DEVELOPING A GLOBAL ROAD SAFETY MODEL

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ABSTRACT

Road accidents constitute a major social problem in modern societies, with road traffic injuries being estimated to be the eighth leading cause of death globally. The need for action based on evidence based policy making becomes more and more pronounced. In this context, this paper presents SafeFITS, a global road safety model, developed for the United Nations Economic Committee for Europe, which is based on global historical road safety data (72 indicators for 130 countries) and may serve as a road safety decision making tool for three types of policy analysis, i.e. intervention, benchmarking and forecasting analysis. A hierarchical conceptual framework of five layers of the road safety system is suggested (namely, economy and management, transport demand and exposure, road safety measures, road safety performance indicators, and road safety outcomes), and a dedicated database was developed with various road safety indicators for each layer. A two-step approach was opted for the purposes of the research, including the calculation of composite variables and then their introduction in a regression model, and the development of a model on the basis of short-term differences, accumulated to obtain medium- and long-term forecasts. The model developed has overall satisfactory performance and acceptable prediction errors, and preliminary validation provided encouraging results. Its usage might be proved highly useful for testing road safety policies, taking however into account the model limitations, mostly related to data availability and accuracy, and the recommendations for its optimal use.

Key-words: global road safety model, decision making tool, global database.

INTRODUCTION

Background and objectives

Road accidents constitute a major social problem in modern societies, with road traffic injuries being estimated as the eighth leading cause of death globally. Moreover, more than half of the people killed in traffic accidents are young, aged between 15 and 44 years, thus a heavy burden is put on people just entering their most productive years. Particularly in low and middle income countries, road traffic injuries rates are twice those in high income countries and still increasing. This can be partly attributed to rapid motorization in many developing countries, without road safety related investment. Current trends suggest that, unless action is taken, traffic injuries will become the fifth leading cause of death by 2030, with the disparity between high- and low-income countries further increasing (*1*).

In order to guide countries on taking concrete, national-level actions to achieve this goal, a Global Plan of Action was developed (*2*) by the United Nations (UN), intended to serve as a guiding document for countries, and at the same time to promote coordinated action. In April 2014, the UN General Assembly Resolution 68/269 commended member states that have developed national road safety plans in line with the Global Plan of Action and encouraged member states that have not yet done so, to adopt such a plan.

Within this context, the United Nations Economic Commissions for Europe launched the Safe Future Inland Transport Systems (SafeFITS) project, which aims to develop a road safety decision making tool for national and local governments both in developed and developing countries, based on the related scientific knowledge and data available worldwide. The tool is intended to assist governments and decision makers to decide on the most appropriate road safety policies and measures in order to achieve tangible results.

This paper presents a global road safety model, developed within the SafeFITS project, which is based on global road safety data (72 indicators for 130 countries) and may serve as a road safety decision making tool for three types of policy analysis, i.e. intervention, benchmarking and forecasting analysis. A conceptual framework of five layers of the road safety system is suggested, and a dedicated database was developed with various road safety indicators for each layer (i.e. fatalities and injuries, performance indicators, road safety measures, economy and background). A two-step modelling approach was implemented the purposes of the research, including first the calculation of composite variables, and then their introduction in a generalized linear model correlating them with road safety outcomes.

Literature Review

Research on modelling the evolution of road safety at international level is extensive, and several studies aimed to identify the factors that mostly affect the road safety performance of the countries and forecast future developments. An extensive review of the literature is beyond the scope of this paper, and the reader is referred to (*3*, *4*). The main studies relevant to the context of this research are outlined below.

Page (*5*) compared road safety levels and trends in OECD countries from 1980 to 1994. The statistical model applied, pooling cross-sectional and time series data, supplies estimates of elasticity to the fatalities for each of seven exogenous to road safety variables examined, and a rough estimate of the safety performance of countries. Dupont et al. (*6*), presented a unified methodology for modelling the evolution of road safety in 30 European countries, which was also used for forecasting fatalities up to 2020. Annual exposure and fatality data were analyzed with the bivariate latent risk time series model.

Research in highly motorized countries has shown that road traffic is growing in a less than exponential way, while the macroscopic trends of casualty rates are shown to decay exponentially (*7*). In another study (*8*) piece-wise linear regression models were fitted to identify critical changes in macroscopic road accident trends in European countries, and the results suggested that the maximum fatality rates experienced in various countries over time lied within a relatively short range of vehicle ownership, namely around 200–300 vehicles per 1000 inhabitants, a point at which the fatality rates switched from an increasing trend to a decreasing one.

