Transportation Research Board
97th Annual Meeting
January 7–11, 2018 • Washington, D.C.

Developing a Global Road Safety Model

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Introduction - Background

- Road accidents constitute a **major social problem** in modern societies, with road traffic injuries being estimated as the eighth leading cause death globally.
- Particularly in **low and middle income countries**, road traffic injuries are twice those in high income countries and still increasing.
- **UN Decade of Action**: need to strengthen global and national efforts for casualty reduction through evidence-based approaches.

Main objective

- **Develop a global road safety model** based on global road safety data, which may serve as a road safety decision making tool for three types of policy analysis, i.e. intervention, benchmarking and forecasting analysis.

Methodology

- 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.

Research challenges

- The relationships between indicators and road safety outcomes are complex and in some cases random.
- 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 and comes mostly from industrialized countries.
- There is lack of detailed historical data on several indicators and road safety outcomes at international level.

LAYERS	PILLARS: 1. Road Safety Management	2. Road Infrastructure	3. Vehicle	4. User	5. Post-Crash Services
1. Economy & Management	Economic Developments, Strategy & Targets, Regulatory framework (compliance with UN regulations)	Existence of motorways, of non-paved roads, of road tunnels, Existence of guidelines (for design, RSA etc.), Legislation on speeding	Number of registered vehicles, Vehicle age, Technical inspection legislation (maintenance, roadworthiness, overweight, ADR)	Requirements & regulations on drivers' licensing, Drivers' training, Medical exams of drivers, Legislation on alcohol / use of seatbelts / use of helmets	Trauma management sector level of development Number of hospitals / doctors / Intensive Care (IC) beds per population
2. Transport demand & exposure	Transport Modal Split (road/rail, passenger/freight, private/public), Share of urban areas, Weather conditions	Exposure with regard to road type, Length of road per road type, Share of Motorway length out of the total road network, Number of railway level crossings	Exposure with regard to vehicle type, Share of PTW, HGV / carriage of dangerous goods vehicles in the vehicle fleet	Exposure with regard to age & gender	
3. Road Safety Measures	Assessment of measures, Data collection & analysis, International comparisons, Vehicle taxation, Road pricing	Treatment of High Risk Sites, Road Safety Audits, Tunnel Road Safety Management, Improvement of signage, Installation of road restraint systems, Lighting, Speed limits in urban areasTraffic Calming	Renewal rate of vehicle fleet, Measures for second-hand vehicles, Vehicle related roadside controls, Automated driving	Enforcement, campaigns, Road safety education, Training	e-call, First aid training, Existence & organisation of trauma centers
4. Road Safety Performance Indicators	Safety targets, stakeholders' involvement, detail of analysis for intervention selection, economic evaluation	Number of RSAs conducted, Percentage of High Risk Sites treated	Global NCAP score, Mean age of the vehicle fleet per vehicle type, Existence of safety equipment, e-safety	Speeding / Drink & drive infringements, Seatbelts use, Helmets use, Driver distraction, Driver fatigue	Emergency response time, Type of field treatment, Speed of treatment in hospital, Number of ambulances per population, Number of good samaritanians per population
5. Fatalities & Injuries	Fatalities / injuries per million inhabitants, fatalities / injuries per million passenger cars, fatalities / injuries per 10 billion passenger-km	Fatalities / injuries in motorways, in 2-lane rural roads, in urban roads	Share of motorcycle fatalities out of the total fatalities	Share of pedestrian / bicyclist / motorcyclist fatalities out of the total fatalities, drink-driving related fatalities	Death rate, Hospitalization in IC Unit, Total length of hospitalization

Modelling Approach

- **Two-step approach of statistical modeling:**
  - Estimation of **composite variables** (factor analysis) in order to take into account as many indicators as possible of each layer.
  - Correlating road safety outcomes with indicators through composite variables by developing a **regression model with explicit consideration of the time dimension**.
- **Model specification**

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

Where [Composite Variable]

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

Conceptual Framework

Based on the 5 pillars of WHO Global Plan of Action (WHO, 2011) and an improved version of the SUNflower pyramid (2002):

SafeFITS layers

1. Economy and Management
2. Transport Demand and Exposure
3. Road Safety Measures
4. Road Safety Performance Indicators
5. Fatalities and Injuries

SafeFITS pillars

1. Road Safety Management
2. Road Infrastructure
3. Vehicle
4. User
5. Post-Crash Services

Estimation of Composite Variables

- The **factor analyses** were implemented on each one of the layers of the road safety system, constrained to yield one factor per layer.
  - Economy and Management
  - Transport Demand and Exposure
  - Road Safety Measures
  - Performance Indicators
- For **fatalities and injuries indicators**, the fatality rate per population was selected as main dependent variable.

