Is road safety management linked to road safety performance?

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Abstract

This research aims to explore the relationship between road safety management and road safety performance at country level. For that purpose, an appropriate theoretical framework is selected, namely the 'SUNflower' pyramid, which describes road safety management systems in terms of a five-level hierarchy: (i) structure and culture, (ii) programmes and measures, (iii) 'intermediate' outcomes' - safety performance indicators (SPIs), (iv) final outcomes - fatalities and injuries, and (v) social costs. For each layer of the pyramid, a composite indicator is implemented, on the basis of data for 30 European countries. Especially as regards road safety management indicators, these are estimated on the basis of Categorical Principal Component Analysis upon the responses of a dedicated road safety management questionnaire, jointly created and dispatched by the ETSC/PIN group and the 'DaCoTA' research project. Then, quasi-Poisson models and Beta regression models are developed for linking road safety management indicators and other indicators (i.e. background characteristics, SPIs) with road safety performance. In this context, different indicators of road safety performance are explored: mortality and fatality rates, percentage reduction in fatalities over a given period, a composite indicator of road safety final outcomes, and a composite indicator of 'intermediate' outcomes (SPIs). The results of the analyses suggest that road safety management can be described on the basis of three composite indicators: "vision and strategy", "budget, evaluation and reporting", and "measurement of road user attitudes and behaviours". Moreover, no direct statistical relationship could be established between road safety management indicators and final outcomes. However, a statistical relationship was found between road safety management and 'intermediate' outcomes, which were in turn found to affect 'final' outcomes, confirming the SUNflower approach on the consecutive effect of each layer.

Key words: road safety management; road safety performance; composite indicators; poisson regression; beta regression.

1. Background and objectives

The need for optimized road safety management systems, leading to better road safety performance, is often underlined by researchers and policy makers, under the basic assumption that effective organization of road safety management is one of the conditions for obtaining good road safety results (OECD, 2008; WHO, 2009). Recently, the International Standard ISO 39001:2012 (ISO, 2012) published requirements and guidance for safety management systems.

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A road safety management system can be defined as “a complex institutional structure involving cooperating and interacting bodies which supports the tasks and processes necessary to the prevention and reduction of road traffic injuries” (Muhlrad et al., 2011). By definition, a road safety management system should meet a number of “good practice” criteria spanning the entire policy making cycle, from agenda setting, to policy formulation, adoption, implementation and evaluation, and including efficient structure and smooth processes, in order to enable evidence-based policy making.

On the other hand, it has been argued that road safety performance, in terms of low casualty rates, may not truly reflect the existence of best practice in road safety management (Johnston, 2010). Bliss & Breen (2009) suggest that effective road safety management can be achieved with various structural and procedural forms, making it difficult to identify a single “good practice” model. Papadimitriou et al. (2012) carried out an exhaustive investigation of road safety management systems in 14 European countries, and found that not all “good practice” elements in road safety management are met in the best performing countries; however, a lack of several “good practice” elements was systematically observed in poor performing countries. Wegman et al. (2005) point out that useful road safety management lessons may be found not only in the ‘known’ best performing countries, but also in the experience of the ‘rapid improvers’, i.e. countries with a poorer starting point.

Several researchers have analysed the road safety management systems in various countries and have attempted to estimate the impact of road safety management components on road safety performance. Wong & Sze (2010) evaluated the effect of setting quantitative targets for fatality reductions on the final outcomes for 7 European countries, and found a significant positive effect. Elvik (2008) presented a critical assessment of the Norwegian “management by objectives” approach and identified strengths and weaknesses. Broughton and Knowles (2010) assessed the expected reduction in fatalities from the national road safety programme in the UK.

Chapelon & Lassarre (2010) analysed the structures, processes, data and methods used in the road safety management system of France, with particular emphasis on demonstrating how specific performance indicators are monitored to assess the progress of specific road safety problems. Schulze & Kossman (2010) describe the road safety management tools established in Germany, serving to explain reasons of safety deficits, define and recommend evidence based measures, assess the safety impact of an implemented single measure and continuously control in how far the objectives of the national road safety action plan are met.

From the review of the literature, it is concluded that road safety management systems are complex, including several components (structures, plans, processes, outputs, tools etc.), making it extremely difficult to even describe them in a standardised way. Moreover, despite the common belief that better road safety management structures and processes are positively associated with better road safety performance, there is indication that the relationship is more complex and case-specific. In fact, the relationship between the road safety management system in a country as a whole, and the related road safety outcomes, in terms of road accident casualties, has not been adequately explored.

A first step was presented in a recent research (Elvik, 2012), where a statistical model was built linking road safety performance with road safety management and a couple of other possible confounding factors, but no relationship was identified. This was attributed partly to the small sample size (17 countries) and the way road safety management was 'measured' (i.e. as the number of road safety management tools implemented in each country).

Within this framework, the objective of this research is to investigate the relationship between road safety management and road safety performance at a country level. For that purpose, a comprehensive framework of road safety management systems is adopted, and composite indicators are used for describing the components of the system. Especially as regards road safety management, appropriate indicators are estimated on the basis of data from the ETSC/PIN group and the 'DaCoTA' research project. Then, statistical models are developed in order to associate road safety performance with road safety management indicators and other related indicators.

2. Methodological framework

The road safety management 'footprint' of a country at a specific point in time can be described on the basis of the SUNflower pyramid (Koornstra et al., 2002; Wegman et al. 2005), which includes a target hierarchy of five levels of road safety components, starting from the bottom, as follows (see Figure 1):

- The road safety performance of a country is related to structural and cultural characteristics (i.e. policy input) at the bottom level.
- It is consequently related to common practice (i.e. safety measures and programs - policy output), resulting from these structural and cultural characteristics, at level 2.
- To link these first two 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 (SPIs) on issues like speeding, drinking and driving, as well as a concise depiction of the road network and the main features of the vehicle fleet.
- Final outcomes expressed in terms of road casualties are then necessary to understand the scale of the problem. This type of information is found at level 4, and consists of different types of road risk indicators.
- The top of the pyramid includes an estimate of the total social costs of road accidents.