Other studies aimed to forecast road fatalities through the examination of the relationship between economic and road safety developments. Van Beeck et al. (*9*) examined cross-sectional and longitudinal associations of traffic related variables with the prosperity level of 21 industrialized countries. In a long-term perspective, the relation between prosperity and traffic accident mortality appears to be non-linear, since economic development first leads to a growing number of traffic related deaths, but later becomes protective. Additionally, Kopits and Cropper (*10*) examined the relationship between traffic fatality risk and per capita income, and used it to forecast traffic fatalities by geographic region by using panel data for 88 countries. It was found that the per capita income at which traffic fatality risk (fatalities/population) begins to decline is $8600 (1985 international dollars) when separate time trends were used for each geographic region. Authors also concluded that if developing countries follow historic trends, it will take many years for them to achieve the motor vehicle fatality risks of high income countries.

A study (*11*) sets out the framework for the development of a comprehensive set of indicators to benchmark road safety performances of countries or of sub-national jurisdictions based on the SUN-flower pyramid. Three types of performance indicators for road safety are distinguished: road safety performance indicators, policy performance indicators and implementation performance indicators, which are embedded in a policy context, 'the structure and culture of a country'. The three indicators are suggested to be combined into a composite index.

Moreover, Shen et al (*12*) described the theoretical background of the benchmarking approach and determined five core activities for road safety benchmarking, with the development of a road safety index being highlighted as the most valuable tool. The study highlighted the large differences in reporting practices and definition in different countries concerning fatality data and the lack of reliable and comparable data concerning road user behavior or some risk factors, such as infrastructure. Analysis at disaggregated level of both road safety outcomes and exposure was also suggested as disaggregated data allow the examination of unique interactions in a way that aggregated data cannot.

Research Challenges

There are several challenges involved in the development of the SafeFITS model:

- The relationships between indicators and road safety outcomes are complex and in some cases random. The literature suggests that the effect of an indicator (economy, exposure, measure or intervention, etc.) may vary considerably in different countries and time periods, and there may be several contextual effects (known as modifying conditions) affecting the size and type of the relationship between indicator and road safety outcome. Consequently, the problem is multi-dimensional, and transferability of known causalities in a global context is not recommended.
- Existing knowledge on road safety causalities is incomplete, as there are several key indicators for which very few results are available. Moreover, most existing causalities

identified in the literature are based on analyses from industrialized countries, and it is highly unlikely that these estimates can be safely transferred to emerging economies.

- There is lack of data on several indicators and road safety outcomes at international level. There are very few databases with global road safety data and performance indicators, and in these databases there are several limitations due to lack of data for several countries, especially developing countries. For example, safety performance indicators, which are known to significantly associate with road safety outcomes, are very partially available, even for industrialized and good performing countries.

In order to meet the objectives of this research, an appropriate analysis methodology was developed, allowing to address the main challenges of the project as much as possible within the limitations of the existing data.

METHODOLOGY

Conceptual framework

The methodological framework designed combines the five road safety pillars of Global Plan of Action (*2*) with the concept of the SUNflower pyramid (13), and suitably adjusted in order to serve the needs of the research. As a result, the road safety management system is described as a hierarchical structure that includes five layers, as follows:

- The first layer, Economy & Management, reflects the structural, economic, cultural and regulatory characteristics (i.e. policy input) of each country, that are related to road safety performance.
- Transport demand and Exposure, at the second layer, reflects the characteristics of the transportation system and the exposure of the population due to urbanization and urban sprawl, modal split (share of trips per mode), road network type, share of traffic (vehicle- and passenger-kilometers) of travel per mode and per road type etc., which are all related to road risk.
- Road Safety Measures (policy output), at the third layer, are a result of structural and economical characteristics.
- To link these three layers to the actual road accident outcomes, an intermediate layer specifies the operational level of road safety in the country, containing road safety performance indicators (RSPIs) on issues related to the five pillars (e.g. speeding, drinking and driving, road network, the main features of the vehicle fleet, etc.).
- Final outcomes expressed in terms of fatalities and injuries (road casualties) are then necessary to understand the scale of the problem. This type of information is found at layer 5, and consists of different types of road risk indicators.

Modelling Approach

The present research needs an explanatory approach for modelling road safety outcomes, as the main interest is the development of a model that may be useful for testing policy scenarios. In this context, it is necessary to take into account as many indicators as possible. Moreover, efficient forecasting of future developments needs to take into account previous developments, therefore make explicit consideration of the time dimension. For example, countries for which fatalities have been increasing in the last few years, are more likely to exhibit the same trend in the coming years (and vice versa) (*3*). In order to meet these requirements, a two-step approach was opted for the purposes of the research, which includes the calculation of composite variables and then their introduction in a generalized linear model explicitly taking into account past developments (namely on the basis of short-term differences, accumulated to obtain medium- and long-term forecasts, as described below).

Each layer of the modelling framework may comprise numerous different indicators, from the five pillars of the UN Global Plan for Action (*2*): road safety management, road user, vehicle, road, post-crash care. In order to reduce the number of dimensions of the analysis, while exploiting as much information as possible, the analysis of composite variables (i.e. combinations of indicators), instead of individual indicators was selected.

