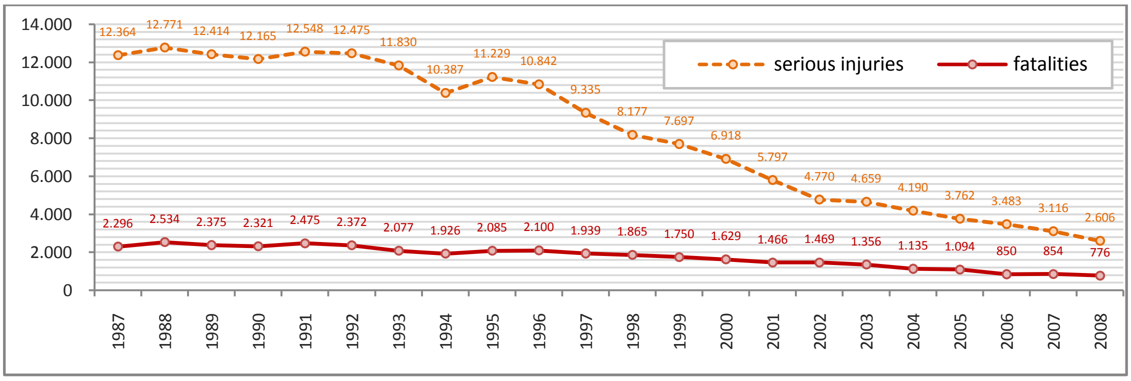

FIG. 3: ANNUAL EVOLUTION OF SOME INDICATORS OF ROAD ACCIDENTS IN THE PERIOD 1987-2007 (SOURCE: ANSR)

In 2003, to tackle the high number of road accidents and in accordance with the European Union, the National Plan for Road Safety (PNPR - Plano Nacional de Segurança Rodoviária) was published. The main goal of the PNPR was to reduce by half (referring to the average accident rate from 1998 to 2000) the number of fatalities and serious injuries till 2010.

The goal was met four years earlier, in 2006. Portugal was, alongside France, the EU country in which the rate of road accidents was most reduced, ahead of countries like Spain and Austria.

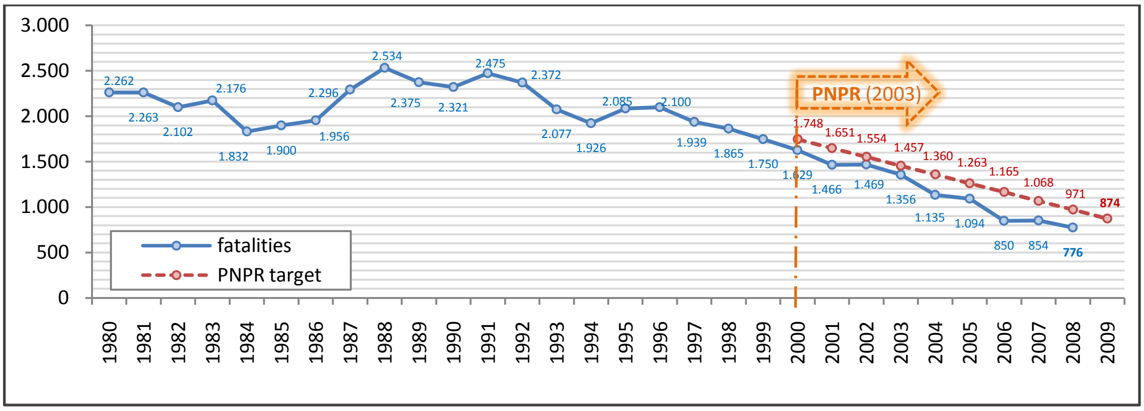

FIG. 4: EVOLUTION OF THE NUMBER OF FATALITIES IN PORTUGAL. (SOURCE: ANSR)

The year of 2008 recorded the lowest victim values ever registered (fatalities and severe and light injuries). Relatively to 2007, there were 78 less fatalities (-9.1%), 510 less severe injuries (-16.4%) and 1875 less light injuries (-4.3%) totalizing 2463 less victims (-5.2%) (ANSR).