Figure 1 to be inserted here

This pyramid implies an indirect impact of road safety policies, and specific programmes and measures on road safety performance, either in terms of 'intermediate' outcomes (SPIs) or final outcomes (fatalities and injuries). There are numerous studies that examine the effect of specific policies and measures to specific outcomes, for instance, alcohol-related measures (e.g. enforcement) to the share of drink-driving, and to alcohol-related accidents. However, this relationship has not been examined as a whole in the international literature, in terms of the relationship of the road safety management level with the overall road safety performance.

In this research, the SUNflower 'footprint' methodology was selected as the framework for the investigation of the relationship between road safety management and road safety outcomes.

Intuitively, in such an analysis, the dependent variable would be the road safety outcomes (i.e. fatality risk) and the explanatory variables would include structural and cultural indicators (e.g. socioeconomic, reflecting background characteristics), road safety management (RSM) indicators, and safety performance indicators (SPIs).

However, it should be noted that SPIs are by definition representative of the operational level of road safety, which is also affected by structural and cultural characteristics and road safety policies, and are thus often referred to as 'intermediate outcomes'. The purpose of using SPIs is to fill the gap in the lack of knowledge on causal relationships between interventions and final outcomes (Hollo et al, 2010). In this research, it will be examined whether SPIs may be also used as a dependent variable of the analysis, and consequently whether road safety management may also affect 'intermediate' road safety outcomes.

More specifically, in the present analysis, three hypotheses are tested:

- Road safety management is associated with a country's road safety performance as reflected in its final outcomes (i.e. fatality risk);
- Road safety management is associated with a country's road safety outcomes' development (e.g. in the percentage reduction in fatalities over a given time period);
- Road safety management is associated with a country's 'intermediate' road safety outcomes, namely the SPIs reflecting the operational level of road safety in that country.

These hypotheses are tested for 30 European countries, namely the 27 EU Member States, plus Norway, Switzerland and Israel. It has been argued that composite road safety indicators may be the most promising tool for comparing countries' performance in terms of various road safety issues (Wegman & Oppe, 2010; Gitelman et al., 2010). For the purposes of the present analysis, various data sources are used in order to obtain or estimate appropriate composite indicators for testing the above hypotheses.

3. Data collection and handling

3.1. Road safety outcomes data

A country's road safety performance can be measured in a number of ways, i.e. mortality or fatality rates at a given year (road safety outcomes per million inhabitants or per million vehicle-kilometres of travel), development over time (e.g. percentage decrease over a decade, or average annual change over a decade), etc.

In this research, it was decided to test both the road safety level and the road safety development of each country. Fatality data for years 2000-2010 were extracted from the CADaS database of the European Commission, whereas population and passenger-kilometres[2] data for year 2010 were obtained from the Eurostat database (see Appendix I).

A third option was also explored, namely to describe road safety outcomes on the basis of a composite indicator. In recent research (Bax et al. 2012), a composite index concerning road safety outcomes was created, on the basis of a weighted score of seven normalised outcomes indicators:

- Fatalities per million inhabitants, 2008
- Fatalities per million vehicle fleet, 2008
- Fatalities per 10 billion pkm, 2008
- Annual average percentage reduction in fatalities, 2001-2008
- Pedestrian as a % of total fatalities, 2008
- % of pedal cycle fatalities of the total, 2008
- % of motorcycle and moped fatalities of the total, 2008

The composite index includes both fatality risk rates and development indicators, together with indicators concerning particular – vulnerable – road user groups. Care was taken that the indicators were expressed in the same direction with respect to road safety performance, i.e. higher scores correspond to better road safety performance and lower risk.

The basic methodological steps for the development of this composite road safety outcomes indicator can be outlined as follows:

- Selection of indicators: the set of individual indicators to combine in a composite indicator was defined on the basis of theoretical criteria and on data availability / quality.
- Data preparation: handling of outliers, normalisation to eliminate scale differences between individual indicators, imputation of missing values etc.
- Weighting: the weights assigned to each individual indicator for the calculation of the composite indicator were defined on the basis of Data Envelopment Analysis. This is an optimization technique that determines the best possible weights, i.e., the weights resulting in the highest composite indicator score for a country, on the basis of the imposed restrictions and taking into account the data for all countries in the data set. This technique was opted for over other weighting techniques for being an objective weighting technique which takes into account the relative performance of countries.
- Aggregation: arithmetic averaging was used for combining the indicators into a composite indicator.

For further details on the development of this composite road safety outcomes indicator, the reader is referred to Bax et al. (2012). The indicator values for the 30 countries examined are presented in Appendix I.

[2] Passenger-kilometres data concern passenger cars only; however, passenger car traffic is considered to be quite representative of national traffic.

3.2. Road safety management data

Due to the lack of data, and of quantitative indicators in particular, for the description of road safety management systems, one of the specific objectives of this research is the estimation of such road safety management indicators. For that purpose, data of the ETSC/PIN group and the 'DaCoTA' research project were used.

More specifically, the 'DaCoTA" working group on road safety management collaborated with the European Transport Safety Council (ETSC), in order to collect data on road safety management in the European countries through the ETSC Road Safety Performance Index (PIN) panel members (Jost et al., 2012). A questionnaire with 18 basic questions on road safety management was dispatched to the PIN panel members, as shown in Table 1.

Table 1 to be inserted here

This PIN/DaCoTA questionnaire aimed to obtain a general overview of the road safety management system in the 30 countries, although in a minimum level of detail. Usable responses come from 29 countries, as it was not possible to obtain any response from Bulgaria.