TABLE 1 Indicator loadings and coefficients on the estimated factor (composite variable) per layer

		Factor (composite variable)	
		Loadings	Score coefficients
Economy and Management	EM2_lt15yo	-0,778	-0,250
	EM3_gt65yo	0,714	0,229
	EM4_UrbanPop	0,709	0,228
	EM7_NationalStrategy	0,697	0,224
	EM8_NationalStrategyFunded	0,626	0,201
	EM9_FatalityTargets	0,692	0,222
Transport Demand and Exposure	TE1_RoadNetworkDensity	0,497	0,161
	TE2_Motorways	0,460	0,149
	TE3_PavedRoads	0,734	0,238
	TE4_VehiclesPerPop	0,839	0,272
	TE5_PassCars	0,825	0,267
	TE7_PTW	0-,681	-0,221
	TE10_PassengerFreight	0-,360	-0,117
Road Safety Measures	ME2_ADR	0,681	0,069
	ME4_SpeedLimits_urban	0,443	0,045
	ME6_SpeedLimits_motorways	0,634	0,064
	ME7_VehStand_seatbelts	0,877	0,088
	ME8_VehStand_SeatbeltAnchorages	0,906	0,091
	ME9_VehStand_FrontImpact	0,908	0,092
	ME10_VehStand_SideImpact	0,904	0,091
	ME11_VehStand_ESC	0,891	0,090
	ME12_VehStand_PedProtection	0,862	0,087
	ME13_VehStand_ChildSeats	0,896	0,090
	ME15_BAClimits	0,670	0,068
	ME16_BAClimits_young	0,670	0,068
	ME17_BAClimits_commercial	0,645	0,065
	ME19_SeatBeltLaw_all	0,570	0,057
	ME20_ChildRestraintLaw	0,628	0,063
	ME22_HelmetFastened	0,334	0,034
	ME23_HelmetStand	0,379	0,038
	ME24_MobileLaw	0,375	0,038
	ME25_MobileLaw_handheld	0,350	0,035
	ME27_PenaltyPointSyst	0,378	0,038
	ME29_EmergTrain_nurses	0,399	0,040
Road Safety Performance Indicators	PI1_SeatBeltLaw_enf	0,756	0,144
	PI2_DrinkDrivingLaw_enf	0,812	0,155
	PI3_SpeedLaw_enf	0,795	0,152
	PI4_HelmetLaw_enf	0,837	0,160
	PI5_SeatBelt_rates_front	0,811	0,155
	PI6_SeatBelt_rates_rear	0,766	0,146
	PI7_Helmet_rates_driver	0,784	0,150
	PI8_SI_ambulance	0,667	0,127
	PI9_HospitalBeds	0,607	0,116

Generalized Linear Model Development

The **optimal performing model** for the purposes of the analysis:

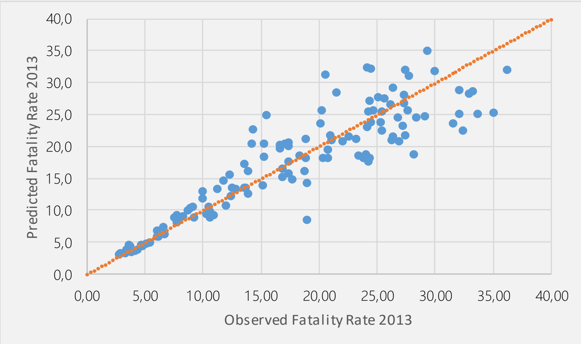
- The **dependent variable** is the logarithm of the fatality rate per population for 2013
- The main **explanatory variables** are the respective logarithm of fatality rate in 2010 and the respective logarithm of GDP per capita for 2013
- Four **composite** variables: the Economy & Management, the Transport Demand and Exposure, the Measures and the SPIs

