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Transportation Research Procedia 00 (2020) 000–000

Transportation Research Procedia

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23rd EURO Working Group on Transportation Meeting, EWGT 2020, 16-18 September 2020, Paphos, Cyprus

European Countries' Road Safety Evaluation by Taking Into Account Multiple Classes of Fatalities

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Abstract

According to the annual accident report (2018) of the European Commission it is clear that during the decade 2007-2016 fatalities by mode of transport have dropped significantly inside the European Union (EU). However, there is always a place for further improvements. It is also clear that the changes in the socio-economic and demographic context of the EU countries have reported impacts on the fatalities by different modes of transport and overall, to their road safety levels. Therefore, in order to support the road safety strategies of the EU countries that have an under-performing system (in terms of road safety levels), it is essential to incorporate exposure and socio-economic factors and provide a comparative analysis of the performances of EU countries. This paper aims the support of road safety policymakers by investigating the road safety performance of 18 EU countries over the time period 2007-2016 (incorporating their exposure level and socio-economic context) and measuring the effect that these factors have on the countries' road safety performance. For the evaluation of the countries' road safety performance, a benchmarking analysis was implemented, namely Data Envelopment Analysis (DEA). The resulted technical efficiency scores of the countries in relation to their exposure and socio-economic context were used in a censored regression framework, i.e., Tobit regression analysis, for measuring the extent of relation with road safety performance. Overall, this paper aims to provide a 'picture' of the road safety level inside the EU region during the decade 2007-2016.

Peer-review under responsibility of the scientific committee of the 23rd EURO Working Group on Transportation Meeting.
Keywords: Road safety levels; Fatalities by mode of transport; Benchmarking analysis; Data Envelopment Analysis; Tobit regression model

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Peer-review under responsibility of the scientific committee of the 23rd EURO Working Group on Transportation Meeting.

1. Introduction

In 2010, the European Commission (EC) adopted the "Road Safety Programme", which aimed to halve road deaths in Europe in the decade 2011-2020. Besides the efforts and the progress that has been made with reducing the number of fatalities still, this target has not been reached yet (*EC, 2019*). The road safety problem varies systematically in the EU by country, reflecting different cultures and socioeconomic conditions, behavioral characteristics, modal shares, and levels of road infrastructure development (*Laiou et al, 2017*). Additionally, great discrepancies in road fatalities among the various groups of road users, as well as in relation to vehicle and road types also exist (*Bauer at al, 2016).*

For international analyses, risk exposure data are used as explanatory information. For instance, differences in the road safety level between countries may be explained by differences in the level of motorization, while the number of vehicle kilometers traveled by transport mode reveals differences among the different road user types which in turn may influence collision severity (*Hakkert & Braimaister, 2002*). Besides exposure measurements, socio-economic factors are highly interrelated with road fatalities. A correlation between the GDP and road fatalities at both short-term and long-term levels in European countries has been found (e.g. *Yannis et al., 2014; Antoniou et al., 2016*), indicating the strong relationships between economic developments and traffic fatalities. A significant relationship between socio-economic and demographic factors and road fatalities over the globe (121 United Nation member countries) has also been found (*Dimitriou et al., 2017*). Understanding the differences in exposure and socio-economic developments across different countries can help identify which policies and interventions are effective in facing the road safety problem and thus, transferring good practices from the best-performing (from a road safety perspective) countries to those less so. Several studies have focused on the evaluation of the performance of different countries in order to provide a "picture" of their road safety performance and identify the under-performing countries (e.g. *Nikolaou and Dimitriou, 2018*).

This paper developed a straightforward methodological approach for evaluating the road safety performance of 18 EU countries during the time period 2007-2016 by taking into account exposure and socio-economic indicators. The novelty approach of this paper (as far as we know from the literature) is the evaluation of the countries' road safety performance for the different modes of commuting. The first stage of this approach was the evaluation of the countries' road safety performance using an extensive application of benchmarking analysis, namely, Data Envelopment Analysis (DEA). The resulted efficiency levels of performance for each country were used in the second-stage approach for measuring the extent that exposure and socio-economic context of the countries are affecting their efficiency level. Thus, the questions that this paper addressed are: Which countries are under-performing concerning all different modes for a varying period? Which best-performing countries should the under-performing follow for overcoming their performance? Which factors are affecting the efficiency level of the countries' road safety and to what extent?