Each layer can be described by a composite variable (denoted as [Composite Variable] in the following), estimated as a function of several indicators. Overall, for a set of countries, (i) fatalities and injuries specific indicators are considered, (j) specific safety performance indicators, (k) road safety measures indicators, (l) transport demand and exposure indicators, and (m) economy and management indicators. More specifically, each composite variable is defined as a linear combination of indicators as follows:

[Fatalities and Injuries] = α_1 ** (Fatalities and Injuries Indicator 1) +* α_2 ** (Fatalities and Injuries Indicator 2) + …+* α_i ** (Fatalities and Injuries Indicator i) + e* *(1a)*

[RSPI] = β_1 ** (RSPI Indicator 1) +* β_2 ** (RSPI Indicator 2) + …+* β_k ** (RSPI Indicator j) + v* *(1b)*

[Road Safety Measures] = γ_1 ** (Road Safety Measures Indicator 1) +* γ_2 ** (Road Safety Measures Indicator 2) + …+* γ_k** (Road Safety Measures Indicator k) + w* *(1c)*

[Transport demand & exposure] = δ_1 ** (Transport demand & exposure Indicator 1) + …+* δ_l ** (Transport demand & exposure l) + y* *(1d)*

[Economy & Management] = ε_1 ** (Economy & Management Indicator 1) +* ε_2 ** (Economy & Management Indicator 2) + …+* ε_m ** (Economy & Management Indicator m)+ z* *(1e),*

with α, β, γ, δ, ε *parameters to be estimated, and e, v, w, y, z error terms expressing the uncertainty in the estimation of the composite variables.*

There are several methods for calculating composite variables, ranging from simple weighting and standardization techniques, to statistical techniques (*14*, *15*, *16*). Techniques such as factor analysis are also most appropriate for the estimation of composite variables.

In the next step, the development of a model linking road safety outcomes with composite variables was pursued. The objective of this analysis is to estimate the effect of individual indicators on road safety outcomes, through the composite variables. A logarithmic model is outlined as follows:

Log[Fatalities & Injuries]$_i$ *=* $A_i + K_i$ ** [Economy & Management]*$_i$ *+* L_i ** [Transport demand & Exposure] + Mi * [Road Safety Measures]*$_i$ *+* N_i ** [RSPI]*$_i$ *+* ε_i *(2)*

with (i) countries, ***A****, K,* ***L****,* ***M, N*** *parameters to be estimated, and* $\boldsymbol{\varepsilon}$ *error term expressing the uncertainty in the estimation of the relationship.*

However, as mentioned above, the relationships between road safety outcomes and indicators (individual ones or sets of indicators in a composite variable) depend on the underlying trends in the evolution of outcomes. The hierarchy of road safety management systems described above depicts a “snapshot” of the system on a given year (*13*, *17*).

Consequently, it is necessary to account for this underlying trend, so that the effects of indicators may be truly attributed to the changes in the values of the indicators and not to the existing trend.

In theory, there are two approaches for modelling road safety developments (4):

- A short-term analysis, which may correlate short-term (e.g. annual) differences in road safety outcomes with short-term (e.g. annual) differences in other indicators (e.g. GDP, vehicle-kilometers of travel) (e.g. *18*).
- A macroscopic analysis, which uses a regression of road safety outcomes and other indicators over the examined time period.

An optimal and methodologically recommended approach, especially when there is interest in a group (panel) of countries would be to combine short term and long term analysis in a model aggregating (i.e. grouping together) the estimates of individual countries.

A detailed presentation of these techniques and their applications is beyond the scope of the present report, a full review is presented in (*4*). It should be underlined, however, that these techniques do not fully fit the purpose of the present research, and adjustments are needed for a more explanatory model not heavily depending on long series of historical data (which are not available for many countries).

The time dimension can be taken into account by implementing a medium-term forecasting approach, on the basis of the developments over the last few years, for which data is available. By applying the same approach on the future forecasted outcomes, long-term forecasts may be also obtained under certain conditions. The key variable that was taken into account in the forecasts to account for past and future developments is GDP. Several recent studies have shown that, in the absence of mobility and exposure data (e.g. vehicle- and passenger-kilometers of travel), GDP is considered an appropriate indicator for modelling and forecasting road safety developments (*10, 4*). Terms are introduced in the models, relating the road safety outcomes of year t to those of previous years, and to GDP (or its development over the same period) (*18*).

The final specification of the generalized linear model of Equation (2) including of short-term differences (τ years) in fatality rates is as follows:

$$Log(Fatalities\ per\ Population)ti = A_i + Log(Fatalities\ per\ Population)_{(t-\tau)} + B_i * GDP_{ti} + K_i * [Economy\ \&\ Management] + L_i * [Transport\ demand\ \&\ Exposure]_{ti} + M_i * [Road\ Safety\ Measures]_{ti} + N_i * [RSPI]_{ti} + \varepsilon_i \quad (3)$$

DATABASE

The database was developed in order to cover the structure of the road safety management system as adopted in the context of the SafeFITS model development. This structure includes the five layers and five pillars referred in the methodology. The relevant data were explored in international databases, such as World Health Organization (WHO) database, United Nations (UN) database, World Bank database, International Road Federation (IRF), OECD databases etc., aiming to select representative indicators for each layer and collect reliable and most recent data on these indicators for the greatest possible number of UN Member States. Consequently, data were collected for 130 countries, namely the countries with population higher than 2,8 million inhabitants, to ensure sufficient road safety outcomes sample for statistical analysis for 2013, for which there are the latest available fatality data. An overview of the indicators included in the database is given in Table 1.