Besides the decrease of accidents with casualties, this value was, in 2008, similar to that recorded in the mid 80's (around 38 000 in 1987 and 33 000 in 2008) when vehicle fleet and road traffic were significantly smaller. However, the Severity Index (IG) of road accidents with casualties was, that year, the lowest ever, about three times lower than that recorded in 1980. It should be borne in mind that the risk exposure was in the mid 80's, significantly lower than today.

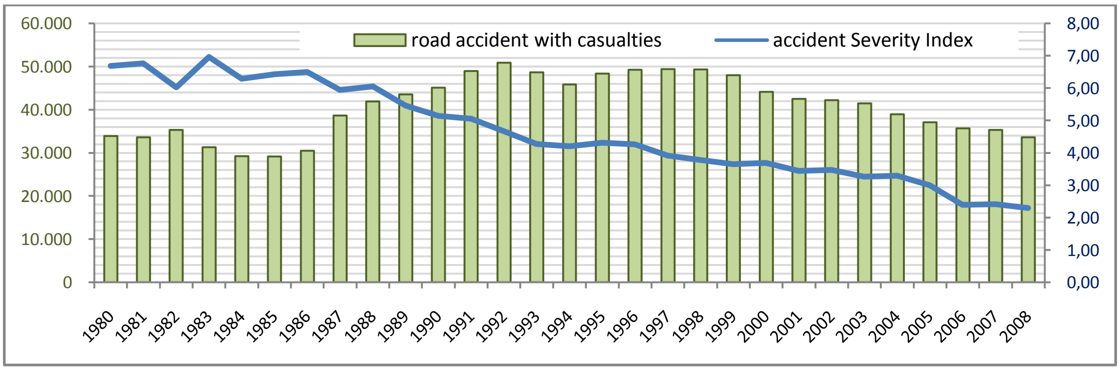

FIG. 5: EVOLUTION OF ROAD ACCIDENT WITH CASUALTIES AND THE SEVERITY INDEX OF ACCIDENTS. (SOURCE: ANSR)

Compared to 1987 the main indicators of road accidents decreased (FIG. 2, FIG. 3 AND FIG. 5). The most significant decrease was recorded in serious injuries, decreasing above 9700 casualties and 1520 fatalities (-66.2%).

The MAI points out, as causes of road safety's progress: the highway network; improved vehicle safety levels; Security Forces more frequent and effective supervision; and civic awareness and responsible attitudes acquired by drivers (MAI, 2009).

3. Data

The selected variables to be analyzed in this study focused on the numbers of road accidents in Portugal, between 1987 and 2007, and took into account the theoretical multiplicity of factors responsible for those accidents' variation. Multiple databases from different agencies were consulted during the research and collection of variables: Autoridade Nacional de Segurança Rodoviária (ANSR - National

Road Safety Authority); Instituto Nacional de Estatística (INE - National Statistics Institute); Direcção Geral de Energia e Geologia (DGEG - Directorate-General Energy and Geology); Associação Automóvel de Portugal (ACAP - Automobile Association of Portugal), Banco de Portugal (BP – Portugal Bank); Diário da República (Daily Republic).

It is emphasized the information gap on drivers' education and supervisions' efficiency.

The purpose of this study implies that the chosen dependent variables for the analysis belong to the set of road accidents' indicators. Thus, six of these indicators were chosen as dependent variables: the number of accidents with victims (ACV), number of fatalities (MORT); accident Severity Index (IG); number of fatalities per million liters of fuel sold (MC); number of fatalities on motorways per one hundred million liters of fuel sold (MAEC); number of road accidents with casualties per hundred million liters of fuel sold (ACVCOMB).

Exposure risk is extremely important in a temporal road accidents analysis because its variation can directly interfere in data and results. The same fatalities' value from road accidents will have different readings depending on higher or lower exposure's risk. One risk exposure indicator is the fuel consumption. Although crude, due to decreased consumption of most vehicles (with the performances taking place in recent years of analyzed period) is an easily accessible variable and perfectly adjusted to the desired type of analysis. Three independent variables in the study were weighted by risk exposure.