2. Methodological Framework

This section presents the fatality, exposure, and socio-economic data collected for the purposes of this study and provides a brief description of the methodologies applied for evaluating the countries' road safety performance.

2.1. Data Collected

Fatality data were retrieved for 18 EU countries over the period 207-2017 form the CARE database, the official EU database with disaggregate accident data. Fatality data for different transport modes and road user types were considered, i.e. car occupants, Powered Two Wheelers (PTWs), Heavy Goods Vehicles (HGVs), pedestrians and cyclists. All these variables are expressed as an indicator "mortality rate" (fatalities per million population). Figure 1 presents the overall fatalities per population during the period 2007-2017. Due to a lack of fatality data for some countries (i.e. Lithuania, Ireland, and Slovakia) for 2017, this year was not considered in the analysis. The figure presents a percentage of mortality rate for each instant year and thus the countries were ranked based on this percentage. Lithuania recorded the highest mortality rate in 2007, while Bulgaria and Romania recorded the worst performance in terms of road fatalities in 2017.

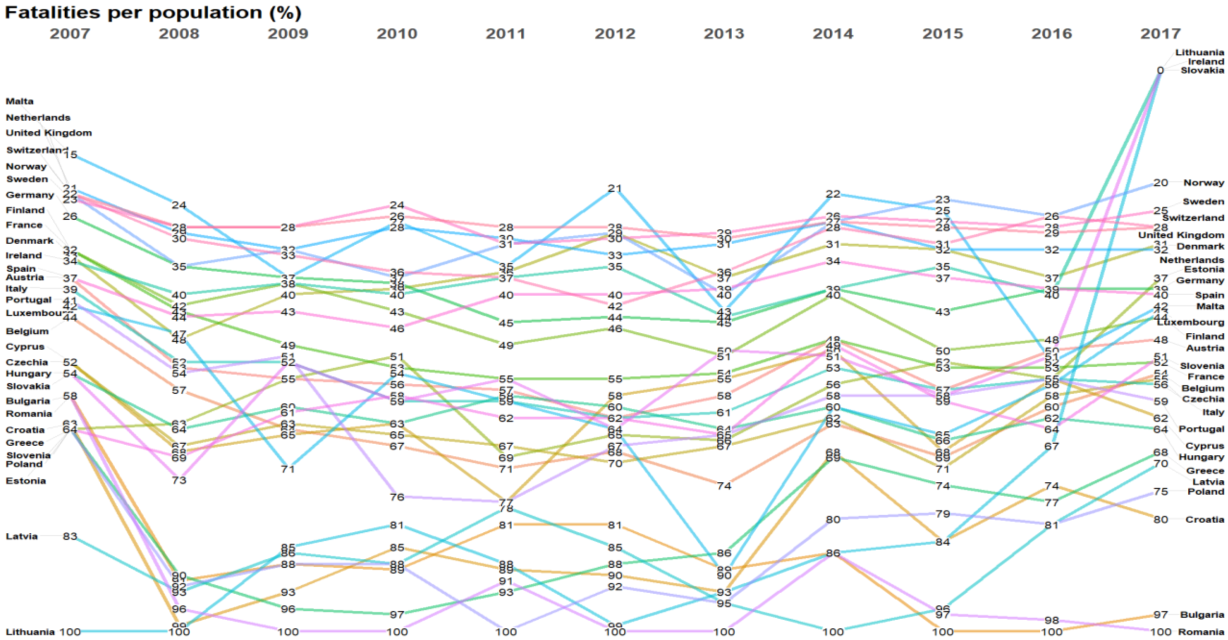

Fig. 1. Mortality rate (fatalities per million population) concerning 30 EU countries during the time period 2007-2017.

Fig. 2. Mortality rate expressed for each different mode of road users: (a) Car occupants; (b) PTW; (c) HGV; (d) pedestrians; (e) cyclists.

Figure 2 shows five different treemaps for the mortality rate for each transport mode, concerning the overall period 2007-2016. Concerning the car occupant fatalities, Bulgaria is in the top place recording the highest number of fatalities and Malta is in the last place. As for the PTW fatalities, Greece and Cyprus are in the “leading” positions. Moving to the HGV related mortality rates, Portugal, Latvia, Poland, and Croatia record the highest numbers. Additionally, the highest pedestrian mortality rates have been recorded in Romania, Latvia, Poland, and Lithuania, while the highest cyclist mortality rates appear in the Netherlands, Romania, Poland, and Hungary recorded the highest number of mortality rates in the overall time period.