A datafile was created on the basis of the PIN/Dacota data, with the following variable coding for each question: [1: yes, 0.5: partially, 0: No, 99999: Unknown], and a thorough consistency check of the data was carried out. The data coding was implemented by one person as follows: most PIN/Dacota questions were already coded by this type of coding; for a few questions, more than one intermediate categories were available (e.g. "yes, but..." and "no, but..." responses) and these were merged into a common response corresponding to "partially". In each case, a free text field was available to the respondents for comments and explanations; these fields were carefully examined in order to cross-check and validate the coding adopted.

Subsequently data handling was carried out with two objectives: one, to identify questions with little usability due to many missing / unknown values or other (theoretical) reasons, and second, to identify "consensus" questions that would not add variability in the analysis and would thus be not meaningful to examine. These questions are highlighted in Table 1.

Two questions, namely 5b and 5c, concerning the adequacy and the changes in the budget dedicated to road safety, have more than 10 unknown values, and were therefore excluded from the analysis. On the other hand, in questions 10a and 10b, concerning the measurement of attitudes towards road user behaviour and related measures, there are only a couple of unknown values, which can be handled in the statistical analysis (e.g. replaced by the mean of the known responses).

Concerning the selection of "consensus" questions, the sum of all responses, as well as the counts of "yes", "partially" and "no" responses was calculated. The criteria for considering a question to be a consensus were a combination of many "yes" values, few "partially" values and very few "no" values. Consequently, questions 7a (monitoring), 7b (monitoring results published), 4 (national programme / plan), 3a (target for fatalities), 6a and 6b (lead agencies) were eventually considered as “consensus” questions.

Two other questions were considered unusable, namely questions 3b and 3c concerning the targets about serious injuries or other specific road user groups; such targets have only been very recently adopted by some countries, and therefore their existence is not expected to correspond to the current level of efficiency or maturity of the road safety management system. The remaining 8 questions were considered usable and useful for the estimation of road safety management indicators, as will be described in section 4.1.

3.3. Background indicators: structure and culture

Within the first stages of this analysis, it was attempted to use a geographical grouping of countries in order to reflect the common socioeconomic, transport and road safety backgrounds between countries, i.e. northern / western, central / eastern and southern. However, given that such a classification was not very informative, it was decided to exploit the work of Bax et al. (2012), whose objective was the grouping of EU countries on the basis of structural and cultural data.

The description of the extensive research carried out by Bax et al. (2012) is beyond the scope of this paper. Nevertheless, it is worth mentioning that, despite the fact that slightly different results were obtained when testing different methods and data, it was concluded that:

- The basic background indicators among the numerous data examined were GDP per capita and the level of motorization.
- In various different clusterings of countries attempted, two relatively stable “groups” of countries were identified.
- The first group includes 10 countries: Romania, Bulgaria, Hungary, Slovakia, Latvia, Poland, Estonia, Portugal, the Czech Republic and Lithuania, and, on average, is characterized by lower values of the background country characteristics.
- The second group includes the remaining 20 countries.

3.4. Road safety intermediate outcomes data: Safety performance indicators

As was the case for final outcomes, in Bax et al. (2012) a composite index was developed for the ‘intermediate’ road safety outcomes. This indicator was based upon a weighted score of 8 normalised SPIs concerning road user behaviour, enforcement and vehicles in each country namely:

- Roadside police alcohol tests per 1,000 population, 2008
- Percentage of drivers above legal alcohol limit in roadside checks, 2008
- Daytime seat belt wearing rates on front seats of cars, 2009
- Daytime wearing rates of seat belts on rear seats of cars, 2009
- Average percentage occupant protection score for new cars sold in 2008
- Average percentage score of pedestrian protection for new cars sold in 2008
- Renewal rate of passenger cars in 2007
- Median age of passenger cars, 2008

All the indicators used for the development of the composite index were normalised and expressed in the same direction with respect to their expected road safety impact, i.e., a higher SPI value should correspond to a better operational level of road safety and a lower crash/injury risk. The composite SPI was calculated using a similar method as the one presented in section 3.1; the data for the 30 European countries are presented in Appendix I.

4. Analysis methods

4.1. Categorical Principal Component Analysis

A distinct part of the analysis is devoted to the estimation of road safety management indicators, given that for all the other levels (layers) of the SUNflower 'footprint', data was available from European databases or appropriate composite indicators had been estimated (Bax et al. 2012).

The 8 selected questions of the PIN/DaCoTA data reflect basic elements of road safety management systems; however, they can not be assumed to be independent variables, given that they examine common, complementary issues and are all intended to express aspects and dimensions of the concept of road safety management, which can not be measured directly. In order to estimate a road safety management indicator (or a small number of appropriate indicators) on the basis of the PIN/DaCoTA data, an appropriate data dimension reduction technique should be used.

A Principal Component Analysis (PCA) would be a typical approach in order to identify such groups of variables ("components"). This technique has two main objectives: the first is to understand the structure of a (usually large) set of variables and the second is to reduce the dataset to a more manageable size and at the same time retain as much of the original information as possible.

Standard PCA assumes linear relationships between numeric variables. However, in the present analysis, variables are discrete ordinal (i.e. the responses are coded as "yes, partially, no"). Moreover, there are reasons to assume nonlinear relationships between variables; it is likely that the "distance" between "yes" and "partially" is very different from the "distance" between "partially" and "no", as assumed by the coding of the responses (i.e. 0, 0.5, 1). Another limitation of standard PCA for the present analysis is the adequate sample size requirement, which is obviously not met here.

For these reasons, another approach was tested, namely Categorical Principal Component Analysis (CATPCA), which falls within the broad family of optimal scaling techniques. With these techniques, discrete (nominal and ordinal) variables can be converted to "interval" variables, i.e. variables which are continuous within a given interval. The optimal-scaling approach allows variables to be scaled at different levels, and categorical variables are optimally quantified in a specified dimensionality. As a result, nonlinear relationships between variables can be modelled (Muelman et al. 2004).

The process results in the creation of new, transformed variables, which maintain the properties of the initial variables but are interval-continuous ones. Then, the

CATPCA is applied on the transformed (optimally scaled) variables, in order to reduce the dimensionality of the dataset to a predefined number of dimensions.

