Impact of socioeconomic and transport indicators on road safety during the crisis period in Europe

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The risk of being involved in a road crash is typically influenced by mobility, which in turn is influenced by various socioeconomic indicators. This study aims to investigate the impact of socioeconomic and transport indicators on road safety during the economic crisis period in Europe. A database containing Human Development Index (HDI), suicides, passenger-kilometers and road fatalities per population was developed. Linear Mixed Models were applied for all the examined countries and the different groups that were selected for the period 2006-2015. The results led to the conclusion that HDI has the most important impact and its increase leads to road fatalities decrease. Moreover, the evolution of human development affects the outcomes of road crashes more than suicides and passenger-kilometers travelled. After the end of the crisis, the impact of human development is even higher. Concerning passenger-kilometers travelled, there is an increase in the relative impact on road fatalities after the end of the crisis.

Keywords: road fatalities; road safety; Human Development Index; passenger-kilometers; economic crisis

Introduction

In our modern society, road crashes have enormous social and economic costs, which makes it a priority for each country to limit them. Despite considerable efforts and relevant progress in the field of road safety, it still remains a major issue globally. Road traffic injuries are the eight leading cause of death for people of all ages and in 2016 it is estimated that around 1.35 million people lost their lives as a result of road crashes (World Health Organization, 2018). Moreover, their cost to the countries is estimated to be around 3% of their Gross Domestic Product (GDP) (World Health Organization, 2015). According to the European Commission, around 22,800 road fatalities were reported by the 27 European Union Member States in 2019 (European Commission, 2020).

The risk of involvement and injury in a road crash is typically related to mobility, which is generally expressed by the vehicle-kilometers of travel. As several studies have shown, these mobility estimates and, by extension, the level of road safety are affected by socioeconomic factors that reflect the economic development and the level of citizens' prosperity. Many studies aimed at investigating this phenomenon by examining the influence of socioeconomic factors, either alone or in combination with other transport indicators, dating since 1968 (Smeed, 1968).

Short-term analysis studies have also explored the influence of economic phenomena of specific periods on road safety. The economic recession of the early 1980s has been studied by several researchers as a probable cause of the significant decline in road crash casualties in the United States. A significant concurrent inverse relationship between the rate of unemployment and the frequency of crash involvement was revealed (Wagennar, 1984). Further studies were carried out during that recession period in order to associate the unemployment rates with road fatalities, suicides and homicides (Reinfurt et al., 1991).

The relationship between indicators that reflect the social conditions of a country and road fatalities has also been investigated in more recent studies. Unemployment rate is one of the most widely used indicators in such kind of studies. The 2008 reduction in the number of road fatalities in the United States has been investigated using historical annual data and the results pointed out that the annual change in the unemployment rate and the Consumer Price Index (CPI) are strongly correlated with the annual change in the number of road crashes and the number of fatalities in them (Kweon, 2011). In another study which was conducted in Sweden, it was found that road fatalities decrease with unemployment (Krüger, 2013). The results of a recent study which aimed to investigate the mechanisms that explain the falling road fatalities during the Great Recession in the United States, revealed that the increase of unemployment rates leads to a decrease in road fatalities (He, 2016).

Many researches have been conducted globally to investigate the impact of economic indicators on road safety, both at macroscopic and microscopic level of analysis. It is very common to model the influence of economic status and industrial production using metrics such as the GDP of each country (Antoniou et al., 2016; Li et al., 2018). A research of 2000 investigated the association between prosperity and mortality in road crashes in industrialized countries from a macroscopic point of view (1962-1990) and demonstrated that at a macroscopic level the relationship of prosperity and mortality to road crashes appears to be non-linear (Van Beeck et al., 2000). A statistical model comparing road mortality in countries of the Organisation for Economic Co-operation and Development (OECD) showed that the higher the GDP per capita, the higher the vehicle ownership in each country, whereas the number of road fatalities per registered vehicles tends to decrease over time as GDP increases (Page, 2001). More recently, researchers used linear and logarithmic models to model specific trends in road fatality mortality and income growth using panel data from 1963 to 1999 for 88 countries (Kopits & Cropper, 2005). Another study associated annual changes of GDP with related annual changes in road crash mortality rates using data for 27 European countries during the period 1975-2011. The results of this research suggested that an annual increase of GDP per capita leads to an annual increase of mortality rates and vice versa (Yannis et al., 2014).

