ROAD SAFETY FORECASTS IN FIVE EUROPEAN COUNTRIES USING STRUCTURAL TIME-SERIES MODELS

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ABSTRACT

Modeling road safety development is a complex task, which needs to consider both the quantifiable impact of specific parameters, as well as the underlying trends that cannot always be measured or observed. The objective of this research is to apply structural time series models for obtaining reliable medium- to long-term forecasts of road traffic fatality risk, using data from five countries with different characteristics from all over Europe (Cyprus, Greece, Hungary, Norway and Switzerland). Two structural time series models are considered: (i) the local linear trend model and the (ii) latent risk time-series model. Furthermore, a structured decision tree for the selection of the applicable model for each situation (developed within the DACOTA research project) is outlined. First, the fatality and exposure data that are used for the development of the models are presented and explored. Then, the modeling process is presented, including the model selection process, the introduction of intervention variables and the development of mobility scenarios. The forecasts using the developed models appear to be realistic and within acceptable confidence intervals. The proposed methodology is proved to be very efficient for handling different cases of data availability and quality, providing an appropriate alternative from the family of structural time series models in each country. A concluding section providing perspectives and directions for future research is finally presented.

INTRODUCTION

Modeling road safety is a complex task, which needs to consider both the quantifiable impact of specific parameters, as well as the underlying trends that cannot always be measured or observed. The sensitivity of users to road safety campaigns, the improved quality of the vehicle fleet, the improvement of the driving skills of the general population, and the overall improvement of the condition of the road network are only some of the aspects that cannot be easily modeled directly. Therefore, modeling should consider both measurable parameters and the dimension of time, which embodies all remaining parameters.

The objective of this research is to apply structural time series models for obtaining reliable medium- to long-term forecasts of fatality risk. In the process of achieving this objective, several sub-objectives are set. A first such objective is to develop robust models for modeling the relationship between mobility and risk and examine the effect of mobility on risk. A further objective is to develop (and apply) a structured methodology for the selection of the optimal forecasting models, based on a number of criteria, diagnostics and measures of goodness of fit. In order to demonstrate that the developed approach is robust and applicable to different conditions and environments, the approach is applied to data from five European countries with very different characteristics.

The remainder of this paper is structured as follows. The next section presents the methodological background, highlighting the state-of-the-art in related methodologies and approaches and putting the proposed approach in context. The following section presents the methodology, both in terms of the structural form of the models as structural time-series models and in terms of the decision tree that has been developed within the DACOTA project for the selection of the appropriate models. Application of the models in five countries are presented next; the collected data are presented first, followed by the results of the alternative models, while at the end a synthesis presents and compares the forecasts of the models. The paper continues with a section that discusses the methodology application in the various countries, and a concluding section that summarizes the main points and presents directions for future research.

BACKGROUND

A number of approaches for modelling road safety developments have been proposed, a critical review of which can be found in *(1-3)*. Page *(4)* presented an exponential formula that yields fatalities as the product of all explanatory variables' influence and attempted to rank countries based on their road mortality level. Beenstock and Gafni *(5)* show that there is a relationship between the downward trend in the rate of road accidents in Israel and other countries and suggest that this reflects the international propagation of road safety technology as it is embodied in motor vehicles and road design, rather than parochial road safety policy. Van Beeck et al. *(6)* examine the association between prosperity and traffic accident mortality in industrialized countries in a long-term perspective (1962-1990) and find that in the long-term the relation between prosperity and traffic accident mortality appears to be non-linear. Kopits and Cropper *(7)* use linear and log-linear forms to model region specific trends of traffic fatality risk and per income growth using panel data from 1963 to 1999 for 88 countries. Abbas *(8)* compares the road safety of Egypt with that of other Arab nations and G-7 countries, and develops predictive models for road safety. Vehicle fleet may also affect the number of fatalities, given that an increase in the vehicle number leads to higher average traffic volumes, which in turn may translate to e.g. a reduction in average speeds, or an increase in the need for more and safer road environment, in which the drivers' behaviour tends to be also better *(9,10)*.

During the last decade, the modeling approach of structural time-series models, such as those proposed by Harvey and Shephard *(11)* and Harvey *(12)*, is applied by several researchers. In this approach, which belongs to the family of unobserved component models, latent variables are decomposed into components (hence the term "unobserved components"), which are incorporated into the structural models. Harvey and Sheppard *(11)* propose to decompose a univariate time-series y_t into the following components:

$$y_t = \mu_t + \psi_t + \gamma_t + \varepsilon_t \qquad (1)$$

where μ_t is a trend, ψ_t is a cycle, γ_t is a seasonal and ε_t is an irregular component. All components are assumed stochastic (except for the mean, a zero mean is expected for the other components) with uncorrelated disturbances.

Lassarre *(13)* presented an analysis of ten European countries' progress in road safety by means of a structural (local linear trend) model, yielding two adjusted trends, one deterministic and one stochastic. Stipdonk *(14)* applied multivariate analysis of the "three levels of risk" (i.e. exposure, fatality risk and accident severity) with structural time series models to quarterly data for the years 1987-2000 in France and the Netherlands, both at the national level, and stratified by road type for France.

METHODOLOGY

Two structural time series models are considered in this paper: (i) the local linear trend model and (ii) the latent risk time-series model *(15)*. Furthermore, a structured decision tree for the selection of the applicable model for each situation (developed within the DACOTA research project) is outlined.