4.2. Modelling road safety outcomes and road safety management

Once the road safety management indicators are estimated on the basis of CATPCA techniques, it is possible to develop statistical models linking these road safety management indicators and the other related indicators (i.e. background, SPIs etc.) to the road safety outcomes.

The modelling techniques applied fall within the broad family of Generalised Linear Models (GLM), which allow for a large set of distributional assumptions to be considered (mainly normal / Gaussian and exponential, but also others). Furthermore, due to the properties of some of the dependent variables considered in the analysis, another family of models is used, namely the Beta regression models.

4.2.1. Poisson models

As mentioned in section 3.1, two types of risk rates are examined in terms of their association with RSM indicators and other variables: the mortality rate (fatalities per million inhabitants) and the fatality rate (fatalities per million vehicle-kilometres of travel).

A Poisson GLM is considered, in which the dependent variable is the logarithm of the count of fatalities, and the explanatory variables include an ‘offset’ term, namely the logarithm of the exposure, so that rates are modelled instead of counts:

$$\text{Log}\,(F_i) = \log\,(E_i) + \beta_0 + \beta_1\, x_i + \ldots + e_i$$

Where F_i are the actual fatality counts of country (i), E_i represents the expected number of fatalities (offset term) i.e. the amount of exposure, β_0 is the constant term, β_k are parameter estimates of the explanatory variables x_i, and e_i is the observation variance (error term).

The Poisson model assumes equal sample means and variance. However, in the present case there are theoretical reasons to assume that extra-Poisson variation may be present in the data, i.e. that the variance is greater than the mean, since the counts examined come from significantly heterogeneous populations, and thus the expected values may vary significantly more than the mean of the distribution would allow (Dean, 1992; Hauer, 1986). In order to handle this ‘overdispersion’, an additional dispersion (scale) parameter α is estimated, resulting in what is known as an extra-Poisson or quasi-Poisson distribution. The Negative Binomial model would have been another alternative, however it is known to be inappropriate for implementation with small samples.

4.2.2. Beta regression models

The reduction in fatalities between 2001-2010 is a continuous variable and could be modelled as such by a GLM assuming a normal, lognormal or other distribution. However, it should be taken into account that the values are proportions, i.e. real numbers lying within the unit (0,1) interval, and therefore there is a natural ‘floor’ and ‘ceiling’ in the values of this variable. The same is the case for the composite indicators of ‘final’ and ‘intermediate’ road safety outcomes, which also lie within the unit interval.

Such dependent variables do not fall within the GLM family, not only because they do not come from the exponential family, but also due to a number of other properties (Ferrari & Cribari-Net0, 2004). Moreover, regressions involving data from the unit interval such as rates and proportions are typically heteroscedastic: they display more variation around the mean and less variation as we approach the lower and upper limits of the standard unit interval. Finally, the distributions of proportions are typically asymmetric, and thus Gaussian-based approximations for interval estimation and hypothesis testing can be quite inaccurate, especially in small samples (Cribari-Neto & Zeileis, 2010).

Typically, a suitable candidate for modelling unit interval data (e.g. rates and proportions) is the beta distribution. The models recently proposed in the literature for such dependent variables are known as Beta regression models. These model both the mean (location) and the variance (dispersion) of the dependent variable, with their own distinct sets of predictors (continuous and/or categorical), thereby explicitly modeling heteroscedasticity. In contrast, the GLM models only allow for the estimation of a fixed dispersion (scale) parameter. The case of a Beta regression model with fixed dispersion can be considered ‘analogous’ to a quasi-Binomial GLM (Cribari-Neto & Zeileis, 2010).

The location sub-model link function is the logit - allowing for the predicted values to be ‘squeezed’ into the unit interval - whereas the dispersion sub-model is log-linear - in order to obtain only positive values for the variance (Smithson & Verkuilen, 2006).

The beta regression model can be this written as follows. For a Beta distributed dependent variable, with mean μ and dispersion φ:

$\text{Logit}\ (\mu_i) = \text{Log}\ [\mu_i\ (1\text{-}\mu_i)] = \beta_0 + \beta_1\ x_i + \ldots$
$\text{Log}\ (\varphi_i) = \gamma_0 + \gamma_1\ x_i + \ldots$

The Beta regression model requires a particular estimation technique, based on nonlinear models estimation, whose description is beyond the scope of this analysis. For details the reader is referred to Smithson & Verkuilen (2005).

One of the main questions in a Beta regression analysis is whether the dispersion should be considered fixed (i.e. modelled by means of a constant term only) or variable (i.e. modelled by means of some or all the variables used to model the mean). Although it would be preferable to account for heteroscedasticity in the data, difficulties in the estimation may occur when the number of variables in the dispersion equation increases.

Therefore, it was decided to keep the number of variables in the dispersion equation to a minimum, in order to avoid estimation problems or over-fitting the model. More specifically, fixed dispersion models are initially estimated i.e. assuming the dispersion in the reduction of fatalities between 2001-2010 is fixed. If the mean (location) model yields statistically significant parameters, it is further tested whether there are variables affecting the dispersion model.

5. Results

5.1. Estimation of road safety management indicators

As mentioned in section 4.1, two alternative methods of data dimension reduction were tested:
(i) Principal Component Analysis (PCA);
(ii) Categorical Principal Component Analysis (CATPCA)

Standard PCA was first applied for the estimation of road safety management indicators on the basis of the 8 variables. As a result, 3 components were extracted with Eigenvalues higher than 1, which explain 71% of the variance. The interpretability of the 3 components was improved through rotation. Orthogonal rotation was selected in order to be sure that the estimated components are unrelated. It was decided to suppress all component loadings less than 0.5 to make the interpretation substantially easier. The 3 components can be summarised as follows:

- Component 1: Presence of a national vision and strategy as regards road safety.
- Component 2: Existence of dedicated budget for road safety management, regular evaluation of programmes and measures and reporting of the evaluation results.
- Component 3: Measurement of road user attitudes and behaviour.