TABLE 2 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	0,2737	1,157	2,230	38,291	1	<0,001
Comp_ME	-0,135	0,0646	-0,261	-0,008	4,358	1	0,037
Comp_TE	-0,007	0,0028	-0,013	-0,002	7,230	1	0,007
Comp_PI	-0,007	0,0030	-0,013	-0,001	5,652	1	0,017
Comp_EM	0,007	0,0051	-0,003	0,017	2,009	1	0,156
LNFestim_2010	0,769	0,0462	0,678	0,859	276,322	1	<0,001
LNGNI_2013	-0,091	0,0314	-0,153	-0,030	8,402	1	0,004
(Scale)	0,038						
Likelihood Ratio	1379,00						
df	6						
p-value	<0,001						

Statistical Model Assessment

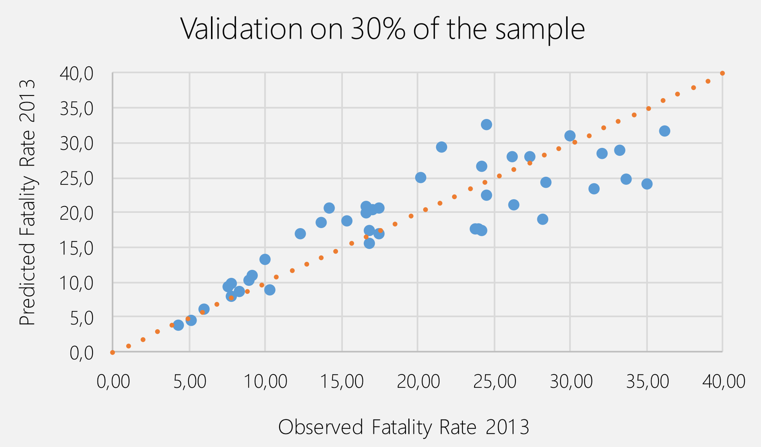
- The mean absolute prediction error is estimated at **2,7 fatalities per population**, whereas the mean percentage prediction error is estimated at **15%** of the observed value.

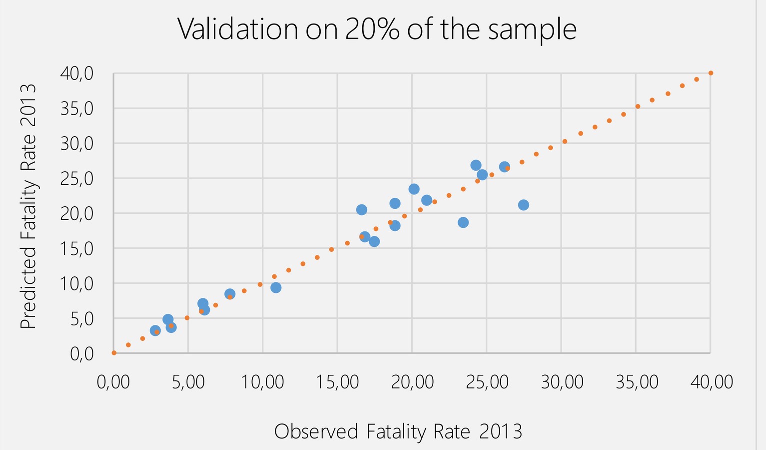


Statistical Model Validation

In order to validate the model, a cross-validation was carried out with two subsets:

- **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
- **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





Conclusions –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.

- Data and analysis methods have some **limitations** which should be kept in mind:
  - Fatality data are in some cases estimated numbers, and in all subject to **under-reporting.**
  - **Missing values** were addressed by imputation.
  - The available data for several indicators were **not detailed**.

- The **optimal use** of the model depends on a number of recommendations and rules:
  - The model provides overall forecasts of **short-term developments**, which might be extrapolated in the future.
  - The model includes many indicators which are correlated, thus testing **combinations of "similar" interventions** is recommended.
  - The model may not fully capture the effects on countries with very **particular characteristics**.
  - **Developing countries** are expected to be more sensitive in the testing of interventions than developed ones.

- The **lack of a global road safety database** with detailed and comparable data certainly compromises the efforts to develop a global road safety model.
- 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.
- **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 suggested to **closely monitor global developments in data availability and accuracy**, so that the data are updated regularly and continuously, allowing to improve the model with more and more accurate data.

Acknowledgement

This paper is based on work carried out in the framework of the "Safe Future Inland Transport Systems (SafeFITS)" project of the United Nations Economic Commission for Europe (UNECE), financed by the International Road Union (IRU).