Structural time-series models: Local Linear Trend (LLT) and Latent Risk Time-Series (LRT) models

A basic concept in road safety is that the number of fatalities is a function of the road risk and the level of exposure of road users to this risk *(2)*. This implies that in order to model the evolution of fatalities it is required to model the evolution of two parameters: a road safety indicator and an exposure indicator:

$$\begin{aligned} &\mathit{Traffic\ volume} = \mathit{Exposure} \\ &\mathit{Number\ of\ fatalilties} = \mathit{Exposure} \times \mathit{Risk} \end{aligned} \qquad (2)$$

which represents a latent risk time-series (LRT) formulation. In this case, both traffic volume and number of fatalities are treated as dependent variables. Effectively, this implies that traffic volume and fatality numbers are considered to be the realized counterparts of the latent variables "exposure", and "exposure x risk". When the logarithm of Equations 2 is taken (and the error term is explicitly written out) the –so called– measurement equations of the model can be rewritten as:

$$\begin{aligned} &\mathit{Log\ Traffic\ volume} = \log \mathit{exposure} + \mathit{random\ error\ in\ traffic\ volume} \\ &\mathit{Log\ Number\ of\ fatalities} = \log \mathit{exposure} + \log \mathit{risk} + \mathit{random\ error\ of\ fatalities} \end{aligned} \qquad (3)$$

The latent variables [log (exposure) and log (risk)] need to be further specified by "state" equations, which, once inserted in the general model, describe the development of the latent variable.

Equations (4) and (5) show how a variable can be modeled (to simplify the illustration only the number of fatalities is decomposed as an example):

Measurement equation:

$$\log \mathit{Number\ of\ Fatalities}_t = \log \mathit{LatentFat.}_t + \varepsilon_t \qquad (4)$$

State equations:

$$\begin{aligned} &\mathit{Level}(\log \mathit{LatentFat}_t) = \mathit{Level}(\log \mathit{LatentFat}_{t-1}) + \mathit{Slope}(\log \mathit{LatentFat}_{t-1}) + \xi_t \\ &\mathit{Slope}(\log(\mathit{LatentFat}_t) = \mathit{Slope}(\log \mathit{LatentFat}_{t-1}) + \zeta_t \end{aligned} \qquad (5)$$

A more general formulation is presented in Equation (6), in which Y_t represents the observations and is defined by the measurement equation within which μ_t represents the state and ε_t the measurement error. The state μ_t is defined in the state equation, which essentially describes how the latent variable evolves from one time point to the other.

$$\begin{aligned} Y_t &= \mu_t + \varepsilon_t \\ \mu_t &= \mu_{t-1} + \nu_{t-1} + \xi_t \\ \nu_t &= \nu_{t-1} + \zeta_t \end{aligned} \tag{6}$$

In the present case, the state μ_t thus corresponds to the fatality trend at year *t*. It is defined by an intercept, or level μ_{t-1} (thus the value of the trend for the year before, assuming an annual time-series) plus a slope ν_{t-1}, which is the value by which every new time point is incremented (or decremented depending on the slope sign, which is usually negative in the case of fatality trends). The slope ν_t thus represents the effect of time on the latent variable. It is defined in a separate equation, so that a random error term can be added to it (ζ_t). These random terms, or disturbances, allow the level and slope coefficients of the trend to vary over time.

The basic formulation presented in Equation (6) allows the definition of a rich family of trend models which covers an extensive range of series in a coherent way; when both the level and slope terms are allowed to vary over time the resulting model is referred to as the local linear trend (LLT) model.

The next model is a Latent Risk Time-Series (LRT), which simultaneously models exposure and fatalities. To accomplish this, the latent risk model contains two measurement equations: one for the exposure (e.g. traffic volume) and one for the fatalities; two state equations can be written for each measurement equation, modeling the level and slope of the corresponding latent variable.

For *traffic volume*:

Measurement equations:

$$\log TrafficVolume_t = \log Exposure_t + \varepsilon_t^{\,e} \tag{7}$$

State equations:

$$\begin{aligned} Level(\log Exposure_t) &= Level(\log Exposure_{t-1}) + Slope(\log Exposure_{t-1}) + \xi_t^{\,e} \\ Slope(\log Exposure_t) &= Slope(\log Exposure_{t-1}) + \zeta_t^{\,e} \end{aligned} \tag{8}$$

For *the fatalities*:

Measurement equation:

$$\log Number\,of\;\;Fatalities_t = \log Exposure_t + \log Risk_t + \varepsilon_t^{\,f} \tag{9}$$

State equations:

$$\begin{aligned} Trend(\log Risk_t) &= Level(\log Risk_{t-1}) + Slope(\log Risk_{t-1}) + \xi_t^{\,r} \\ Slope(\log Risk_t) &= Slope(\log Risk_{t-1}) + \zeta_t^{\,r} \end{aligned} \tag{10}$$

Note that Equation (9) now includes the Risk (and not the fatalities), which can be estimated as:

$$\mathrm{logRisk}_t = \log\ \mathrm{LatentFat}_t\text{-}\log\ \mathrm{Exposure}_t \tag{11}$$

Seemingly Unrelated Time-Series Equations (SUTSE) *(16)*, a third class of models, are also used in this approach as a preliminary step in establishing whether the two time-series may be correlated.

Model selection logic

The family of structural time-series models lends to a large number of assumptions that distinguish the resulting models into different categories. Within the framework of the DACOTA research project, a decision process and model selection logic has been developed, in which the following steps are considered:

- Investigate exposure: the first step in every modeling effort is to assess the quality and characteristics of the underlying data. Do the available exposure data make sense? Can any sudden changes in the level or slope be explained from some real events?
- Establish whether the two series are statistically related: a SUTSE model is developed and based on the diagnostics, the modeler needs to decide whether the two time-series are correlated.
- Depending on the output of the SUTSE model determine whether an LLT or an LRT model should be pursued: If one or more of the null-hypotheses regarding the correlation of the disturbances is rejected, the time-series may be related and therefore an LRT can be estimated. If, on the other hand, none of the hypotheses can be rejected, then there is no evidence that the two time-series are correlated and therefore an LLT model would be more appropriate.