As a next step, CATPCA techniques were applied, to account for possible inaccuracies in the PCA results due to the sample and variables properties. The optimal scaling of the 8 road safety management variables was carried out, as described in section 4.1. Taking into account the results of the standard PCA, a solution of 3 dimensions was sought in the CATPCA. The results, presented in Table 2, confirm that a 3 dimension solution is the optimal one, given that 3 ‘dimensions’ have Eigenvalues higher than 1, explaining in total 77% of the variance – a share that is higher compared to the standard PCA’s. The dimensions’ strongest loadings are presented in Table 3.

Table 2 to be inserted here
Table 3 to be inserted here

The dimensions can be summarized as follows:

- Dimension 1: Systematic measurement of road user attitudes and behaviour.
- Dimension 2: Dedicated budget for road safety, regular evaluation and reporting on programmes and measures.
- Dimension 3: National vision and strategy of road safety.

Both methods tested provided a single identical solution. The main differences of the two methods lie (a) on the assumptions concerning the data properties, and (b) on the country scores of the indicators, both in terms of scale and values. Given that standard PCA is clearly compromised by the small sample size and the requirement for continuous variables, the CATPCA results are considered to be more reliable for the estimation of road safety management indicators, and only these will be used in the statistical analysis that is presented in the following sections.

5.2. Modelling results

5.2.1. Fatality rates and road safety management

The explanatory variables considered in the Poisson models are the background indicator (country group), the composite SPI and the three road safety management dimensions scores for each country. The results of the best fitting models for the mortality rate (fatalities per million inhabitants) are presented in Table 4.

Table 4 to be inserted here

The results suggest no statistically significant association of mortality rates with none of the RSM indicators. On the other hand, the background indicator and the composite SPI are strongly associated with mortality rates. More specifically, countries belonging to background group 1 (i.e. lower economic and motorization level) have higher mortality rates than countries belonging to background group 2 (i.e. stronger economic and motorization level). Moreover, increased composite SPI scores are related to lower mortality rates.

When modeling the fatality rates, i.e. the number of fatalities per billion passenger-kilometres of travel (see Table 5), only the background variable is statistically significant, as the statistical significance of the SPI score fell beyond 90%.

Table 5 to be inserted here

In both models, a Likelihood Ratio Test is statistically significant, leading to accept the model as significantly improved over the null ('empty' / constant only) model. Moreover, in both models, a high dispersion parameter (scale) was estimated, confirming the assumption of overdispersed fatality counts in the European countries.

Road safety management indicators were not found to be significant predictors of the mortality and fatality rates in the European countries on year 2010. As a next step, it is investigated whether the evolution in fatalities over the last decade is affected by road safety management indicators.

5.2.2. Development in fatalities and road safety management

The results of a fixed dispersion Beta regression model concerning the reduction in fatalities in the European countries in the period 2001-2010 suggested that the model was of very poor fit and none of the variables examined in the location sub-model was statistically significant.

The same model was also fitted as a simple linear GLM, and the results were strongly consistent with those of the beta regression. For completeness, it was attempted to include explanatory variables in the dispersion sub-model of the beta regression, without success.

These results suggest no relationship between road safety management indicators and the 2001-2010 fatalities reduction in the European countries.

5.2.3. Composite indicator of road safety outcomes and road safety management

The composite road safety final outcomes index was tested next, in terms of its association with road safety management indicators. A fixed dispersion Beta regression model was fitted to the data and the results are presented in Table 6.

Table 6 to be inserted here

The results show that, apart from the constant term, the background indicator is significant, and the SPI composite index is also marginally significant (i.e. a higher SPI index lead to a higher outcomes index). On the other hand, none of the RSM indicators appears to have an effect on the road safety outcomes composite index. Moreover, the fixed dispersion parameter is highly significant. The model is improved over the ‘null’ model. Similar results are also obtained by a GLM approach (assuming a normal distribution for the road safety outcomes index).

Adding explanatory variables to the dispersion equation, starting from the statistically significant parameters of the location equation, did not lead to any improvement, whereas convergence problems were encountered.

These results suggest that the road safety outcomes indicator is strongly affected by background country characteristics, and also by SPIs, which is not surprising, as SPIs and road safety outcomes are “neighbour” layers of the SUNflower pyramid.

5.2.4. Intermediate outcomes (SPIs) and road safety management

The results in the previous sections indicate a lack of a strong relationship between road safety management and road safety final outcomes. However, they do reveal a relationship between the intermediate road safety outcomes (SPIs) and the final outcomes. As a last step of the analysis, it was tested whether road safety management is related to the intermediate outcomes (SPIs).

Again, a Beta regression approach is opted for. In this case, explanatory variables include road safety management indicators and background indicators. The results of a fixed dispersion beta regression model revealed that all parameter estimates, including the road safety management indicators, are significant (although in some cases marginally). This led to attempting a variable dispersion model with the same predictors in the variance sub-model (see Table 7). The variable dispersion model converged smoothly and the fit was improved.

Table 7 to be inserted here

The following relationships between road safety management and the intermediate road safety outcomes were identified:

- Countries of group 2 (i.e. economically stronger countries) have a higher operational level of road safety;

- Countries with a higher score on road safety management indicator 1 (i.e. regular measurement of road safety attitudes and behaviours) have a higher operational level of road safety than the EU average;
- Countries with a higher score on road safety management indicator 2 (i.e. dedicated road safety budget, systematic evaluation of measures and reporting) have a higher operational level of road safety;
- Countries with a higher score on road safety management indicator 3 (i.e. road safety vision and strategy) have a lower operational level of road safety.

These results suggest that road safety management indicators are associated with the operational level of road safety in the European countries, as expressed by SPIs. It is somewhat surprising that such a link was established, while practically no direct link between road safety management and final outcomes could be established. On the other hand, the SUNflower pyramid suggests that, by definition, road safety policies, programmes and measures affect directly the operational level of road safety (intermediate outcomes), which in turn determines the final outcomes. On the other hand, given the small sample of countries (i.e. large standard errors), any relationship between road safety management and road safety outcomes would have to be very strong to be found statistically significant.