Apart from socioeconomic factors, it is normal to use a wide variety of transport indicators in studies that aim to evaluate the road safety performance of a country or to identify in which way these indicators affect the evolution of road crashes and the related casualties. A study investigated the relationship between road fatalities and economic and transport characteristics in selected developing countries. It was observed that the rates of fatalities in road crashes are not only related to GDP per capita but they are also related to the density of vehicles per kilometer of road (Jacobs & Cutting, 1986). In 2001, the local linear trend model applied to ten European countries and used the estimated trend and estimated elasticities to determine the relationship between traffic flow and the number of road fatalities (Lassare, 2001). Another study using data for 25 members of the European Union in the period 1970-2003 showed that the shape of the road fatalities curve (ascending, stable descending) depends on the ratio of the number of vehicles to population (Yannis & Tsoumani, 2011). More recently, piece-wise linear regression models were used to identify critical changes in macroscopic trends in road crashes and it emerged that the maximum fatality rates recorded in different countries over time lied within a relatively short range of vehicle ownership, which is 200-300 vehicles per thousand inhabitants, a point at the fatality rates switched to a decreasing trend (Yannis et al., 2011).

During the last few years, several studies have been conducted in order to identify the effects of the recent economic recession on various road safety indexes (Rojo et al., 2016; Noland & Zhou, 2017; Mpogas et al., 2017). A recent research on the impact of the economic recession (2008-2010) on road crashes in OECD countries was conducted in 2017 (Wegman et al., 2017) and it has shown that GDP decline and rising unemployment mean a reduction in the number of road crashes. This research also showed that the total number of vehicle kilometers of travel did not change significantly as a result of the economic recession.

The objective of the present research is to investigate the impact of socioeconomic and transport indicators on road safety during the economic crisis period in Europe. More specifically, the present research aims to associate the Human Development Index (HDI), suicides and passenger-kilometers travelled with the road crashes' mortality rates in Europe. In order to assess the impact of the economic crisis on the relationship of these indicators with crash mortality, different models were developed for the periods before and after the end of economic crisis. Once the objective has been set, the required data were collected and the relevant database was developed. Linear Mixed Models were used for the statistical analysis. A total of eight statistical models with the same dependent and independent variables were developed; four for the five-year period 2006-2010 and four for the five-year period 2011-2015.

Methodology

Data collection and processing

In order to achieve the objective of this research, it was necessary to collect the appropriate data relating to the countries of Europe and in particular the 27 Member States of the European Union, United Kingdom, Norway and Switzerland. Data for these 30 European countries have been extracted from different data sources for the ten-year period from 2006 until 2015. More specifically, data on the number of people killed in road crashes have been obtained from the International Traffic Safety Data and Analysis Group (IRTAD) database (IRTAD, 2018) and from the Common Road Accident Database - CARE database (CARE, 2018) for countries that were not included in IRTAD database. Population data have been obtained from the World Bank database (World Bank, 2018). The HDI has been extracted from the United Nations Development Program (UNDP) database (UNDP, 2018). The Global Health Observatory of the World Health Organization (World Health Organisation, 2020) was used for suicide rates per 100,000 population data. Lastly, passenger-kilometers travelled have been obtained from the International Road Federation (IRF) – World Road Statistics (IRF, 2014; IRF, 2017).

In the present study, HDI has been selected as a representative indicator for the human development level of the countries, suicides for the social conditions of the countries and passenger-kilometers travelled as a transport indicator. It should be noted that HDI is a socioeconomic indicator that reflects both economic and social level, since it is a composite indicator including both aspects. More specifically, HDI constitutes an index that was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI is a statistic composite index of life expectancy, education and per capita income indicators. A country scores a higher HDI when the life expectancy is higher, the education level is higher and gross national income (GNI) per capita is higher (UNDP, 2019).

For the purposes of this research, the examined countries were classified into three groups based on the results of a two-step cluster analysis according to their population, GDP and the number of road fatalities in 2015 (Mihou-Archimandritou, 2018). Therefore, three groups of European countries were used, as follows:

- Group 1 – High Economic Performance Countries: Belgium, Denmark, Luxembourg, the Netherlands, Austria, Finland, Sweden, Norway, Switzerland
- Group 2 – Largest Countries: Germany, Spain, France, Italy, United Kingdom
- Group 3 – Low Economic Performance Countries: Bulgaria, Czech Republic, Estonia, Greece, Croatia, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovenia, Slovakia

During the data collection process, the only problem arose in some cases was the unavailability of the required data for all countries. More specifically, passenger-kilometers travelled for Cyprus and Ireland were not available and for this reason, these two countries were not included in the statistical analysis.