MODEL APPLICATION

Data collection and analysis

Figure 1 shows the fatalities and exposure series for the 5 examined countries. The fatalities series show quite distinct trends in different countries, and the available exposure measure is also different. Moreover, information on road safety or transport-related interventions, or other socio-economic events that may have influenced fatalities and exposure was collected, mainly from the members of the National Experts group on road safety of the European Commission.

Fatalities in Greece present an increasing trend until 1995, followed by a decreasing trend. In Greece there are no traffic volume data available, so -to forecast the fatalities- the number of vehicles in circulation is used. The number of vehicles in circulation shows an increasing rate from 1960 to almost 2008. During the last couple of years, there appears to be a slower rate of increase, reflecting the effect of the recession. However, this effect is not as evident as it would be if a more appropriate measure of exposure, such as vehicle-kilometers, was available. There are three main events that can be considered as interventions: a financial crisis in 1986, an “old-car-exchange” scheme in 1991, and the switch of the fatality recording system from 24-hour to 30-day definition of fatalities in 1996.

The fatality figures in Hungary present considerable fluctuation from 1970 to 1990, with two visible peaks in 1971 and 1978, and a striking one on 1990. From 1990 onwards, an overall decrease is observed – despite a small rise on 2002 - which appears to be more intense after 2008. The available exposure measure is the passenger kilometres (in millions), which present a sharp constantly increasing trend between 1970 and 1989, a decrease between 1989-1993, followed by a relatively flat trend until 2002, and a decreasing trend from 2008. The following is known about possible intervention variables: a significant increase in the man-power of the Police took place on 1979, the change of regime on 1990, an increase of motorway length by 19% took place on 2002 and a large set of road safety measures was introduced on 2008.

In Switzerland, the fatality figures present a constantly decreasing trend throughout the period 1975 - 2010. The vehicle kilometers in Switzerland in that period present a constantly increasing trend, interrupted by a small drop on 1993. The mobility in that country does not appear to be affected by the global recession. The 30-days definition for fatalities is used throughout the series, and no other information about road safety interventions or other socio-economic events was available.

An overall consistent decreasing trend of fatalities can be identified in Norway when looking at the time-series as a single line. It is also possible to identify three sub-sections with a steeper decreasing slope (1973-1981, 1986-1996 and 1998-2009), connected by short periods of increasing number of fatalities. However, there is no evidence of specific events occurring during these periods in Norway. Vehicle-kilometres present an increasing trend during the examined period, which was steeper in the seventies and eighties.

In Cyprus data is available for the period 1990-2010. During the first years of the fatality series, there is some variability and no clear trend can be observed. There is a dip in the first half of the 2000s and a consistent drop after 2004. This could possibly be attributed to the accession of Cyprus to the EU (which took place that year). The available exposure measure is the fuel consumption (x1000 tn.eq. of oil). A fairly consistent increasing trend can be noticed until 2008, at which point - possibly due to the recession - fuel consumption started declining.

In the following sections, the proposed methodology is applied for modeling and forecasting road safety developments in the 5 European countries. Model selection is based on the decision tree presented in the previous section. Moreover, in each case, particular decisions are taken as regards data handling (e.g. outliers), introduction of intervention variables etc.