While most of the effects identified are intuitive, the effect of road safety management indicator 3 is not, as it is suggested that the existence with a road safety vision and strategy in the European countries is associated with a lower score on SPIs. This result may be partly due to the fact that the “presence” of a vision and strategy may not necessarily imply implementation of that vision and strategy - indeed, several Europan countries have road safety visions and strategies which are very incompletely, if at all, implemented (e.g. Greece, Poland). On the other hand, some of the best performing countries do not have high scores on vision and strategy (e.g. UK, Netherlands, France), but there is an ongoing implementation process of road safety programmes. It should be also kept in mind that it may take several years for a road safety “vision” to show effects.

In contrast, the other road safety management indicators concern more practical aspects of road safety management (i.e. budget, evaluation, surveys etc.) and therefore the country scores may be considered to reflect more precisely the maturity and effectiveness of the road safety management system.

6. Discussion

The modelling results are summarised in Table 8, with the model in the last column being considered the best model for the examined data.

Table 8 to be inserted here

These results are not sufficient to support a strong relationship between road safety management and intermediate outcomes. They are based on a small sample of countries, marginally sufficient for statistical analysis. Consequently, they should be considered with some caution, and various aspects of the analysis background and methodology should be kept in mind.

The small sample of European countries is a known problem for related statistical analysis. Elvik (2012) carried out a similar analysis for 17 European countries, finding no relationship between road safety management and road safety performance, and underlined that any statistical relationship would have to be very strong to attain statistical significance in such a small sample. Therefore, safety management may have an impact on road safety outcomes, which is however not too strong and therefore unidentifiable by the method.

In the present analysis, particular emphasis was put in eliminating as much bias due to the sample characteristics as possible, by selecting the appropriate techniques that met the data properties. It was shown that, while overall the differences in the results between conventional techniques (PCA for dimension reduction, GLM for models development) and more advanced techniques (CATPCA, Beta regression) were not striking, they were essential. In fact, the relationship between road safety management and SPIs would have clearly not been revealed by means of conventional techniques.

The small size of the sample also posed the risk of over-fitting the models. On the other hand, it was necessary to account for as many confounding factors as possible (Elvik, 2012), as it can not be assumed that road safety management is the sole determinant of road safety performance. In the present analysis, additional ‘layers’ of the SUNflower pyramid were examined as much as possible, by adding no more than two related variables in the models. Still, there may be other factors affecting road safety performance, which have not been accounted for (e.g. mobility, economy, long traditions, weather etc.).

It should be also noted that the PIN/Dacota data are not exhaustive in their description of the road safety management system; they mainly reflect the RSM structure in each country and include only a few variables on the implementation process. On the other hand, it is unlikely that an exhaustive description of road safety management would have been more efficient in such statistical analysis. Papadimitriou et al. (2012) attempted similar analyses on the basis of an extensive Dacota questionnaire (5 sections with 54 questions in total) for selected countries, and early concluded that such an option would not be possible, and a ‘section by section’ analysis was opted for.

7. Conclusions

The results of the present research suggest that road safety management in the European countries can be adequately described by three composite indicators. Moreover, these indicators appear to not directly affect road safety final outcomes (i.e. fatalities). However, they appear to affect the intermediate outcomes, namely the SPIs reflecting the operational level of road safety. This is what is in fact suggested by the SUNflower framework, that the policy output in terms of implementation of programmes and measures affects the ‘intermediate’ outcomes (SPIs), which in turn determine the final outcomes (road accidents and related casualties). Therefore, it is confirmed by the present research that the effect of road safety management on fatality rates is conditional to its effect on SPIs.

In particular, the existence of a dedicated budget for road safety, the systematic evaluation of the results of road safety programmes and the related reporting appear to be positively associated with the operational level of road safety in a country. Moreover, the regular measurement of road user attitudes and behaviour also corresponds to better operational level of road safety. On the other hand, the presence of a national vision and strategy was found correlated with lower operational level of road safety, and this may be attributed to the fact that the adoption of a vision may take a long time to show effects in terms of road safety outcomes, while the existence of a strategy may not necessarily correspond to more efficient road safety management process and implementation.

In this context, it should be kept in mind that the present analysis concerns a 'snapshot' of the road safety system (as is the SUNflower pyramid in general). The time dimension was not sufficiently taken into account. The road safety management indicators and the other variables examined concern the situation in the period 2008-2010. It is also underlined that several countries were experiencing a period of transition in their road safety management at the time of the PIN/Dacota survey, with changes in structures, new visions etc. The evolution of the road safety management system may be a stronger determinant of road safety performance, and this is an important field for further research.

Finally, another aspect that may partly explain the difficulty in identifying strong relationships between road safety management and road safety outcomes is the fact that European countries do not exhibit very big differences in road safety outcomes, and no 'very' big differences in road safety management overall (a minimum acceptable level exists in both cases). For example, it was recently shown that European Region countries have 10.3 fatalities per 100 000 population on average, whereas the respective figures for Asian and African regions range from 18.5 to 24. At the same time, only 28 countries, mostly European and Northern-American, have implemented road safety laws and policies on all key road accident risk factors (WHO, 2013). Therefore, if one included e.g. developing countries in the analysis, one might find a stronger relationship between road safety management and road safety performance.