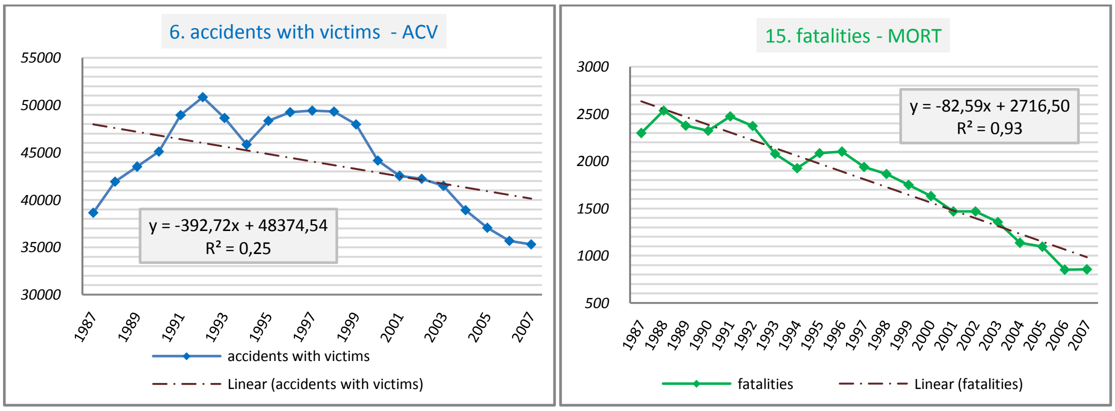

FIG. 6: VARIATION OF THE DEPENDENT VARIABLES – ACV; MORT (*1987-2007*) (SOURCE:ANSR)

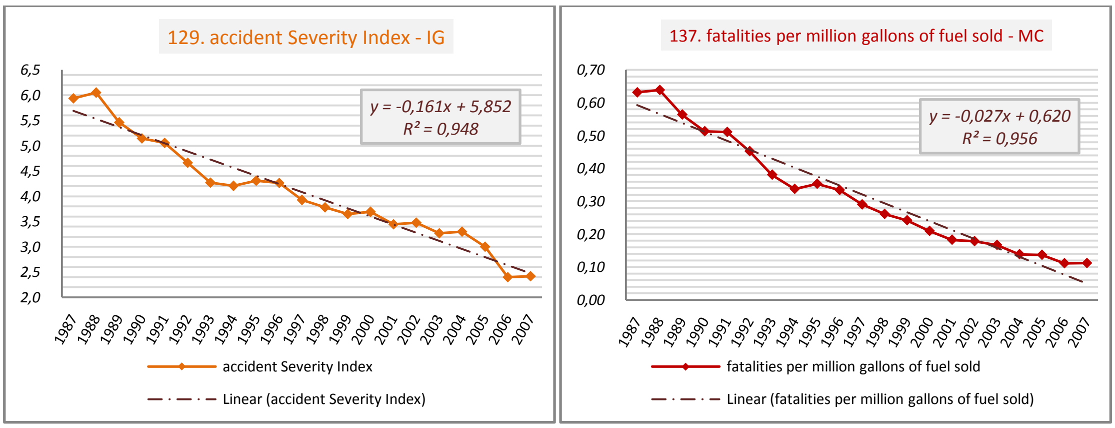

FIG. 7: VARIATION OF THE DEPENDENT VARIABLES – IG; MC (*1987-2007*) (SOURCE:ANSR)