An initial investigation aimed at identifying a pattern between the evolution of HDI, suicides and passenger-kilometers travelled and the evolution of road fatalities per population during the period 2006-2015 was carried out and is presented in the following figures (Figure 1, 2 and 3). For these figures, a sample of three European countries was selected. More specifically, this sample includes one country from the High Economic Performance Countries group (Finland), one country from the Largest Countries group (France) and one country from the Low Economic Performance Countries group (Latvia).

*** Insert Figure 1 here***

Figure 1. Evolution of road fatalities per population and HDI for three countries, 2006-2015

*** Insert Figure 2 here***

Figure 2. Evolution of road fatalities per population and suicides for three countries, 2006-2015

*** Insert Figure 3 here***

Figure 3. Evolution of road fatalities per population and passenger-kilometers travelled for three countries, 2006-2015

Based on the overall picture of the previous figures, it can be observed that there is a different pattern in the relationship between the evolution of road crashes' mortality rate and the evolution of the other three variables among the countries of the three different groups. The following statistical analysis and its results is expected to shed some light on how these variables affect the number of road fatalities per population in each group of countries. In the statistical analysis of this research, two five-year periods were chosen to investigate the impact of the economic crisis on road safety. The economic recession started in 2008 and 2010 is considered the milestone year after which the economy in the majority of the European countries started to recover from the economic crisis and for this reason the period 2011-2015 could be considered as the after-crisis period (Wegman et al., 2017).

Linear Mixed Models

Statistical analyses were carried out using the Linear Mixed Model (McLean et al., 1991). The Linear Mixed Models procedure expands the general linear model so that the data are permitted to exhibit correlated and non-constant variability. It, therefore, provides the flexibility of modeling not only the means of the data but their variances and covariances as well. Linear Mixed Models' mathematical relation in matrix form is the following:

$$y = X\beta + Zu + \varepsilon,$$

Where:

y is a N×1 column vector, the outcome variable

X is a N×p matrix of the p predictor variables

β is a p×1 column vector of the fixed-effects regression coefficients (the βs)

Z is the N×q design matrix for the q random effects (the random complement to the fixed X)

u is a q×1 vector of the random effects (the random complement to the fixed β)

ε is a N×1 column vector of the residuals, that part of y that is not explained by the model, Xβ+Zu.

Results

In the context of this statistical analysis, the dependent variable was the mortality rate in road crashes, expressed as the natural logarithm of the number of fatalities in road crashes per 100,000 population. Mortality rate was correlated with the HDI, the number of suicides per 100,000 population, the square root of the passenger-kilometers (Pkm) travelled and the groups of the countries. In the present research, panel data with repeated observations for each country were analysed and for this reason Linear Mixed Models have been selected. All the explanatory variables in the Linear Mixed Models were considered as fixed effects. The results of the statistical models are presented below for all countries (Table 1) and for each group per examined time period (2006-2010 and 2011-2015) (Table 2). Moreover, it is noted that the relative influence of the independent variables of each model on the respective dependent variable is determined by the elasticity value. Relative influence (ei*) is used to quantify the influence of each variable individually, thus enabling comparisons between the influences of the different variables of the same model.

Table 1. Linear mixed model for mortality rate in all countries

	2006-2010				**2011-2015**			
	ALL COUNTRIES							
Parameter	**Estimate**	**t**	**Sig.**	**e_i^***	**Estimate**	**t**	**Sig.**	**e_i^***
Intercept	4.039	3.748	0.000		6.406	7.552	0.000	
Group=1	5.678	2.162	0.032		4.069	1.791	0.076	
Group=2	12.779	3.356	0.001		9.405	2.910	0.004	
Group=3	0[a]				0[a]			
HDI	-2.662	-2.009	0.047	-8.66	-5.929	-5.786	0.000	-22.13
Suicides	0.020	4.540	0.000	1.00	0.019	5.166	0.000	1.00
Pkm	0.031	3.370	0.001	1.41	0.038	5.613	0.000	2.19
Group=1*(HDI)	-5.957	-2.076	0.040		-4.067	-1.677	0.096	
Group=2*(HDI)	-15.894	-3.343	0.001		-12.201	-3.096	0.002	
Group=3*(HDI)	0[a]				0[a]			
Group=1*(Suicides)								
Group=2*(Suicides)								
Group=3*(Suicides)	0[a]				0[a]			
Group=1*(Pkm)	-0.068	-3.463	0.001		-0.071	-4.426		
Group=2*(Pkm)								
Group=3*(Pkm)	0[a]				0[a]			
LR test	180.500				272.760			
	Estimate	**Wald Z**	**Sig.**		**Estimate**	**Wald Z**	**Sig.**	

Residual	0.091	8.000	0.000		0.049	8.000	0.000	

[a] indicates the reference category of the categorical variable Group

The statistical models that emerged for all European countries are shown in Table 1. The results presented in the previous table indicate the following:

- The HDI has a negative relationship with the dependent variable, showing that as HDI increases, the mortality rate in road crashes decreases.
- The positive sign of suicides shows that the number of road fatalities per population and the number of suicides rate are positively correlated.
- The number of road fatalities per population increases when the value of passenger-kilometers also increases.