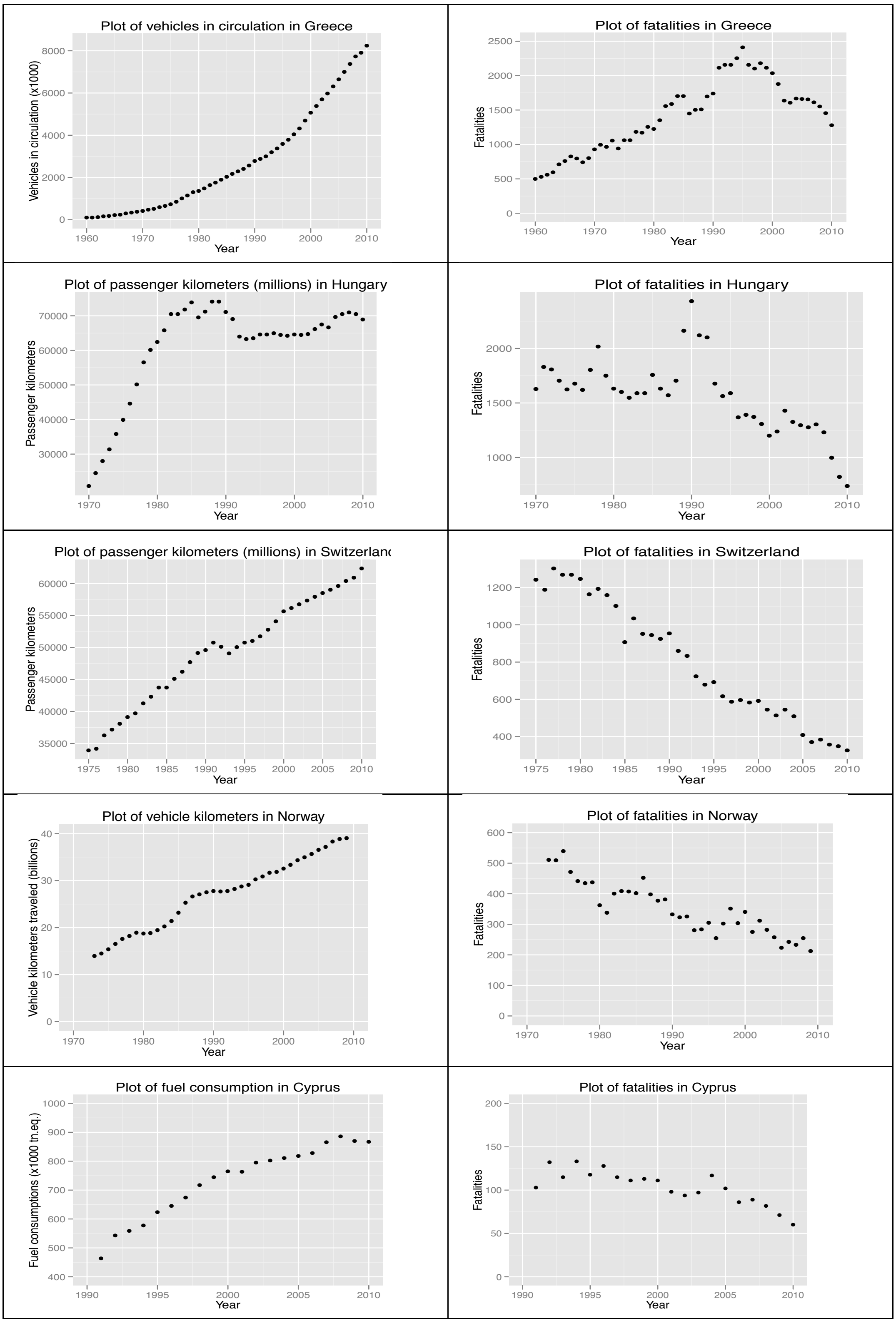


FIGURE 1. Overview of data for the five countries

Models by country

As a first step, the modeling process and results for Switzerland are presented in detail, that country being considered as a typical example of successful LRT modeling. Subsequently, the final models for the remaining 4 countries are presented and described more briefly. All models were fitted by means of the R software *(17)*, on the basis of code developed by Bijleveld *(15)*.

Modeling results for fatality risk in Switzerland

The SUTSE model was implemented for Switzerland, revealing a strong correlation between the fatality and the exposure series. More specifically, the correlation between the two levels is 0.84 and marginally significant at 90% ($p=0.095$). The correlation between the two slopes is equal to 1 and non significant ($p=0.156$) at 90% or 95%; it is however significant at approximately 85%. The relation between exposure and fatalities estimated by the beta coefficient in a restricted SUTSE/LRT model is 2.21 and is highly significant ($p<0.001$) at 99% suggesting that the two series are strongly related. Consequently, LRT models are examined for Switzerland.

Three versions of the LRT model are presented: a full model, a restricted model (fixed level exposure and fixed slope risk), and a restricted model with intervention variables (see Table 1). The full LRT model (LRT 1) suggests that both the level and slope of both components are non significant. All components are also indicated to be common, suggesting that it might be wise to start fixing "half" of the related components (i.e. the slopes). Moreover, the covariances between components are significant in the full LRT model, and the correlation between them is close to one.

Initially, a restricted model with fixed slope of the risk was fitted (LRT2 – not presented here), in which the remaining three components were still non significant. Two alternatives were then examined: in the first one, both slopes (exposure and risk) were fixed; the output of this model (LRT3 – not presented here) was still problematic, as the covariance between the two levels was very significant and the smoothed output plots reflected a deterministic exposure level. The second option was a model with a fixed slope risk and a fixed level exposure (LRT4); this was proved to be a better option, as the remaining components were significant and the output was satisfactory overall.

Concerning the possible interventions, no information was available for specific road safety interventions or other socioeconomic events, it was therefore attempted to describe the most important changes reflected in the data series itself. A change in exposure level on 1993 was considered as intervention variable, in LRT5 model. This variable was significant at 99% (p-value lower than 0.001). This model presents significantly improved fit compared to the full model (the difference in log-likelihood is equal to 12) and the prediction errors for fatalities are improved compared to the full model. Consequently, this model (LRT5) is selected as the best performing model for Swiss fatality risk.

TABLE 1. Model selection table for Switzerland

Model type	LRT full	LRT restricted	LRT restricted with interventions
Model Criteria			
ME10 Fatalities	-6037	-5374	-4918
MSE10 Fatalities	5.56827	4.79550	4.35124
log likelihood	18156	17675	17071
AIC	-36262	-35322	-34115
Variance of state components			
Level exposure	1.61E-04	-	-
Level risk	5.84E-04	7.66E-04 *	7.79E-04 *
Slope exposure	6.46E-06	4.15E-05 *	6.84E-06 *
Slope risk	9.41E-06	-	-
Correlations between state components			
level-level	0.64	-	-
slope-slope	1	-	-
Observation variance			
Observation variance exposure	2.95E-06	5.95E-05 *	7.32E-05 *
Observation variance risk	4.18E-06	2.99E-04	2.47E-04
Interventions			
(1993 exposure level)	-	-	-0.0501062 *
Model Quality			
Box-Ljung test 1 Exposure	0.228	121.897	136.467
Box-Ljung test 2 Exposure	0.801	241.477	503.337
Box-Ljung test 3 Exposure	0.8525	329.751	583.505
Box-Ljung test 1 Fatalities	216.579	286.154	263.737
Box-Ljung test 2 Fatalities	255.335	316.426	265.737
Box-Ljung test 3 Fatalities	311.375	376.553	33.562
Heteroscedasticity Test Exposure	0.386	0.454	0.807
Heteroscedasticity Test Fatalities	269.171	302.679	280.834
Normality Test standard Residuals Exposure	5.99954*	132.338	329.738
Normality Test standard Residuals Fatalities	0.0189	0.312	0.525
Normality Test output Aux Res Exposure	0.0439	0.458	353.243
Normality Test output Aux Res Fatalities	124.914	159.349	183.043
Normality Test State Aux Res Level exposure	338.426	307.695	0.0385
Normality Test State Aux Res Slope exposure	129.975	0.706	0.183
Normality Test State Aux Res Level risk	3.574	8.381*	7.704*
Normality Test State Aux Res Slope risk	0.068672	3.92E-05	3.37E-05