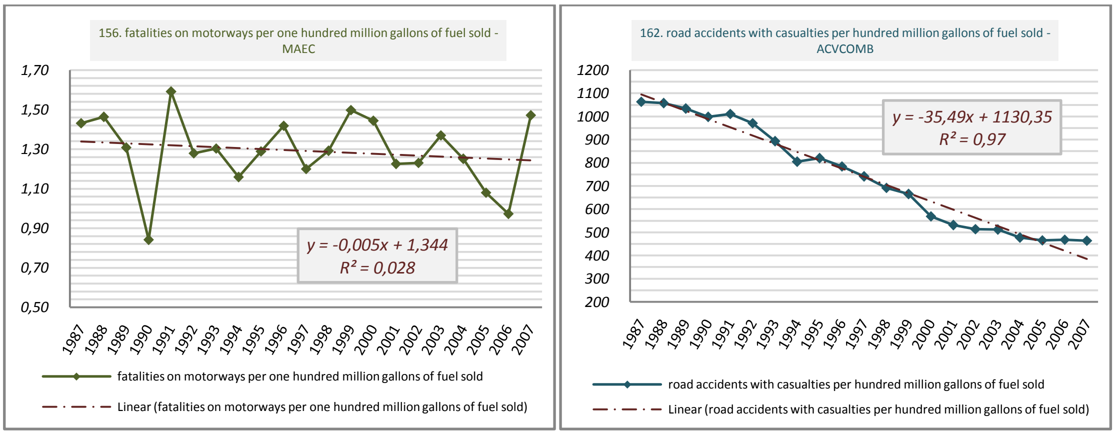

FIG. 8: VARIATION OF THE DEPENDENT VARIABLES – MAEC; ACVCOMB (*1987-2007*) (SOURCE:ANSR)

All dependent variables showed a decline of values in the period under review. The variable with the biggest decline is MC (-80%). Against all values registered, highway fatalities (MAEC) have wide swings, with the slope of the trend line of practically zero and a small decrease of 2.8%. For these values may have contributed the enormous increase (almost 20 times) of motorways' network in the reviewed period.

Several authors stated that traffic accidents and resulting casualties, may come from a wide range of potential causative factors (VROLIX, 2006; BESTER, 2001; PAGE, 2001). There is, in literature, a wide range of variables included in road accidents models (PAGE, 2001, BESTER, 2001, NOLAND, 2004, NOLAND, 2003, PAULOZZI, 2006, YANNIS, 2008, KIM, 2006, LOO, 2005, RIVAS-RUIZ, 2007, AMEEN, 2001, EL-SADIG, 2002 and also FRIDSTRØM and INGEBRIGTSEN, 1991; BEENSTOCK and GAFNI, 2000; ZLATOPER, 1987; HAKKERT and BRAIMAISTER, 2002; PARTYKA, 1983 and 1987; WAGENAAR, 1983; WINTEMUTE, 1985; BESTER, 2001; SCUFFHAM AND LANGLEY, 2002; GAUDRY and LASSARRE, 2000; ELVIK and VAA, 2004, cited in VROLIX, 2006). Some categories of potential explanatory variables used are listed in FIG. 9.

Category	*Variables*
Risk Exposure	Fuel sold; population; total vehicle; number of passenger car.
Car fleet	Vehicle fleet composition (light and heavy vehicles); average age of vehicles
Routes	Roads lenght; roads density; motorways lenght.
Economics	Gross national product; fuel prices.
Road safety policies	Legislation.

FIG. 10: SOME CATEGORIES OF POTENTIAL EXPLANATORY VARIABLES USED IN ANALYSIS.

4. Methodology

The multiple linear regression was the used analysis in this study. This analysis predicts and/or explains how the dependent variable (Y) statistically depends on independent variables (Xi; i=1, …, p) (HAIR, 2009). This relation can be written as a mathematical equation:

$$Y_j = \beta_0 + \beta_1 X_{1j} + \beta_2 X_{2j} + \ldots + \beta_p X_{pj} + \varepsilon_j \quad (j = 1, \ldots, n) \tag{1.0}$$

Where β_i are the regression coefficients and ε_j represents the errors of the model. β_0 is the ordinate in the origin (y_j value when $x_{ij} = 0$; i = 1, …, p) and β_i (i = 1, …, p) represents the partial gradient (an influence measure of X_i in Y, in other words the Y variation per unit change of X_i) (MAROCO, 2007). The term ε_j (errors of the model), reflects the measurement errors and natural variation in Y (idem).