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Table 1: PIN/Dacota common questions on road safety management

	PIN / Dacota question	Coding	count of 'yes'	count of 'partially'	count of 'no'	count of 'unknown'	sum of responses*
1.	Has a national road safety vision been set in your country?	1_Vision	13	7	9	0	16.5
2.	Has a national long-term road safety strategy been set in your country?	2_Strategy	20	4	5	0	22
3a.	Has a national quantitative road safety target been set in your country for reducing the number of deaths?	3a_Target_fatalities	**26**	**0**	3	0	**26**
3b.	Has a national quantitative road safety target been set in your country for reducing the number of people seriously injured?	3b_Target_seriousinj	11	0	18	**0**	11
3c.	Have any other quantitative road safety targets been set in your country?	3c_Target_other	13	2	14	**0**	14
4.	Has a national road safety programme or plan been formulated and adopted in your country?	4_Programme_plan	**21**	**6**	2	0	**24**
5a.	Is there a budget dedicated to the implementation of your national road safety programme or plan?	5a_Budget	5	8	14	2	9
5b.	Is the budget seen as being adequate to make your country's targets achievable?	5b_Budget_adequate	5	7	4	**13**	8.5
5c.	Have there been any changes since 2009 to the budget allocated to roads policing in your country?	5c_Budget_changes	6	1	11	**11**	6.5
6a.	Is there a lead agency or structure bearing responsibility for road safety policy-making in your country?	6a_LeadAgency_PolicyMaking	**23**	**2**	4	0	**24**
6b.	Is there a lead agency that is empowered to co-ordinate the road safety activities of the main actors involved in advancing road safety in your country?	6b_LeadAgency_Coordination	**21**	**4**	4	0	**23**
7a.	Does regular quantitative monitoring of your country's road safety performance take place?	7a_Monitoring	**27**	**2**	0	0	**28**
7b.	Are the results of this monitoring published periodically?	7b_Monitoring_published	**23**	**3**	3	0	**24.5**
8.	Does a regular evaluation of the efficiency of the road safety measures or interventions implemented in your country take place?	8_Evaluation	10	11	8	0	15.5
9.	Is there regular reporting on the road safety measures and interventions implemented in your country?	9_Reporting	15	8	6	0	19
10a.	Are the attitudes of people towards road safety measures being measured nationally?	10a_Attitudes_measures	10	12	5	2	16
10b.	Are the attitudes of people towards behaviour of road users being measured nationally?	10b_Attitudes_behaviour	11	10	6	2	16
10c.	Are behaviours of road users being measured nationally?	10c_Behaviours	17	8	4	0	21
		unusable questions					
		consesnus questions					
		*excluding "unknown"					

Table 2. Eigenvalues and % of total variance explained for the estimated dimensions of road safety management – CATPCA

Dimension	Eigenvalues		
	Total	% of Variance	Cumulative %
1	2,804	35,051	35,871
2	1,806	22,581	57,632
3	1,563	19,535	77,167
4	,638		
5	,555		
6	,292		
7	,197		
8	,144		

Table 3. Road safety management dimensions matrix – CATPCA

	Dimension		
Variable	**1**	**2**	**3**
1_Vision			1,873
2_Strategy			1,779
5a_Budget		1,272	
8_Evaluation		1,807	
9_Reporting		1,760	
10a_Attitudes_measures	1,491		
10b_Attitudes_behaviour	1,486		
10c_Behaviours	1,392		

Table 4. Quasi-Poisson model for mortality rates (fatalities per million inhabitants) in the European countries – 2010

Parameter Estimates					
	B	Std. Error	Wald	p-value	
Constant	4,650	,3110	223,622	,000	*
[Background indicator=1]	,407	,1481	7,536	,006	*
[Background indicator=2]	0	.	.	.	
Composite SPI score	-,937	,4025	5,426	,020	*
RSM Dimension 1 score	-,003	,0953	,001	,975	
RSM Dimension 2 score	,175	,1184	2,180	,140	
RSM Dimension 3 score	-,142	,1400	1,027	,311	
Scale	81,030				
Model's fit					
Likelihood Ratio Chi-Square	34,690				
degrees of freedom	5				
p-value	,000				

** indicates a significant effect at 95% confidence level*

Table 5. Quasi-Poisson model for fatality rates (fatalities per billion passenger-kilometres) in the European countries – 2010

Parameter Estimates					
	B	Std. Error	Wald	p-value	
Constant	2,233	0,454	24,179	0,000	*
[Background indicator=1]	0,948	0,211	20,150	0,000	*
[Background indicator=2]	0,000	.	.	.	
Composite SPI score	-0,828	0,594	1,942	0,163	
RSM Dimension 1 score	0,056	0,144	0,154	0,695	
RSM Dimension 2 score	0,136	0,172	0,629	0,428	
RSM Dimension 3 score	-0,139	0,206	0,455	0,500	
Scale	176,066				
Model's fit					
Likelihood Ratio Chi-Square	40,973				
degrees of freedom	5				
p-value	,000				

** indicates a significant effect at 95% confidence level*

Table 6. Beta regression model (fixed dispersion) for the composite road safety final outcomes index in the European countries

	Estimate	Std. Error	95% Confidence Interval		
Location sub-model			Lower Bound	Upper Bound	
Constant	-2,507	1,239	-4,937	-,077	
Background indicator	1,103	,676	-,223	2,429	*
Composite SPI score	2,930	2,790	-2,541	8,401	
RSM Dimension 1 score	-,183	,382	-,933	,567	
RSM Dimension 2 score	-,269	,395	-1,044	,506	
RSM Dimension 3 score	-,508	,526	-1,540	,523	
Dispersion parameter	-2,374	,335	-3,032	-1,716	*
Models fit					
Null Log-likelihood	-15,258				
Final Log-likelihood	-27,867				

*Note: *indicates a significant effect at 95%. Parameters are bootstrap estimates based on 2000 samples*

Table 7. Beta regression model (variable dispersion) for the composite SPI in the European countries

	Estimate	Std. Error	95% Confidence Interval		
Location sub-model			Lower Bound	Upper Bound	
Constant	-1,223	,741	-2,677	,231	*
Background indicator	1,306	,432	,460	2,153	*
RSM Dimension 1 score	,221	,339	-,444	,886	
RSM Dimension 2 score	,741	,395	-,034	1,515	*
RSM Dimension 3 score	-,727	,320	-1,355	-,099	*
Dispersion sub-model					
Constant	-2,619	,409	-3,421	-1,816	*
RSM Dimension 1 score	1,757	,895	,001	3,513	*
RSM Dimension 2 score	-,874	1,743	-4,293	2,545	
RSM Dimension 3 score	1,372	1,500	-1,569	4,313	
Models fit					
Null Log-likelihood	-11,376				
Final Log-likelihood	-28,179				