Based on the interactions of the country group with the examined indicators, it was found that:

- An increase in the HDI has a higher effect in road crashes' mortality rate decrease in the group of countries with high economic performance and in the largest countries compared to the countries with low economic performance.
- An increase in passenger-kilometers travelled has a lower effect in road crashes' mortality rate increase in the group of countries with high economic performance compared to the countries with low economic performance.
- Estimates for suicides were not statistically significant.

Table 2. Linear mixed model for mortality rate in each group of countries

	2006-2010				**2011-2015**			
	LOW ECONOMIC PERFORMANCE (Group 3)							
Parameter	**Estimate**	**t**	**Sig.**	**e_i^***	**Estimate**	**t**	**Sig.**	**e_i^***
Intercept	4.039	2.905	0.004		6.406	6.694	0.000	
HDI	-2.662	-1.605	0.113	-12.32	-5.929	-5.128	0.000	-24.28
Suicides	0.020	3.629	0.001	1.71	0.019	4.579	0.000	1.38
Pkm	0.031	2.693	0.009	1.00	0.038	4.974	0.000	1.00
LR test	7.910				21.547			
	Estimate	**Wald Z**	**Sig.**		**Estimate**	**Wald Z**	**Sig.**	
Residual	0.142	5.745	0.000		0.063	5.745	0.000	
	LARGEST COUNTRIES (Group 2)							
Parameter	**Estimate**	**t**	**Sig.**	**e_i^***	**Estimate**	**t**	**Sig.**	**e_i^***
Intercept	16.817	10.955	0.000		15.811	8.332	0.000	
HDI	-18.557	-9.669	0.000	-12.76	-18.131	-7.829	0.000	-67.91
Suicides					0.025	2.535	0.019	1.00
Pkm	0.047	4.810	0.000	1.00	0.061	5.859	0.000	6.70
LR test	56.694				48.118			
	Estimate	**Wald Z**	**Sig.**		**Estimate**	**Wald Z**	**Sig.**	
Residual	0.016	3.240	0.001		0.018	3.240	0.001	
	HIGH ECONOMIC PERFORMANCE (Group 1)							
Parameter	**Estimate**	**t**	**Sig.**	**e_i^***	**Estimate**	**t**	**Sig.**	**e_i^***
Intercept	9.719	5.674	0.000		10.476	5.289	0.000	
HDI	-8.619	-4.737	0.000	23.08	-9.996	-4.838	0.000	29.86
Suicides					0.029	1.703	0.096	-1.20
Pkm	-0.037	-2.976	0.005	1.00	-0.033	-2.421	0.020	1.00
LR test	46.210				70.748			
	Estimate	**Wald Z**	**Sig.**		**Estimate**	**Wald Z**	**Sig.**	
Residual	0.046	4.528	0.000		0.043	4.528	0.000	

Statistical models were also developed for each group of countries separately for the two examined periods before and after the end of economic crisis, as shown in Table 2. It is noted that in all statistical models, the independent variable with the highest influence on the number of fatalities in road crashes is the HDI. The results of the statistical models presented in Table 2 indicate the following:

- For all three groups of countries in both time periods, the HDI has a negative relationship with road crashes' mortality rate, meaning that an increase in HDI leads to a decrease in mortality rate.
- Suicides are correlated positively with the number of road fatalities per population for all statistical models except for the two statistical models of the group of largest countries and countries with high economic performance for the period 2006-2010, where suicides are not statistically significant.
- Passenger kilometers travelled have a positive relationship with the dependent variable for the groups of low economic performance countries and largest countries in both time periods. However, the same is not true for the group of countries with high economic performance. For countries with high economic performance, an increase in passenger kilometers travelled does not mean an increase in road crashes' mortality rate.

Identifying the differences between the 2006-2010 and 2011-2015 models would help to notice in which way the economic crisis has affected the number of road fatalities per population in Europe. It can be observed that the evolution of the human development influences the outcomes of road crashes more than suicides and passenger-kilometers travelled. Moreover, it can also be observed from the statistical model for all countries that after the end of the economic crisis, the impact of the human development is even higher (2.5 times higher) and regarding the passenger-kilometers' variable, there is an increase in the relative influence on the number of fatalities per population in road crashes (1.5 times higher).