With this kind of model each explanatory variable (or independent variable) contribution can be defined. However, a simple comparison of the regression coefficients doesn't make valid the importance of each independent variable in the model (due to the magnitude differences of variables). To make a proper comparison between independent variables weights, standardized variables must be used on model adjustment, or by other hand, the regression coefficients must be standardized. Model quality (effect size of the explanatory variables) is measured by the determination coefficient (R^2).

5. Results

Dependent Variable	Independent Variable	Coefficients			Model		Durbin-Watson
		β	$\beta_{standardized}$	VIF	R^2	R_a^2	
ACV	(Constant)	43628			0.962	0.925	1.936
	73.PESADOSPERC	4318	0.578	3.730			
	118.LEG01	-5498	-0.542	2.717			
	122.LEG05	-1761	-0.129	1.809			
	157.PREÇOLCOMBSPPIBPCAP	-162328	-0.712	1.848			
MORT	(Constant)	4012			0.978	0.970	2.150
	113.LEG89	-213	-0.121	3.062			
	116.LEG92	-139	-0.114	4.378			
	117.LEG94	-207	-0.188	4.822			
	157.PREÇOLCOMBSPPIBPCAP	-10877	-0.440	10.792			
	149.KMAEPKMREDE	-9030	-1.023	2.480			
IG	(Constant)	6.152	-	-	0.985	0.980	2.141
	113.LEG89	-0.499	-0.146	2.715			
	115.LEG90	-0.287	-0.100	3.863			
	116.LEG92	-0.604	-0.257	2.862			
	122.LEG05	-0.294	-0.103	2.100			
	144.DENSAE	-66.227	-0.595	3.257			
MC	(Constant)	0.6609	-	-	0.991	0.987	2.025
	113.LEG89	-0.0653	-0.114	2.715			
	115.LEG90	-0.0403	-0.084	3.861			
	116.LEG92	-0.0723	-0.183	3.832			
	117.LEG94	-0.0754	-0.212	3.435			
	29.KMAE	-0.0001	-0.571	2.105			
MAEC[1]	67.VVEND2000PERC	-5.363	-0.112	3.738	0.981	0.978	2.040
	122.LEG05	-0.292	-0.085	1.759			
	163.IDD_PQ	0.202	1.109	2.712			
ACVCOMB	(Constant)	232.779	-	-	0.986	0.983	1.858
	118.LEG01	-91.071	-0.197	3.342			
	73.PESADOSPERC	206.131	0.605	7.621			
	115.LEG90	-196.212	-0.315	2.182			
	117.LEG94	-47.543	-0.103	5.546			

[1] *Model without constant*

FIG. 11: MULTIPLE LINEAR REGRESSION MODELS (ACV, MORT, IG, MC, MAEC AND ACVCOMB).

With R^2 values above 0.96 for all models, we can say that at least 96% of the variability of each Y (ACV, MORT, IG, MC, MAEC and ACVCOMB) is explained by the independent variables present in each model. These models can be written as equation *(1.0)*:

$$ACV = 43628 + 4318*PESADOSPERC – 5498*LEG01 – 1761*LEG05 – 162327*PREÇOLCOMBSPPIBPCAP \quad (1.1)$$

$$MORT = 4012 – 213*LEG89 – 139*LEG92 – 207*LEG94 – 10877* PREÇOLCOMBSPPIBPCAP – 9030*KMAEPKMREDE \quad (1.2)$$

$$IG = 6.152 – 0.499*LEG89 – 0.287*LEG90 – 0.604*LEG92 – 0.103*LEG05 – 66.227*DENSAE \quad (1.3)$$

$$MC = 0.6609 – 0.0653*LEG89 – 0.0403*LEG90 – 0.0723*LEG92 – 0.0754*LEG94 – 0.0001*KMAE \quad (1.4)$$

MAEC = - 5.363*VVEND2000PERC – 0.292*LEG05 + 0.202*IDD_PQ

(1. 5)