Note: * denotes significant at 95% level

Modeling results for fatality risk in Greece, Norway, Hungary and Cyprus

From the SUTSE modeling results for Greece, it was concluded that the fatalities and vehicle fleet series are not related and therefore further modeling can be made using the LLT model (instead of the LRT). Three versions of the LLT model were run. The full model (LLT1) was run first, and all residual tests did not indicate a violation of the underlying assumptions. Furthermore, the level and slope components were significant. Therefore, a new model (LLT2) with additional interventions was estimated, namely a level change on 1986 (economic crisis), a level change on 1991 (“old-car-exchange” scheme) and a slope change on 1996 (adoption of the 30-days definition of fatalities). While the fit of this model improved over the original model, the slope component became insignificant. Therefore, a third model (LLT3) was also run, with the interventions, but keeping the slope of the fatalities fixed, which was selected as the best fitting model for Greece.

As regards Hungary, a lot of effort was devoted to the selection of an appropriate modeling approach. It is reminded that, before 1990, although the exposure rised impressively, the fatalities presented a relatively flat trend, with several bigger or smaller peaks. Moreover, the change of political regime in the early nineties is associated with an impressive peak in fatalities, and - rather surprisingly - a drop in exposure. Preliminray modeling attempts suggested that the relationship between exposure and fatalities appears to differ significanty in different parts of the series, making it difficult to model the whole series. It was therefore decided to disregard the pre-1993 parts of both series and focus on the period 1993-2010 for forecasting.

The investigation of the SUTSE model clearly indicated a lack of a relation between exposure and fatalities in Hungary, therefore LLT models were tested. Initially, the level of the fatality series was fixed, as it was non significant in the full LLT model. Two intervention variables were tested, namely a level change on 2002 (increase of motorway length in the country by 19%), and a level change on 2008 (introduction of a large set of road safety measures). Both interventions were highly significant, but the slope of the fatalities became non significant and had to be fixed too. The final model is therefore a deterministic linear trend (LT) model with interventions (LT6).

As regards Norway, the investigation of the SUTSE model did not clearly indicate the presence of a relation between exposure and fatalities in Norway. However, there is also reasonable doubt that these two time series are unrelated. The coefficient (beta) that estimates the relation between the two series is not significant but with p=0.28 it is not small enough to confidently rule out a relation. It was therefore decided to base the forecasting procedure on the LRT model. The full LRT model indicated that the level of the exposure and the slope of the risk were non significant, and were therefore fixed. This restricted model showed slightly higher prediction errors, but this was considered a minor issue as the absolute value of these errors was still very low. No intervention variables were included in this model, as no specific information was available.

The SUTSE model for Cyprus did not clearly indicate the presence of a relation between exposure and fatalities in Cyprus. However, the coefficient (beta) that estimates the relation between the two series has p=0.16, which is not small enough to rule out a relation. The non significant relation between the two series, could be due to the small number of observations. It was therefore decided to base the forecasting procedure on the LRT model. The full LRT model suggests that only the slope of the exposure varies significantly. However, when fixing all the other components, there was no improvement in model’s fit (AIC) and the quality of the prediction was also worse (when holding the last 10 points of the series for prediction). On the basis of the above, it was decided to keep the full LRT model as the final model for Cyprus.

TABLE 2. Summary table of selected models for Cyprus, Greece, Hungary and Norway

Country	**Greece**	**Hungary**	**Norway**	**Cyprus**
Model Type	LLT restricted with interventions	LLT deterministic with interventions	LRT restricted	LRT full
Model Criteria				
ME10 Fatalities	-251.5	196297	24	-2.59
MSE10 Fatalities	70572.97	58253.62	967.3	118.25
log likelihood	65.82	167835	156.941	52.96
AIC	-131.55	-324559	-313.612	-105.02
Variance of state components				
Level exposure	-	-	-	9.22E-05
Level risk	2.67E-03*	-	3.84E-03 *	6.53E-04
Slope exposure	-	-	3.16E-04 *	1.08E-04 *
Slope risk	-	-	-	8.10E-06
Correlations between state components				
level-level	-	-	-	-1
slope-slope	-	-	-	1
Observation variance				
Observation variance exposure	-	-	1.45E-06	3.60E-04
Observation variance risk	1.00E-09	1.88E-03 *	5.40E-04	1.11E-03
Intervention and explanatory variables tests				
(slope fat 1996)	-0.080 *	-	-	-
(level fat 1986)	-0.211 *	-	-	-
(level fat 1991)	0.147 *	-	-	-
(level fat 2002)	-	0.220 *	-	-
(level fat 2008)	-	-0.259 *	-	-
Model Quality				
Box-Ljung test 1 Exposure	-	-	0.15	4.70*
Box-Ljung test 2 Exposure	-	-	1.34	5.3
Box-Ljung test 3 Exposure	-	-	2.35	5.67
Box-Ljung test 1 Fatalities	0.29	150.267	0.42	1.62
Box-Ljung test 2 Fatalities	2.78	188.584	0.42	1.91
Box-Ljung test 3 Fatalities	4.03	322.822	1.91	2.27
Heteroscedasticity Test Exposure	-	-	0.34	0.47
Heteroscedasticity Test Fatalities	0.76	263.094	1.1	2.45
Normality Test standard Residuals Exposure	-	-	1.63	1.98
Normality Test standard Residuals Fatalities	2.06	182.026	1.35	5.89
Normality Test output Aux Res Exposure	-	-	0.84	0.92
Normality Test output Aux Res Fatalities	1.17	118.117	0.55	3.74
Normality Test State Aux Res Level exposure	-	-	0.76	14.54***
Normality Test State Aux Res Slope exposure	-	-	1.71	0.16
Normality Test State Aux Res Level risk	1.1	0.943	1.76	2.69
Normality Test State Aux Res Slope risk	0	145.961	0.06	0.08