Then, a sensitivity analysis was conducted, as shown in Figure 4 and Figure 5. It is shown that the HDI has the highest influence in the group of largest countries and the least influence in the group of low economic performance countries. An increase of passenger-kilometers travelled means an increase in the exposure of road users and therefore, there is a higher risk of injury in a road crash. Nevertheless, the following figures show a negative correlation between the passenger-kilometers and the number of people killed in road crashes for countries with high economic performance.

*** Insert Figure 4 here***

Figure 4. Sensitivity analysis diagrams for HDI

*** Insert Figure 5 here***

Figure 5. Sensitivity analysis diagrams for passenger-kilometers

Discussion

This paper fills an important gap in the literature on capturing the relationships between socioeconomic and transport conditions with mortality rate in road crashes during the economic crisis period in Europe. It examines contributions of three explanatory variables representing socioeconomic and transport conditions in each European country to the number of road fatalities per 100,000 population. For this purpose, eight advanced statistical models were used to investigate the relationship among the variables.

From the various stages of this research, very interesting results were achieved which were directly linked to the main objective of this paper. It was initially found that the increase in the HDI is correlated with the decrease in the number of fatalities in road crashes, indicating that a country's socioeconomic development implies a higher road safety culture. Regarding countries with high economic performance, there is a negative correlation between passenger-kilometers travelled and road crashes' mortality rate in contrast with the other groups of countries. This may be due to the fact that the countries with high economic performance have also ensured the conditions contributing to a better road safety environment and a higher road safety culture and as a result, increase in mobility does not necessarily lead to an increase in road risk exposure.

In addition, it was found that HDI has the highest influence on the group of largest countries compared to the other groups. This could be probably attributed to the fact that many social and economic inequalities exist in these countries, meaning that there is a higher flexibility for improvement in the socioeconomic conditions of a significant proportion of the population. Consequently, this improvement could be reflected in the road safety outcomes. On the contrary, HDI has the least influence on countries with low economic performance. It is noted that the countries with the lowest economic performance are also the countries with the lowest road safety performance. These countries' poor performance in road safety may also be attributed to other factors than economic ones such as lack of education, proper driver training, less strict policing, etc.

The evolution of the human development affects the outcomes of road crashes more than suicides and passenger-kilometers travelled. After the end of the economic crisis, the impact of the human development is even higher (2.5 times). For the passenger-kilometers travelled, there is an increase in the relative influence on the number of people killed in road crashes in the period after the economic crisis (1.5

times higher). Europe's economy recovers, travel and traffic load are increasing, so the impact of passenger-kilometers on road crashes is higher. In addition, between the two time periods, there appears to be a higher change in the impact of the HDI on road crashes in countries with low economic performance, and this influence is even higher over the period 2011-2015. Since the economic crisis had a higher impact on these countries and its results have been more obvious, it is likely that human development changes would more strongly determine the performance of road safety in the following years. In other words, the more a country is hit by the economic crisis, the more obvious are the effects of the recovery of the human development on road safety over time.

Finally, regarding the number of suicides, it has emerged that the increase in the number of suicides is positively correlated with the mortality rates in road crashes. The same positive relationship between the number of suicides and the number of road fatalities has also emerged in another recent research (Kandrychyn & Razvodovsky, 2017). However, this is a quite complex phenomenon that it has not been sufficiently examined and certainly requires further investigation. The division of the ten year period 2006-2015 in two distinct periods indicating the period before the end of the crisis (2006-2010) and the period after the end of the crisis (2011-2015) constitutes a limitation of the present research because time periods before and after the end of the economic crisis are not exactly the same for all the countries. Lastly, it should be acknowledged that in the present study, the effect of age-structure of the countries' population has not been taking into account. This could be considered as an additional limitation of the study as it could be expected that road fatalities and suicide rates are strong functions of age. Thus, this limitation can provide impetus for future research efforts.

In conclusion, it is proposed that the organisations that are responsible for implementing and monitoring the progress of the national road safety program in each country should take into account the influence of socioeconomic and transport indicators in the evaluation phase of the program. Moreover, the decision-making authorities should take into account various social issues which may have an impact on psychology and culture of citizens and therefore in road safety. Finally, countries should aim to improve the quality of life and education of citizens, as the increase in the HDI is associated with a reduction in the number of people killed in road crashes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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