ACVCOMB = 232.779 – 91.071*LEG01 + 206.131*PESADOSPERC – 196.212*LEG90 – 47.543*LEG94

(1. 6)

The legislation influence is visible in all models. Infrastructure (KMAEPKMREDE, DENSAE and KMAE), car fleet features (VVEND2000PERC, PESADOSPERC and IDD_PQ) and economic factors (PREÇOLCOMBSPPIBPCAP), were the other categories present in the models. In the equation the explanatory variables sign represents the proportionality of each one with the dependent variable. Dependent variables' variation is directly proportional to the independent ones whenever their signal is positive and inversely proportional otherwise.

For the selected variables is important to refer that in international studies (BESTER, 2001; PAULOZZI, 2007) the GNP is one of the indicators that contributes to the decrease of number of dead. This indicator is strongly connected with kilometres of motorways in operation (reflected in DENSAE and KMAE variables). We can consider that DENSAE and KMAE reflect the infra-structure degree and road improvement and incorporate economic growth effects.

ACV MODEL

The explanatory variables of this model are: the percentage of heavy vehicles on car fleet (PESADOSPERC); the legislation in force since 2002 and 2005 (LEG01 e LEG05); and the average price per liter of fuel per GDP *per capita* (PREÇOLCOMBSPPIBPCAP - representative variable of the real average cost of fuel liter per citizen). The most influential variable in this model is the one related to fuel prices. This variable (PREÇOLCOMBSPPIBPCAP), as well as those related to legislation (LEG01 and LEG05), contributed to road accidents with victims reduction. The fourth variable in this model vary in a direct proportion with the explained variable, contributing to increase the accidents with registered victims.

MORT MODEL

All variables in this model contributed to the decrease of MORT. The variable with greatest influence on the fatalities decrease was the ratio of motorways per total length of road network (KMAEPKMREDE), followed by PREÇOLCOMBSPPIBPCAP. The remaining variables in the model were those related to the legislation in force since 1989, 1992 and 1994 (LEG89, LEG92 and LEG94).

IG MODEL

All explanatory variables in this model have a negative equation signal. It can be said that all variables contributed to the decrease of accident severity index. The variable that most contributed to this decrease was the motorways density (DENSAE) and the legislation in force since 1992 (LEG92 - obligatory periodic inspections) was the most influent legislation. Legislation from 1989, 1990 and 2005 (LEG89, LEG90, LEG05) are the others variables in the model.

MC MODEL

As in the previous model, all explanatory variables vary inversely with the dependent variable. The most influent one is about KMAE, followed by legislation from 1994, 1992, 1989 e 1990 (LEG94, LEG92, LEG89 e LEG90).

MAEC MODEL

The variable MAEC has very low correlations with the remaining set of variables (less than 35%). The explanatory variable with greatest influence in this model is the one that represents of the average age of vehicles (IDD_PQ) with a positive equation's signal. The other variables in the model, the percentage of vehicles sold with engine capacity exceeding 2000 cc (VVEND2000PERC) and legislation in force since 2005 (LEG05) vary inversely with MAEC.

ACVCOMB MODEL

Several legislation variables (LEG90, LEG01 e LEG94), with negative weight, are present in this model. However, the most influent variable (PESADOSPERC) shows a direct proportional variation with the dependent one. We can conclude that heavy vehicles percentage contributes to increase traffic accidents with casualties.

The influence of legislation in road accidents' improvements can be seen in all models. Common to three models (IG, MC and ACVCOMB) is the influence of the criminalization of driving with blood alcohol rate (TAS – Taxa de Alcoolemia no sangue) exceeding 1.2 g/l (LEG90). This result reinforces the general idea of the negative weight that the TAS has in road accidents, particularly high values of it. The law entered into force in 1989 (LEG89), present in three models (MORT, GA and MC), includes the mandatory use of seat belts, another factor commonly accepted and recognized as lowering the severity of road accidents and fatalities. Periodic inspections mandatory (LEG92) appears as a beneficial intervention in models MORT, IG and MC. The entry into force of the new Highway Code (LEG94) is another variable related to several models (MORT, MC, ACVCOMB) as is LEG05 (the mandatory use of retro reflective vest, aggravation of penalties and incidental and differentiation of fines for speeding), present in ACV, IG and MAEC models. Common to the representative models of accidents with victims (ACV and ACVCOMB), is the legislation from 2001 (LEG01 - several changes to the Traffic Rules Code, convictions to the prohibition of driving and the blood alcohol limit to 0.2 grams per liter blood).