TABLE 1 Overview of indicators in the database

Number	Variable	Source
1	Population in thousands (2013)	World Bank Database
2	Area (sq km) (2013 or latest available year)	World Bank Database
3	Projected Gross Domestic Product per capita in 2010 US $ (2015-2030)	ERS International Macroeconomic Dataset
4	Gross national income per capita in US $ (2013 or latest available year)	World Bank Database
5	Percentage of popualtion under 15 years old (2013)	World Bank Database
6	Percentage of popualtion over 65 years old (2013)	World Bank Database
7	Percentage of urban population (2013)	World Bank Database
8	Existence of a road safety lead agency (2013)	WHO, 2015
9	The lead agency is funded (2013)	WHO, 2015
10	Existence of national road safety strategy (2013)	WHO, 2015
11	The strategy is funded (2013)	WHO, 2015
12	Existence of fatality reduction target (2013)	WHO, 2015
13	Length of total road network (km) (2013 or latest availbale year)	IRF, 2015
14	Percentage of motorways of total road network (2013 or latest available year)	IRF, 2015
15	Percentage of paved roads of total road network (2013 or latest available year)	IRF, 2015
16	Total number of vehicles in use (2013 or latest availble year)	IRF, 2015
17	Number of passenger cars in use (2013 or latest availble year)	IRF, 2015
18	Number of buses/motorcoaches in use (2013 or latest availble year)	IRF, 2015
19	Number of vans and lorries in use (2013 or latest availble year)	IRF, 2015
20	Number of powered two wheelers in use (2013 or latest availble year)	IRF, 2015
21	Total number of vehicle kilometers in millions (2013 or latest available year)	IRF, 2015
22	Total number of passenger kilometers in millions (2013 or latest available year)	IRF, 2015
23	Number of road passenger kilometers in millions (2013 or latest available year)	IRF, 2015
24	Number of rail passenger kilometers in millions (2013 or latest available year)	IRF, 2015
25	Total number of tonnes-kilometers in millions (2013 or latest available year)	IRF, 2015
26	Road Safety Audits on new roads (2013 or latest available year)	WHO, 2015
27	Implementation of ADR	UNECE
28	Existence of national speed law (2013)	WHO, 2015
29	Maximum speed limits on urban roads (2013)	WHO, 2015
30	Maximum speed limits on rural roads (2013)	WHO, 2015
31	Maximum speed limits on motorways (2013)	WHO, 2015
32	Vehicle standards-seat belts (2013)	WHO, 2015
33	Vehicle standards-seat belt anchorages (2013)	WHO, 2015
34	Vehicle standards-frontal impact (2013)	WHO, 2015
35	Vehicle standards-side impact (2013)	WHO, 2015
36	Vehicle standards-Electronic Stability Control (2013)	WHO, 2015
37	Vehicle standards-Pedestrian Protection (2013)	WHO, 2015
38	Vehicle standards-child seats (2013)	WHO, 2015
39	Existence of national drink-driving law (2013)	WHO, 2015
40	BAC limits less than or equal to 0.05 g/dl (2013)	WHO, 2015
41	BAC limits lower than or equal to 0.05g/dl for young/novice drivers (2013)	WHO, 2015
42	BAC limits lower than or equal to 0.05g/dl for commercial drivers (2013)	WHO, 2015
43	Existence of national seat-belt law (2013)	WHO, 2015
44	The law applies to all occupants (2013)	WHO, 2015
45	Existence of national child restraints law (2013)	WHO, 2015
46	Existence of national helmet law (2013)	WHO, 2015
47	Law requires helmet to be fastened (2013)	WHO, 2015
48	Law requires specific helmet standards (2013)	WHO, 2015
49	Existence of national law on mobile phone use while driving (2013)	WHO, 2015
50	The law applies to hand-held phones (2013)	WHO, 2015
51	The law applies to hands-free phones (2013)	WHO, 2015
52	Demerit/Penalty Point System in place (2010)	WHO, 2013
53	Training in emergency medicine for doctors (2013)	WHO, 2015
54	Training in emergency medicine for nurses (2013)	WHO, 2015
55	Effectiveness of seat-belt law enforcement (2013)	WHO, 2015
56	Effectiveness of drink-driving law enforcement (2013)	WHO, 2015
57	Effectiveness of speed law enforcement (2013)	WHO, 2015
58	Effectiveness of helmet law enforcement (2013)	WHO, 2015
59	Seat-Belt wearing rate-Front (2013 or latest available year)	WHO, 2015
60	Seat-Belt wearing rate-Rear (2013 or latest available year)	WHO, 2015
61	Helmet wearing rate-driver (2013 or latest available year)	WHO, 2015
62	Estimated % seriously injured patients transported by ambulance (2013)	WHO, 2015
63	Number of hospital beds per 1,000 population (2012 or latest available year)	Wold Bank Database
64	Reported number of road traffic fatalities (2013 or latest available year)	IRF, 2015
65	Estimated number of road traffic fatalities (2013 or latest available year)	WHO, 2015
66	Distribution of fatalities by road user(%)-Drivers/passengers of 4-wheeled vehicles (2013 or latest available year)	WHO, 2015
67	Distribution of fatalities by road user(%)-Drivers/passengers of motorized 2- or 3-wheelers (2013 or latest available year)	WHO, 2015
68	Distribution of fatalities by road user(%)-Cyclists (2013 or latest available year)	WHO, 2015
69	Distribution of fatalities by road user(%)-Pedestrians (2013 or latest available year)	WHO, 2015
70	Distribution of fatalities by gender(%)-male (2013 or latest available year)	WHO, 2015
71	Distribution of fatalities by gender(%)-female (2013 or latest available year)	WHO, 2015
72	Attribution of road traffic deaths to alcohol (%) (2013)	WHO, 2015