The factors that were used for the analysis of the EU countries’ road safety performance over the period 2007-2016 incorporated the exposure and socio-economic context of the countries and were namely: Gross Domestic Product (GDP) per capita, passenger cars traffic (billion pkm), buses & coaches traffic (billion pkm), total length of road network, pump price for diesel fuel, registered PTWs (thousand), registered passenger cars (thousand), total registered vehicles (thousand) and new passenger car registrations (thousand).

2.2. Benchmarking Analysis: Data Envelopment Analysis

This section provides the mathematical formulation of Data Envelopment Analysis (DEA). In particular, an extensive form of DEA is developed providing comparable efficiency scores of the EU countries’ road safety performance throughout the decade 2007-2016 and thus a realistic “picture” of their standing based on their performance.

DEA is a linear programming methodology that compares the service units (e.g., countries) considering the socio-economic and demographic factors and provides the rankings of the countries (best-performing or under-performing), in terms of performance. The measure of efficiency in DEA is the maximum of a ratio of weighted outputs to weighted inputs subject to some conditions-constrains. However, for the purposes of using DEA for studying the road safety performance of the countries, it is important that the measure of efficiency change, i.e. minimum output level (fatalities) given that of the inputs. Therefore, the suitable adapted to road safety framework DEA equation is given below:

$$min\theta_o^t \quad (1)$$

Subject to:

$$\sum_{j=1}^{s} x_i^t \lambda_j^t \geq x_{io}^t; i = 1, \dots, m \quad (2)$$

$$\sum_{j=1}^{m} y_{ij}^t \lambda_j^t \leq \theta_o^t y_{ro}^t; r = 1, \dots, s \quad (3)$$

$$\lambda_j^t > 0; j = 1, \dots, n \quad (4)$$

Where is the uniform proportion reduction in the DMU_o’s and λ_j^t with j=1,…,n is the dual weight given to the jth DMU’s inputs and outputs. The DEA method that was used in this paper was based on a multi-output/multi-input structure. Additionally, DEA led to a best-practice frontier by identifying the frontier units (best-performing countries) and thus the under-performing countries. Using this ability of DEA, we were able to observe which best-performing countries are benchmarks for the under-performing countries for every explanatory factor.

2.3. Tobit Regression Model

Obtaining the efficiency scores of the EU countries’ road safety performance based on a best-practice frontier (DEA), was not enough for obtaining the goal of this paper, which was the support to the effort of EU’s policymakers for improving the road safety conditions inside of Europe. Therefore, a suitable method was developed for identifying the extent that the factors (exposure and socio-economic) are affecting the EU countries’ road safety performance.

The concept of Tobit was employed for analyzing what determinants affect the efficiency of the region's road safety performance. The reason for developing Tobit and not a classic regression model was due to the capability of Tobit of analyzing censored data and thus Tobit is also known as the censored regression model. The mathematical formation of Tobit model is based on *Tobin (1958)* work and can be seen below:

$$\begin{aligned} y_t &= X_t\beta + u_t \quad if \;\; X_t\beta + u_t \; > 0 \\ &= 0 \qquad\qquad if \;\; X_t\beta + u_t \; \leq 0 \\ & \qquad t = 1,2,\ldots,N. \end{aligned} \tag{5}$$

Where, $\boldsymbol{N}$ is the number of observations (i.e., 18 countries), $\boldsymbol{y_t}$ is the dependent variable (efficiency scores), $\boldsymbol{X_t}$ is a vector of independent variables, $\boldsymbol{\beta}$ is a vector of unknown coefficients, and $\boldsymbol{u_t}$ is an independently distributed error term assumed to be normal with zero mean and constant variance σ^2.

3. Application and Results

This paper investigated the road safety performance of 18 EU countries based on their ten years' fatality record (2007-2016) on five different modes of transportation (car, PTW, HGVs, pedestrian, and cyclists) using their exposure and socio-economic context. Therefore, the methodology that was developed was based on a two-stage approaches.