Note: * denotes significant at 95% level, *** denotes significant at 99.9% level

SYNTHESIS AND FORECASTS

The forecasts obtained from the best fitting model in each country provide an indication of the fatality numbers to be expected between 2010 and 2020 provided that, throughout these years, the trends will keep on following the developments that they have shown in the past, and no principal changes occur in the meantime ("business as usual" assumption). More specifically, if the past development continues, the following forecasts can be made for the number of fatalities in 2020 (see Figure 2):

- In Greece, there were approximately 1300 fatalities on 2010, and the forecast for 2020 is 898 fatalities (95% confidence interval: 585-1379 fatalities).
- In Hungary, there were 740 fatalities on 2010, and the forecast for 2020 is 555 fatalities (95% confidence interval: 472-653 fatalities).
- In Switzerland, there were 329 fatalities on 2010, and the forecast for 2020 is 216 fatalities (95% confidence interval: 167-278 fatalities). The number of vehicle kilometres is expected to increase up to 70.8 billion in 2020, compared to 62.3 in 2010.
- In Norway, there were 212 fatalities on 2009, and the forecast for 2020 is 132 fatalities (95% confidence interval: 53-333 fatalities). The number of vehicle kilometres is expected to increase up to 42 billion in 2020, compared to approximately 40 in 2009.
- Finally, in Cyprus there were 60 fatalities on 2010, and the forecast for 2020 is 37 (95% confidence interval: 53-333 fatalities). The fuel consumption is expected to increase up to 894 million tn.eq. in 2020, compared to 860 million in 2010.

It can be seen in Figure 2 that there is strong uncertainty about the development of the exposure in the 3 countries for which LRT models were fitted (for the countries that an LLT was estimated, exposure is not modeled, so such a plot is not applicable). Given that the exposure influences the prediction of the fatalities, it is interesting to demonstrate how much of the possible variation indicated by the confidence interval around the fatalities is due to the variation in exposure.

Figure 3 below presents three point-estimates for the number of fatalities that can be expected assuming three different scenarios for exposure. The three mobility scenarios presented here are actually the exposure as predicted from the selected LRT model plus/minus one standard deviation. Assuming that these predictions are correct, and thus ignoring the uncertainty surrounding the forecasts for the exposure, what would be the consequences for the number of fatalities to be expected in 2020?

- In Switzerland, a stronger growth in vehicle kilometres travelled would result in 75 billion on 2020, and 230 fatalities forecasted. On the contrary, a contraction in mobility resulting in 66 billion vehicle kilometres on 2020 would result in 202 fatalities forecasted.
- In Norway, a stronger growth in vehicle kilometres travelled would result in 61 billion on 2020, and 196 fatalities forecasted. On the contrary, a contraction in mobility resulting in 20 billion vehicle kilometres on 2020 would result in 89 fatalities forecasted.
- In Cyprus, a stronger growth in fuel consumption would result in 1132 million tn.eq. on 2020, and 49 fatalities forecasted. On the contrary, a contraction in fuel consumption resulting in 701 million tn.eq. on 2020 would result in 27 fatalities forecasted.