An issue that had to be handled during the data preparation was the imputation of the missing values. First, for those variables and countries that there were available time-series, the latest available data were used for 2013. For the remaining countries, for which there were no available data, their substitution with the known mean value was selected. On that purpose, the countries were separated into three groups based on their motorization level, road safety performance and economic performance (low, middle and high performance). Then, these groups were divided into six regions. Thus, the missing values of each indicator of the countries were filled with the known mean value of the indicator in the available countries in their regions. Wherever the available regional data were not sufficient, the overall mean of each of the 3 groups was used.

MODEL DEVELOPMENT

Estimation of composite variables

The factor analyses were implemented on each one of the layers of the road safety system (economy and management, transport demand and exposure, measures, road safety performance indicators, and fatalities & injuries), constrained to yield one factor per layer, an approach which lies within the family of "confirmatory" rather than exploratory factor analysis. It is noted however that exploratory factor analysis indicated that each layer is described by a small number of factors.

The fatality rate per population was used as main dependent variable for two reasons: first, it is the most common indicator, available for all countries, also with adequate historical data; and second, it is known to strongly correlate with GDP and SPI indicators. There were no sufficient data for additional indicators of road safety outcomes to estimate a composite dependent variable.

Table 2 shows the factor loadings and score coefficients estimated by the confirmatory factor analysis of each one the indicators. Indicators with 'loadings' higher than 0.3 (which was the threshold set) were included in the calculation of the composite variables per layer:

- Economy and Management: indicators related to the demographic distribution (population <15 or >65 years old, population living in urban areas) are those with the highest loadings amongst, complemented with some elements of the road safety management system (national strategy, fatality reduction targets etc.). This factor represents 34.7% of the overall variance in the data.
- Transport Demand and Exposure: indicators related to the vehicle fleet distribution (vehicles per population, share of passenger cars and PTW) are those with the highest loadings amongst, complemented with some elements of the road network (density, share of motorways and paved roads etc.) and modal split (passenger vs. freight). It is interesting to note that the share of PTW has a negative loading and coefficient, suggesting that countries that have higher values in the other indicators (e.g. share of passenger cars etc.) tend to have lower values on the share of PTW. This factor represents 30.8% of the overall variance in the data.
- Measures: indicators related to the vehicle standards are the variables with the highest loadings amongst, followed by the BAC limits, the speed limits and the measures on ADR. Several other indicators are included with lower loadings. This factor represents 34.2% of the overall variance in the data.
- Safety Performance indicators: all indicators tested had a high loading, bringing together all the elements of enforcement, as well as variables related to the use of safety

equipment and post impact care This factor represents 58,2% of the overall variance in the data.

TABLE 2 Indicator loadings and coefficients on the estimated factor (composite variable) per layer