*Note: *indicates a significant effect at 95%. Parameters are bootstrap estimates based on 2000 samples*

Table 8. Summary of models development

Dependent variable	Fatalities per million inhabitants	Fatalities per million passenger-kilometres	% reduction in fatalities 2001-2010	Composite index of road safety outcomes	Composite index of 'intermediate' outcomes (SPIs)
Dependent variable type	rate	rate	percentage	Values within [0,1]	Values within [0,1]
Model	Quasi-Poisson regression	Quasi-Poisson regression	Beta regression	Beta regression	Beta regression
Dispersion	Fixed	Fixed	Fixed	Fixed	Variable
Explanatory variables	• Background indicator • Composite SPI • RSM Dimensions	• Background indicator • Composite SPI • RSM Dimensions	• Background indicator • Composite SPI • RSM Dimensions	• Background indicator • Composite SPI • RSM Dimensions	• Background indicator • RSM Dimensions
Significant effects	✓ Background indicator ✓ Composite SPI	✓ Background indicator	None	✓ Background indicator	✓ Background indicator ✓ **RSM Dimensions**

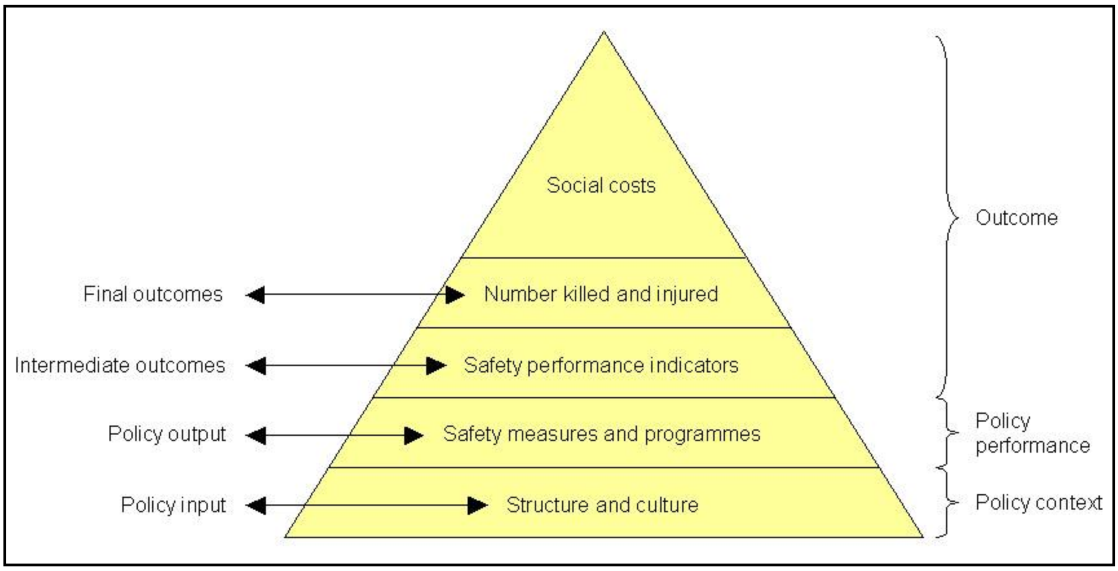

Figure 1: A target hierarchy for road safety (Source: Koornstra et al., 2002)

Appendix I. Road safety outcomes, exposure and SPI data

Country	Background Group	Fatalities (2010)	reduction 2001-2010	Composite index road safety outcomes (2008)	Composite index SPIs (2008)	Passneger-kilometres (billion, 2010)	Population (million, 2010)
AT	2	552	0.43	0.8415	0.7434	73.00	8.38
BE	2	840	0.43	0.8541	0.7316	109.10	10.84
CH	2	327	0.45	0.9773	0.8098	85.50	7.79
CY	2	60	0.46	0.7034	0.6845	5.90	0.80
CZ	1	802	0.46	0.6994	0.7200	63.60	10.53
DE	2	3,648	0.51	0.9613	0.8253	887.00	81.82
DK	2	255	0.49	0.7589	0.7457	51.00	5.53
EE	2	79	0.61	0.7406	0.7695	10.10	1.34
EL	2	1,281	0.37	0.6183	0.5857	99.60	11.31
ES	2	2,478	0.57	0.9451	0.8559	341.60	45.99
FI	2	272	0.31	0.8759	0.9992	64.70	5.35
FR	2	3,992	0.51	0.9743	0.9201	727.30	64.72
HU	1	822	0.38	0.6148	0.6948	52.60	9.88
IE	2	212	0.49	0.9124	0.9062	46.00	4.47
IL	2	352					9.87
IT	2	3,934	0.44	0.8945	0.4504	700.20	60.34
LT	1	300	0.58	0.6127	0.5999	29.90	3.33
LU	2	32	0.58	0.9897	0.6893	6.50	0.50
LV	1	218	0.66	0.6613	0.5417	16.50	7.70
MT	2	15	0.06	0.8432	0.6064	2.20	0.41
NL	2	640	0.41	0.9755	0.8604	141.20	16.57
NO	2	208	0.39	0.8628	0.9919	59.80	4.86
PL	1	3,907	0.29	0.5050	0.5113	297.90	38.17
PT	1	854	0.54	0.9010	0.6440	83.70	10.64
RO	1	2,377	0.04	0.1363	0.3682	75.50	21.46
SE	2	266	0.55	0.9807	0.9947	99.20	9.34
SI	2	138	0.56	0.7356	0.7574	25.60	2.05
SK	1	353	0.44	0.5818	0.6096	26.90	5.42
UK	2	1,905	0.47	0.9586	0.6970	653.80	62.03