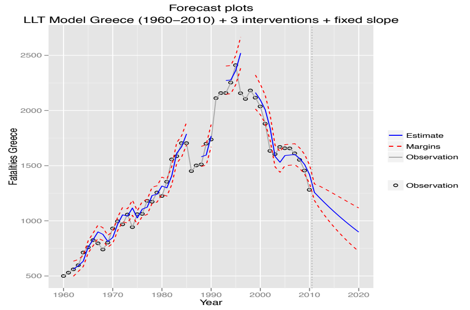
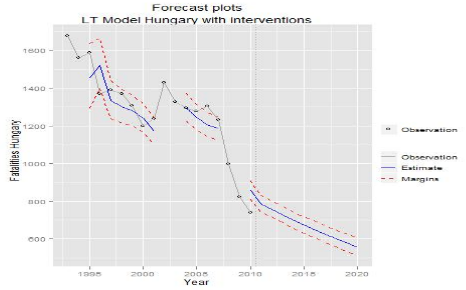
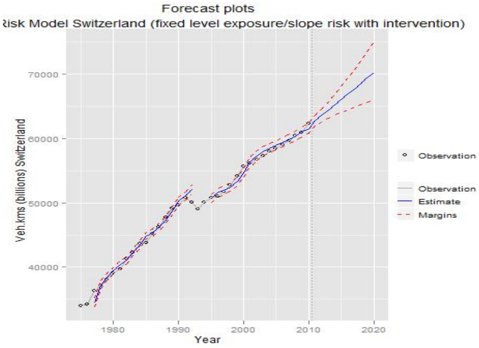
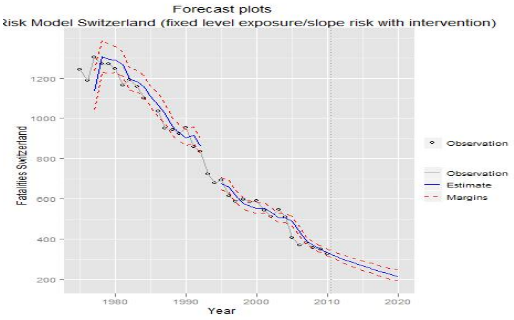
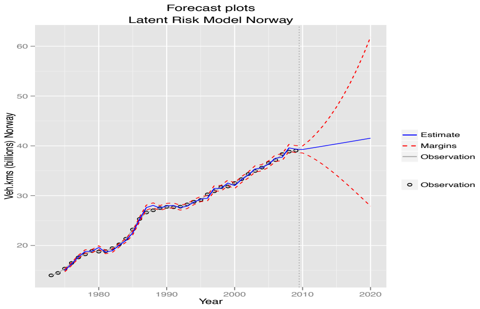
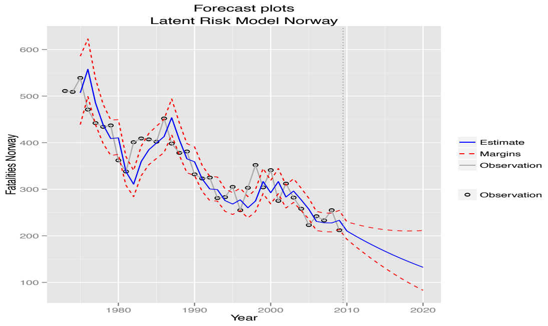
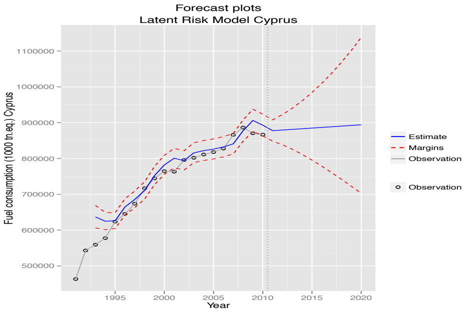
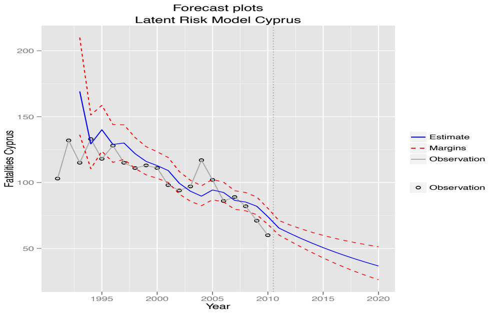
Not applicable (LLT model was estimated)	 Forecast plots LLT Model Greece (1960–2010) + 3 interventions + fixed slope
Not applicable (LLT model was estimated)	 Forecast plots LT Model Hungary with interventions
 Forecast plots Risk Model Switzerland (fixed level exposure/slope risk with intervention) 	 Forecast plots Risk Model Switzerland (fixed level exposure/slope risk with intervention)
 Forecast plots Latent Risk Model Norway 	 Forecast plots Latent Risk Model Norway
 Forecast plots Latent Risk Model Cyprus 	 Forecast plots Latent Risk Model Cyprus

FIGURE 2. Forecasts of exposure (left panel) and fatalities (right panel) for the 5 examined countries for year 2020