		Factor (composite variable)	
		Loadings	**Score coefficients**
Economy and Management	EM2_lt15yo	-,778	-,250
	EM3_gt65yo	,714	,229
	EM4_UrbanPop	,709	,228
	EM7_NationalStrategy	,697	,224
	EM8_NationalStrategyFunded	,626	,201
	EM9_FatalityTargets	,692	,222
Transport Demand and Exposure	TE1_RoadNetworkDensity	,497	,161
	TE2_Motorways	,460	,149
	TE3_PavedRoads	,734	,238
	TE4_VehiclesPerPop	,839	,272
	TE5_PassCars	,825	,267
	TE7_PTW	-,681	-,221
	TE10_PassengerFreight	-,360	-,117
Road Safety Measures	ME2_ADR	,681	,069
	ME4_SpeedLimits_urban	,443	,045
	ME6_SpeedLimits_motorways	,634	,064
	ME7_VehStand_seatbelts	,877	,088
	ME8_VehStand_SeatbeltAnchorages	,906	,091
	ME9_VehStand_FrontImpact	,908	,092
	ME10_VehStand_SideImpact	,904	,091
	ME11_VehStand_ESC	,891	,090
	ME12_VehStand_PedProtection	,862	,087
	ME13_VehStand_ChildSeats	,896	,090
	ME15_BAClimits	,670	,068
	ME16_BAClimits_young	,670	,068
	ME17_BAClimits_commercial	,645	,065
	ME19_SeatBeltLaw_all	,570	,057
	ME20_ChildRestraintLaw	,628	,063
	ME22_HelmetFastened	,334	,034
	ME23_HelmetStand	,379	,038
	ME24_MobileLaw	,375	,038
	ME25_MobileLaw_handheld	,350	,035
	ME27_PenaltyPointSyst	,378	,038
	ME29_EmergTrain_nurses	,399	,040
Road Safety Performance Indicators	PI1_SeatBeltLaw_enf	,756	,144
	PI2_DrinkDrivingLaw_enf	,812	,155
	PI3_SpeedLaw_enf	,795	,152
	PI4_HelmetLaw_enf	,837	,160
	PI5_SeatBelt_rates_front	,811	,155
	PI6_SeatBelt_rates_rear	,766	,146
	PI7_Helmet_rates_driver	,784	,150
	PI8_SI_ambulance	,667	,127
	PI9_HospitalBeds	,607	,116

Generalized Linear Model development

Several alternative model specifications were tested for the selection of the final model. The best performing model for the purposes of the present research is presented in Table 3. The dependent variable is the logarithm of the fatality rate per population for 2013, and the main explanatory variables are the respective logarithm of fatality rate in 2010 (so the development of fatality rate over 2010-2013 is modelled), and the respective logarithm of GDP per capita for 2013, together with the four composite variables: the economy & management, the transport demand and exposure, the measures, and the SPIs.

TABLE 3 Parameter estimates and fit of the final generalized linear model

Parameter	B	Std. Error	95% Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	p-value
(Intercept)	1,694	,2737	1,157	2,230	38,291	1	<,001
Comp_ME	-,135	,0646	-,261	-,008	4,358	1	,037
Comp_TE	-,007	,0028	-,013	-,002	7,230	1	,007
Comp_PI	-,007	,0030	-,013	-,001	5,652	1	,017
Comp_EM	,007	,0051	-,003	,017	2,009	1	,156
LNFestim_2010	,769	,0462	,678	,859	276,322	1	<,001
LNGNI_2013	-,091	,0314	-,153	-,030	8,402	1	,004
(Scale)	,038						
Likelihood Ratio	1379,00						
df	6						
p-value	<,001						

The modelling results can be analyzed as follows: An increase in the GNI results in decrease of the change in the fatality rate. This is intuitive and in accordance to previous research findings.

A higher fatality rate in 2010 is associated with a higher fatality rate in 2013. This is also intuitive, as countries with higher fatality rates in the past are expected (all other things kept equal) to exhibit similar fatality rates in the future. In fact, for a more accurate interpretation of the effect of road safety developments, this can be translated as follows: if fatalities have been increasing (i.e. the fatality rate of 2013 is higher than the fatality rate of 2010), an increase over the next three years is also expected, and vice versa.

All the parameter estimates of the composite variables on Measures or SPIs have a negative sign, suggesting that an increase in the composite variable score (i.e. an increase in one or more of the indicators forming the composite variable) results in a decrease in the fatality rate.

All the parameter estimates are statistically significant at 95% confidence level (p-values <0,050), and the Likelihood Ratio Test leads to accept the model, as its value is significant for an equal chi-square test with 6 degrees of freedom.

As a final step, countries grouping was also attempted. The hypothesis was that groups of countries of similar geographical (and therefore also possibly cultural), economic or road safety characteristics may be better described by dedicated analyses. Two types of grouping were explored, i.e. the geopolitical grouping in which the 5 United Nations Regional Groups grouped into 3 groups and the road safety and economic performance grouping, as explained above (low, middle and high performance). Modelling was performed for each region, however, none of the regional models was of satisfactory performance; this is not very surprising, given that the grouping results in much smaller samples for the regional models, which significantly compromise the model quality.

Model quality and cross-validation

A comparison of the observed and the predicted values is shown in Figure 1, which shows the prediction errors for each country. It can be seen that the model is of very satisfactory performance as regards the good performing countries (low fatality rate) and of quite satisfactory performance as regards the medium performing countries. The prediction error increases for the countries that had a high fatality rate in the first place, which is not surprising, since these countries exhibit many missing values in several indicators, compromising the implementation of the model. The mean absolute prediction error is estimated at 2.7 fatalities per population (maximum prediction error at 10.9 fatalities per population), whereas the mean percentage prediction error is estimated at 15% of the observed value.