In the first stage, the countries' road safety performance was evaluated and the best-performing and under-performing countries were found. Figure A1 in Appendix A presents the frontiers obtained from the DEA method concerning the year 2016. As can be observed from the DEA frontier of 2016, Spain, Sweden, France, Italy, United Kingdom, Germany, Finland, Netherlands, and Denmark appeared as benchmarking countries for the under-performing countries in exposure and socio-economic indicator examined. This must be taken under consideration especially from the national road safety authorities for taking examples from these countries if they want to improve their performance on all the different modes of commuting.

The next stage approach was developed based on the outputs obtained from the DEA method, i.e. the efficiency scores of the countries' road safety performance. In detail, the efficiency scores were used as outputs in the Tobit regression models. However, prior the implementation of Tobit regression a preliminary data analysis (correlation analysis) was developed for discarding from the dataset collinear variables. The omitted from the dataset collinear variables were passenger cars traffic (billion pkm), buses & coaches traffic (billion pkm), registered passenger cars (thousand), total registered vehicles (thousand) and new passenger car registrations (thousand). Thus, only four variables were remained in the dataset: Gross Domestic Product (GDP) per capita, total length of road network, pump price for diesel fuel, registered PTWs (thousand), registered passenger cars (thousand).

The Tobit regression models that were developed revealed the extent of affection of these variables to the efficiency scores of the EU countries' road safety performance. Table A1 in Appendix A presents the outcomes from the Tobit models. As can be seen from the table, diesel price has a significant effect on the countries' road safety performance, indicating that as the diesel price of a country increases the performance of the country also increases. This can be justified as the increase of fuel prices leads to lower use of private motorized vehicles and thus, less exposure to fatality risk. The number of registered vehicles has also a positive relationship with the efficiency levels of the countries, which is in line with previous literature findings indicating that while a positive relationship among the vehicle ownership and fatality risk exists, after a specific motorization rate this relationship is reversed (Yannis et al, 2011). Finally, the relationship of GDP and efficiency levels of the countries shows that economic prosperity plays a beneficial role in the road safety performance of the countries, which is potentially achieved through road infrastructure improvements, vehicle fleet renewal, or associated and cultural changes. However, it should be noted that these results are not consistent during the overall examined period, with some of these indicators not being found statistically significant in all models, which underlines the need for further exploration of this phenomenon.

4. Conclusions

The current study developed a straightforward methodology in order to evaluate the road safety performance of 18 EU countries during an economically unstable time period (2007-2016). The novelty of this paper is the evaluation of the countries' performance taking into account the different road safety patterns of the countries as reflected by the traffic fatalities recorded by transport mode. The paper aimed to rank the road safety performances of the countries concerning each transport mode, by taking into account differences in exposure level and socio-economic situation as well as to highlight the best-performing countries, that could act as benchmarks for the underperforming countries for each different explanatory factor. Additionally, the factors that mainly contribute to the performances of the countries were also explored.

This methodology which does not focus only on the number of collisions, injuries or fatalities, but also takes into account different exposure and socio-economic measurements of the countries, as well as the different transport modes involved in the road accidents, aims to support decision-making process to take actions that could be considered fairer in terms of the road users involved. The results obtained from this paper highlight the countries and the factors that must be taken into consideration in order to achieve the optimum goal which is the decrease or even the elimination of road fatalities. The next research steps would include the exploration of this phenomenon through the use of more indicators covering all EU countries.

Appendix A.