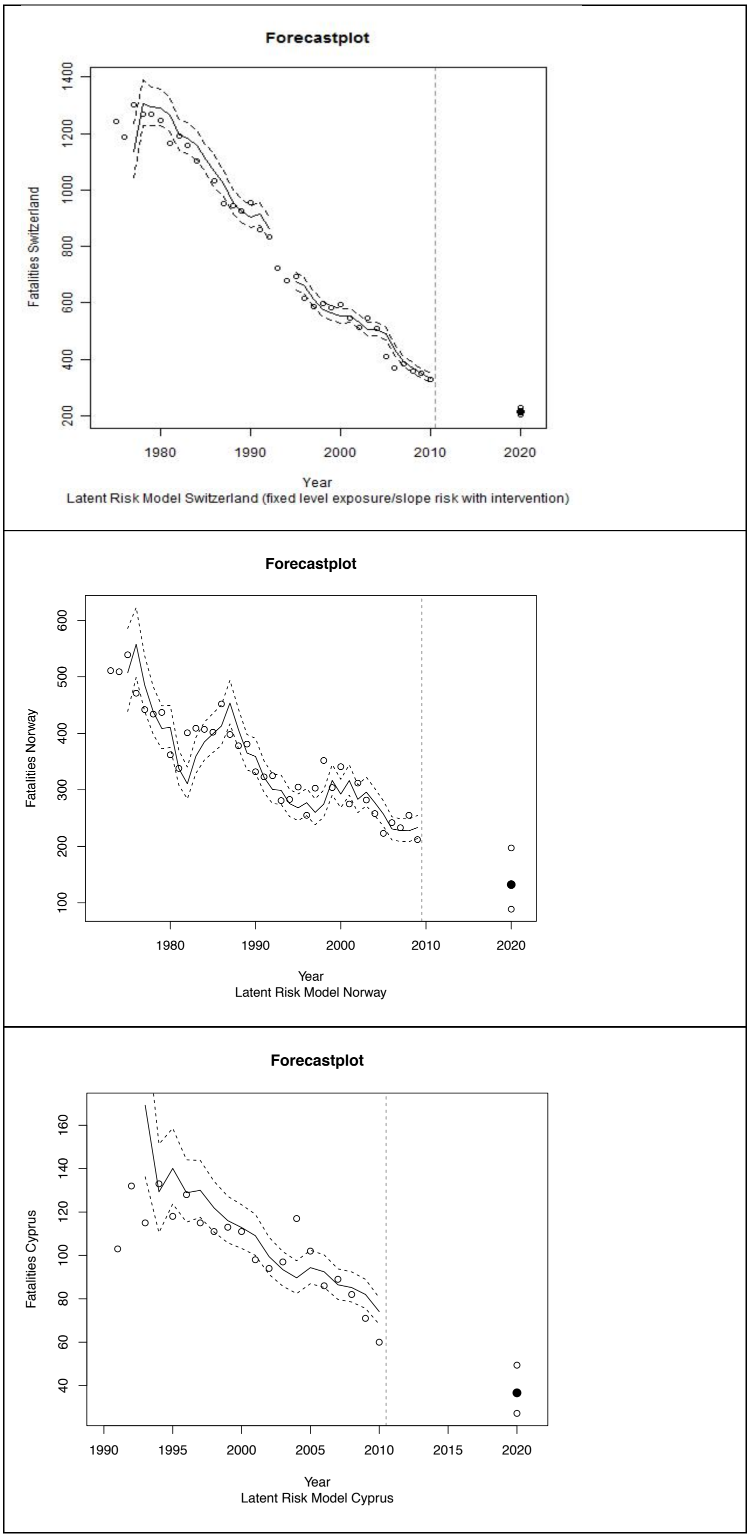


FIGURE 3. Forecasts for 2020 for different mobility scenarios ● Continuation of development (as estimated by LRT model). ◦ Stronger growth (LRT estimate + 1 SD). ◦ No growth (LRT estimate - 1 SD)

DISCUSSION

Table 3 summarizes the methods and results of modeling road safety developments in 5 European countries by means of structural time series models. The 5 examined countries are a quite representative sample of European countries, including Northern / Western, Central and Southern European countries, older and new EU Member States, good and poor performing countries in terms of road safety.

TABLE 3 Overview of for 5 countries

	Cyprus	**Greece**	**Hungary**	**Norway**	**Switzerland**
data available	1990-2010	1960-2010	1970-2010	1970-2009	1975-2010
Exposure	Fuel consumption	Vehicle fleet	Passenger kilometres	Vehicle kilometres	Vehicle kilometres
Recession effect	Yes	No	Yes	No	No
Information on inverventions	No	Yes	Yes	No	No
data used	1990-2010	1960-2010	1993-2010	1970-2009	1975-2010
Model type	LRT	LLT	LT	LRT	LRT
Interventions	No	Yes	Yes	No	Yes
Forecast 2020	Yes	Yes	Yes	Yes	Yes
Mobility scenario	Yes	No	No	Yes	Yes

In all these countries, fatality data are available from the early seventies up to 2010, except from Cyprus, for which data was available from 1990 onwards. For all the countries, the entire data series was used, except from Hungary. In that country, early modeling attempts indicated that there may be different relationships between exposure and fatalities in different parts of the series; especially the pre-1990 data seemed problematic, because a very strong growth in exposure appeared to have no effect on fatalities. It was therefore decided to discard that part of the series for modeling and forecasting.

Different exposure measures were available in different countries, ranging from the most appropriate ones, i.e. passenger and vehicle-kilometres, to the “second best”, i.e. fuel consumption, to the less appropriate, i.e. vehicle fleet. The example of Greece seems to confirm the limited usefulness of vehicle fleet data as a proxy of exposure, as it was proved to be not at all related with road safety developments. However, there was the case of Hungary, where passenger kilometres were available but were not found to be (statistically) related to road safety developments. In the remaining countries, the fatalities and exposure developments were related: strongly in Switzerland, and weakly in Norway and Cyprus.

Consequently, a broad range of models from the family of structural time series models were developed, according to the particularities of each country, ranging from deterministic linear trend (LT) model for Hungary, to local linear trend (LLT) model in Greece, and to different forms of Latent Risk Models (LRT) in the other countries: full LRT in Cyprus, restricted LRT in Norway, and restricted LRT with interventions in Switzerland.

The decision to include intervention variables was based on the availability of information on specific interventions or events (road safety related or socio-economic). An exception was made for Switzerland, where a “data-driven” intervention variable significantly improved model’s fit.

From the best fitting model in each country, road safety and mobility (where applicable) forecasts were made, and their 95% confidence intervals were calculated. Still, in order to better describe the uncertainty in these forecasts, mobility scenarios were calculated, assuming stronger or weaker than expected mobility developments. This may be particularly important when considering that in several countries a recession effect is visible at the end of the fatalities and / or the mobility series, which in turn affects the final forecast. The "optimistic" mobility scenario, in which the forecasted value for 2020 is increased by one standard deviation, may in some cases provide a more realistic picture of future developments, as it takes into account the fact that the recession will end sooner (while in the baseline "business-as-usual" scenario, the effect of the recession is assumed to continue in the future).

CONCLUSION

The present research applied a methodological framework for forecasting road safety and mobility developments with structural time series models on a representative sample of European countries. This framework was developed within the Dacota research project, co-funded by the European Commission. The proposed methodology contributes meaningful steps for model selection, starting with SUTSE modeling and proceeding to LLT / LRT, full or restricted, on the basis of sound criteria in each case. Nevertheless, a good knowledge of the road safety and socioeconomic situation in the examined countries was still necessary, not only for understanding the description and forecasts of the developments, but also for making decisions in data handling, introduction of intervention variables etc.

The proposed methodology was proved to be very efficient for handling different cases of data availability and quality, providing an appropriate alternative from the family of structural time series models in each case. The estimated forecasts in all 5 countries appear to be realistic and within acceptable confidence intervals. Although the forecasts are based on "business-as-usual" scenarios, stronger or weaker mobility development scenarios are provided where possible, providing insight on the effect of various mobility developments of the forecasts.

These results may be useful both to policy-makers and researchers in the field of road safety, for understanding past developments, as well as the dynamics and particularities of the relationship between exposure and fatality risk. The results also provide insight on the effects of safety interventions or other socio-economic events on mobility and road safety. The estimated forecasts reflect the future situation if the existing policy efforts and the socio-economic context extent to the future, and this may be motivating for devoting additional efforts in outperforming these forecasts.

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