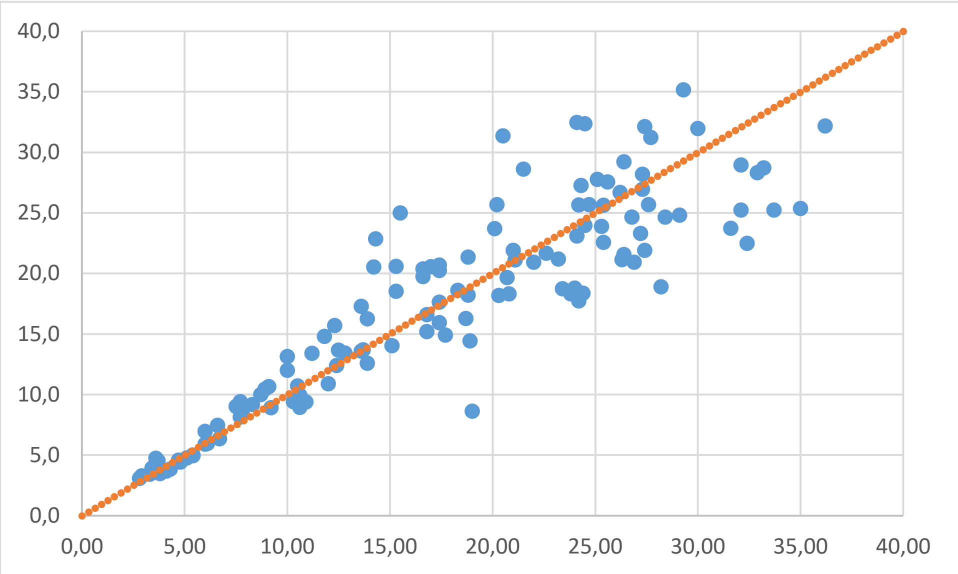

FIGURE 1 Observed vs. predicted fatality rates of year 2013

A cross-validation was carried out with two subsets of the sample:

- A randomly selected 80% of the sample was used to develop (fit) the model, and then the model was implemented to predict the fatality rate for 2013 of the 20% of the sample not used to fit the model.
- A randomly selected 70% of the sample was used to develop (fit) the model, and then the model was implemented to predict the fatality rate for 2013 of the 30% of the sample not used to fit the model.

Figure 2 shows the results of the model cross-validation. In the first case (20% of the sample used for validation) the predictions were quite satisfactory, with the exception of two outliers. The mean absolute prediction error is 1.7 fatalities per population and the mean percentage prediction error is 12%. In the second case (30% of the sample used for validation) no striking outliers exist, but overall there appears to be an underestimation of the fatality rate by the predicted values for countries with more than 20 fatalities per population. This is partly due to the fact that the model performance naturally drops when a significantly smaller sample is used for its development. The mean absolute prediction error is 3.6 fatalities per population and the mean percentage prediction error is 19% (but would drop at 3.5 and 17% respectively if the three largest errors were ignored).

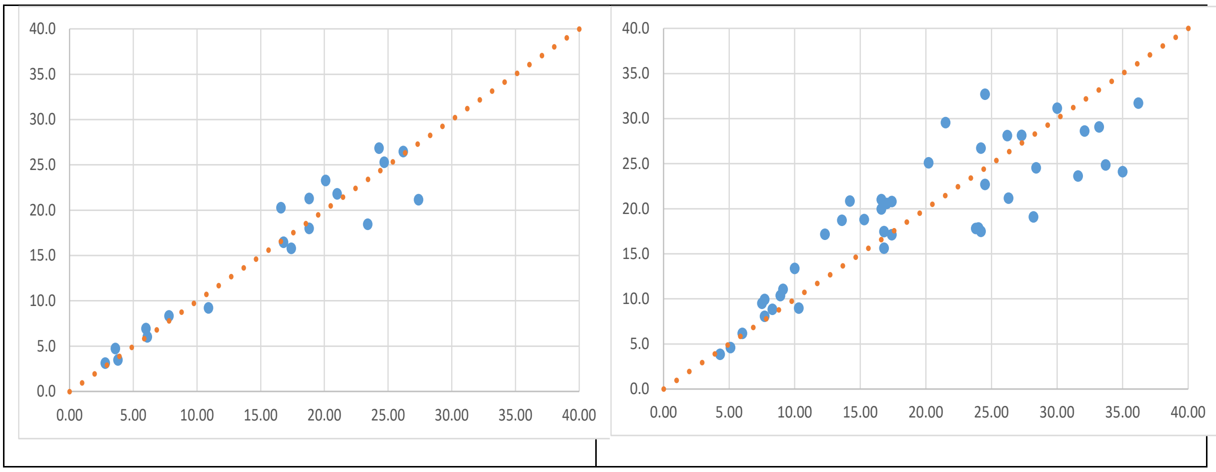

FIGURE 2 Cross-validation of the final model - 20% of the sample kept for validation (left panel), 30% of the sample kept for validation (right panel)

Overall, these results are considered satisfactory given the known limitations of the existing data. It should be noted that, in both cases, the errors are more considerable for the countries that have initially high fatality rates (poor performing countries, mostly African, Latin-American countries).