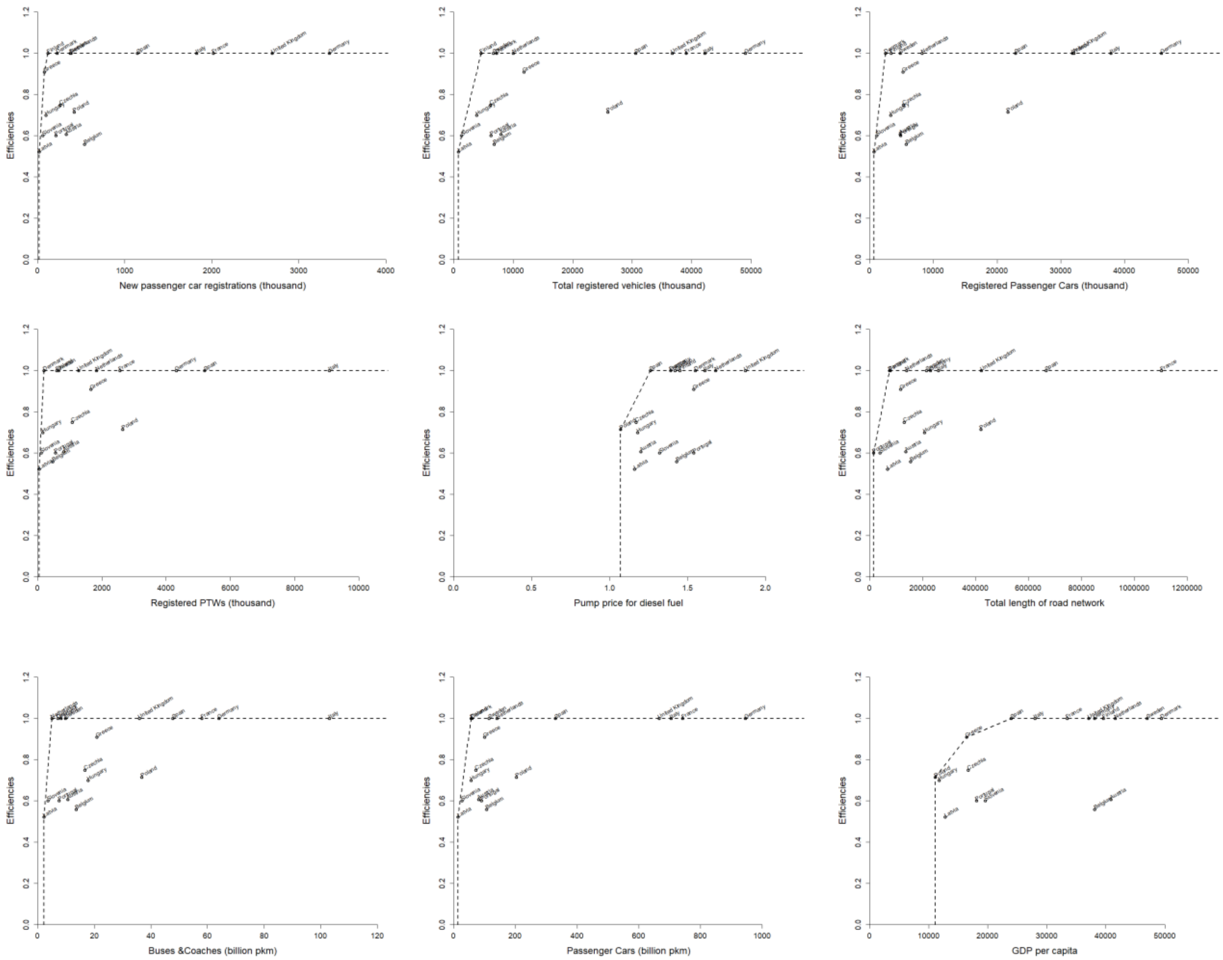

Fig. A1. DEA frontier based on the ten explanatory variables (2016).

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Table 1. Results from the Tobit regression models.

Variables/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Intercept	0.219 (0.370)	-7.260e-03 (0.325)	0.819*** (0.049)	0.470*** (0.092)	0.751*** (0.057)	0.615*** (0.095)	0.058 (0.338)	-0.110 (0.288)	0.059 (0.311)	0.198 (0.229)
GDP per capita	-	-	-	8.714e-06** (3.192e-06)	-	6.102e-06. (3.152e-06)	-	-	-	-
Total length of road network	-	-	-	-	-	-	-	-	-	-
Pump price for diesel fuel	0.468. (0.258)	0.553* (0.234)	5.163e-06. (2.732e-06)	-	-	-	0.356* (0.178)	0.482** (0.160)	0.439* (0.196)	0.399* (0.166)
Registered Passenger Cars (thousand)	-	5.268e-06. (2.846e-06)	-	8.238e-06** (2.586e-06)	6.494e-06* (3.073e-06)	5.024e-06. (2.728e-06)	7.794e-06** (2.602e-06)	6.989e-06** (2.457e-06)	6.316e-06* (2.602e-06)	5.512e-06* (2.392e-06)
Log-Lik.	5.926	8.873	8.310	9.128	5.719	7.845	8.524	9.417	8.358	10.047
AIC	-5.852	-9.745	-10.620	-10.256	-5.437	-7.691	-9.048	-10.833	-8.716	-12.094

Note: *Parenthesis denotes the standard error of the variables*

-: denotes the non-statistically variables that were omitted from the model

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