It is assumed that legislation's effectiveness is directly linked to an effective surveillance by the security forces, which ensure its accomplishment.

It is clear the influence of road infrastructure, particularly motorways (KMAEPKMREDE, DENSAE and KMAE) in models where they appear. This influence can be explained by physical separators between the two directions of traffic and the absence of level crossings, minimizing the frontal and side collision (collisions with the highest percentage of fatalities) (ANSR, 1999-2008). Another important variable is the percentage of heavy vehicles. According to the models ACV and ACVCOMB, the percentage of heavy vehicles was one of the reasons that prevented a bigger decrease in the number of accidents with victims. This can be explained by differences in size and exposure to shock of light and heavy vehicles' occupants. To pass these vehicles can be danger, both by the increased distance required to maneuver due to the length of heavy vehicles, such as the visual field obstruction of smaller vehicles' drivers. On the other hand, the so called dead angle of a heavy vehicle is significantly higher comparatively to a lighter one. This reduces vision and perception of the heavy vehicle's driver relatively to the surrounding and increases the probability of an accident.

The variable PREÇOLCOMBSPPIBPCAP has a strong influence on the present models (ACV and MORT). This influence confirms the direct interference of fuels price in road accidents, particularly accidents with casualties and fatalities.

Variables IDD_PQ (average age of car fleet) and VVEND2000PERC (percentage of sold vehicles with engine capacity exceeding 2000cc) appear only in MAEC model. These variables are related to car fleet improvements, increasing with the vehicles segment and with the vehicles age decreasing. The presence of these variables in this model shows the influence of age and vehicle's quality in fatalities that occur on higher speed roads.

6. Conclusions

The obtained models present a fairly good adjustment and can therefore, be considered as well as describing the evolution of aggregate indicators of road accidents. The constructed models present a fairly good adjustment and can therefore, be considered as good descriptors of the aggregate evolution of road accident indicators. They allow concluding that behavioral changes caused by new pieces of legislation and infrastructuration policies have significantly contributed to a reduction in road fatalities levels.

Despite the large contribution of motorway networks in road accident improvements, this is not the only influent and manipulable accidents' factor. Moreover, at some point, it will no longer make sense or it would be impracticable, building new sections and this factor's improvements, once implemented, will no longer be so evident in the indicators' decrease.

Moreover, the legislative amendments took effect on lowering the levels of road accidents. Therefore, this is a field where investment must continue in terms of rapid adoption of the best international practices and attaching to legislation aspects related to the technological evolution of vehicles (both to ensure the rapid spread of safer vehicles and to ensure a safe operation thereof).

SIVAK e TSIMHONI (cited in WILMOTS, no date) state that some of the simpler problems of road accidents have already been solved (with legislation and infrastructure improvements) and the treatment of more complex problems is needed in order to achieve a further reduction in accident ratios. These problems can only be treated if supported by studies and reviews of road accidents data. Therefore, it is essential the existence of a more detailed and rigorous database.

This last aspect is related, not directly to the results, but with the difficulties found during the execution of this study, particularly the achievement of some variables. It was unable to include (for lack of data) variables that could describe both the levels of supervision and the intensity of Road Safety awareness campaigns. As these are relevant aspects of road accident prevention policies, it is important the data availability so its effectiveness and efficiency can be evaluated. This way, the implementation of an information system to collect and provide data on traffic accidents, and of their related variables, is an important measure which will favor the evaluation of public policies in this area and, therefore, it will contribute to a quicker adoption of the most appropriate and efficient ones.

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