DISCUSSION

The model developed took into account several challenges and particularities of road safety analyses. The task of road safety forecasting on the basis of policy scenarios, i.e. combining an explanatory approach on road safety with the time dimension at global level, was a challenge on its own, as there is no similar example in the literature. The development of a dedicated methodology was required, different statistical techniques were combined and adjusted and several alternative hypotheses were tested, in order to meet the objectives of the analysis while dealing with data and methodological limitations.

While the model was developed on the basis of the most recent and good quality data available internationally, and by means of rigorous statistical methods, however, data and analysis methods have some limitations which should be kept in mind.

- The fatality data used for the model development are in some cases estimated numbers, and in all subject to under-reporting.
- There is lack of data, especially for transport demand, exposure and performance indicators and the missing values were replaced by the regional known mean value.
- In most cases, a binary variable (yes/no) was available, which may not always reflect the true value of the variable. For example, a measure may be partially implemented, a national strategy may exist but there is no information whether it is implemented and monitored, and so on.

Consequently, the optimal use of the model depends on a number of recommendations and rules, in order to minimize errors and inaccuracies in the model outcomes, as follows:

- When used for forecasting purposes, the model can only be based on the extrapolation of short-term developments in the future; this approach has some obvious limitations.

Confidence intervals for the predictions cab ne calculated to reflect the uncertainty in this extrapolation, on the basis of the mean prediction error of the model. The prediction error is considered to increase as the prediction horizon extends.

- The model includes many indicators which are correlated. However, composite variables may also be correlated with one another (e.g. measures with performance indicators), since correlation may exist between indicators included in separate composite variables. Therefore, the effects of interventions may not reflect the unique contribution of each separate intervention. When testing policy scenarios, it is strongly recommended to test combinations of “similar” interventions. The cumulative effect of “similar” variables indicators either within the same composite variable or from separate composite variables is more likely to accurately reflect true (and not conditional) effects.
- The model may not fully capture the effects on countries with very particular characteristics such as very low GDP, very high share of motorcycle or cyclist fatalities etc. Although every effort was made to customize the model for different geographical or geopolitical groups, as well as for such particularities, the available data in the international databases and the available information in the literature was not sufficient so far to allow for such customization.
- Developing countries are expected to be more sensitive in the testing of interventions than developed ones. There are several industrialized countries that already have very high values on all indicators, and their GDP is expected to keep increasing. For these countries, a further slightly decreasing trend is forecasted by the model, but in order to forecast substantial further reductions, other types of interventions will be required, for which no data is currently available. Therefore, the current forecasts for these countries may be quite conservative.

CONCLUSION

In the present research, a statistical model was developed on the basis of actual global road safety data, which can be used in three types of analyses, all very pertinent for road safety policy purposes, i.e. intervention, benchmarking and forecasting analysis. The proposed approach is based on the calculation of composite variables and their introduction in a generalized linear model (two-step approach), and forecast on the basis of short-term differences, accumulated to obtain medium- and long-term forecasts. Both these scientific choices have their limitations, but they were the optimal solutions for dealing with the complexity of the model to be developed on the basis of the available data. To the best of the authors’ knowledge, this is the first attempt to develop an explanatory global road safety model.

The final model developed is robust, with a satisfactory performance and acceptable prediction errors. The cross-validation undertaken is considered successful; however, care should be taken that the limitations of the model are taken into account, and several recommendations are made for optimal use of the model (e.g. combinations of policy scenarios). The development of models for different regions was less successful - and was not retained, largely due to the small sample size resulting from the sub-groups of countries, compromising the statistical analyses.

The current model also has limitations related to data availability and accuracy. The lack of a global road safety database with detailed and comparable data certainly compromises the efforts to develop a global road safety model. Previous studies have indicated that there may be more data on exposure and SPIs at national level, than those reported in international statistics, and their collection, harmonization and use will be a major challenge with considerable added value for improving the model to better support road safety decision making.

In addition, a new wave of historical data may allow to further validate and adjust the model, as well as to take more accurately into account the underlying trends by estimating future developments on the basis of longer historical trends, both as regards fatalities and as regards key economy, exposure and SPI indicators. Additionally, further changes in programs and measures implemented in the various countries will allow to more accurately estimate their effects on outcomes, improving the transferability of estimates in other countries as well. It is therefore suggested to closely monitor global developments in data availability and accuracy, so that the data is updated regularly and continuously, allowing to improve the model with more, and more accurate data.

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