Estimation of fatality and injury risk

by means of in-depth fatal accident investigation data

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Abstract

Objective: In this paper the factors affecting fatality and injury risk of road users involved in fatal accidents are analysed by means of in-depth accident investigation data, with emphasis on parameters not extensively explored.

Methods: A fatal accident investigation (FAI) database is used, which includes intermediate level in-depth data for a harmonized and representative sample of 1,300 fatal accidents in seven European countries. The FAI database offers improved potential for analysis, as it includes information on a number of variables which are seldom available, complete or accurately recorded in road accident databases. However, the fact that only fatal accidents are examined requires for some methodological

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adjustments, namely the correction for two types of effects on a road user's baseline risk: "accident size" effects and "relative vulnerability" effects. Fatality and injury risk can be then modeled through multilevel logistic regression models, which account for the hierarchical dependences of the road accident process.

Results: The results show that the baseline fatality risk of road users involved in fatal accidents decreases with accident size and increases with the vulnerability of the road user. On the contrary, accident size increases non-fatal injury risk of road users involved in fatal accidents. Other significant effects on fatality and injury risk in fatal accidents include road user age, vehicle type, speed limit, the chain of accident events, vehicle manoeuvre and safety equipment. In particular, the presence and use of safety equipment such as seat belt, ABS and ESP are protection factors for car occupants, and especially for those seated at the front seats.

Conclusions: Although ABS and ESP systems are typically associated with positive effects on accident occurrence, the results of this research revealed significant related effects on accident severity as well. Moreover, accident consequences are be more severe when the most harmful event of the accident occurs later within the accident chain.

Key-words

fatal accidents; fatality risk; injury risk; in-depth accident investigation; multilevel logistic regression models.

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BACKGROUND AND OBJECTIVES

In-depth road accident investigation techniques provide detailed and reliable information on road accident characteristics, which may assist road safety researchers in understanding road accident mechanisms, identifying behavioural patterns and assessing road accident causes (Larsen, 2004). The added value of using in-depth road accident investigation data in road safety analyses is twofold; first, a number of variables seldom available in macroscopic road accident data files (e.g. police road accident records) can be made available by in-depth road accident investigations, especially on complicated and often underreported issues such as road user fatigue and impairment, vehicle manoeuvre and chain of accident events, fault assignment etc. Secondly, data quality is significantly improved through in-depth data collection techniques, especially as regards several variables with poor reliability or completeness in most macroscopic data files (e.g. accident location, alcohol level, vehicle safety equipment etc.) (Dupont and Martensen, 2008).

Accident investigation as a scientific basis for understanding crashes and injuries has a history of several decades. It has been and still is the most valuable source of information on the dynamics of road accidents and has made major contributions to vehicle technology and road interventions. The contribution of in-depth road accident investigation data is still acknowledged in several recent studies. Most of these studies examine specific questions related to road accident mechanisms and causes for particular types of accidents, such as "looked-but-failed-to-see" accidents (Koustanaï et al. 2008), motorcyclists' accidents (Kasantikul et al. 2005), elderly drivers accidents (Van Elslande, 2004), head-on and left-turn collisions (Larsen and Kines, 2002) etc.

In several countries, longstanding official in-depth accident investigation databases are in place, such as the Co-operative Crash Injury Study (CCIS) of the Birmingham Automotive Safety Centre in the UK, the German In-Depth Accident Study (GIDAS), the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System (NASS) in the USA. The usefulness of such in-depth accident investigation techniques and systems has been continuously demonstrated by their exploitation at national level (Mackay, 1968; Clayton & Mackay, 1972; Huelke et al. 1977; Carlsson, 1977; Evans & Frick 1986; Viano et al. 1989; Mackay et al. 1992; Stoop, 1995; Fleury and Brenac, 2001; Richter et al. 2005). However, no uniform and comparable data are available at the European level. Within the SafetyNet project of the 6th Framework Programme of the European Commission, an in-depth database was created on the basis of Fatal Accident Investigation (FAI) data, including comparable data for approximately 1,300 representative cases of fatal accidents from seven European countries.

Within this framework, the objective of this paper is to exploit a unique set of comparable European in-depth accident investigation data for the analysis of global road safety questions, with emphasis on parameters not extensively explored. In particular, the paper aims to analyze the combined effect of specific factors related to road users and vehicles involved in fatal accidents, as well as to the road and traffic environment, on fatality and injury risk. The factors investigated include several variables whose effects on accident severity was also studied in previous research (e.g. road user age, vehicle type, road type etc), as well as several variables whose effects on accident severity have not been adequately examined (e.g. vehicle passive safety, chain of accident events etc.).

Moreover, some methodological considerations are required, in order to eliminate specific bias on the fatality risk, which is induced from the fact that only fatal accidents are included in the FAI data. The detailed analysis of these methodological issues is beyond the scope of this paper and the reader is referred to Dupont et al. (2010). However, in order to ensure the accuracy of the results, these methodological issues are also identified and accounted for this research by including specific variables in the analysis.

DATA AND METHODS

Data Description

The FAI database is a broad ranging, intermediate level, fatal accident database, which was developed on the basis of existing accident investigation infrastructure through retrospective investigation methods (Morris and Reed, 2006). For the development of the data collection framework, existing procedures and protocols that were examined in detail included the UK Cooperative Crash Injury Study (CCIS), the UK On-the-Spot Project (OTS), the German In-Depth Accident Study (GIDAS), the US Fatal Accident Reporting System (FARS), and the Swedish Factors Influencing the Causation of Accidents and Incidents project (FICA) (Reed and Morris, 2008).

The dataset was systematically selected according to a defined sampling plan so that the data were broadly representative of the countries in which they were collected, namely France, Finland, Germany, Italy, the Netherlands, Sweden and the UK (Brace, 2005), where national teams brought together the available information from existing data sources. In particular, the data were predominantly derived from strictly factual police documentation of fatal accident investigations in each country, as shown in Table 1, and complemented with information derived from hospital records, insurance companies' records and prosecution records. The information gathered from these sources was also complemented with existing in-depth accident investigation data when available, resulting in 1,300 FAI cases involving around 3,500 road users in total (Reed and Morris, 2008).

Table 1 to be inserted here

A representative national sample of between 2% and 10% of the total fatal crashes in each country during the period 2003-2004 was investigated, depending on the magnitude of the total fatal accidents population, resulting in the sample of 1,300 FAI cases. In particular, each country had to provide a set of representative data according to an agreed matrix of criteria (Brace, 2005). Furthermore, the representativity of the FAI data in relation to the respective European CARE macroscopic database was checked for a number of variables, indicating that their respective distributions match relatively well (Dupont and Martensen, 2008).

The level of detail recorded is considerably greater than the one obtained in e.g. the CARE database or in national road accident statistics, but may be somewhat lower than the one obtained from national in-depth studies; 117 variables with more than 500 data values were typically gathered. Specific areas of data describe the overall accident circumstances, driver and vehicle characteristics, road infrastructure features, and descriptions of other crash participants, so as to provide a description of the whole crash. Additional interpretative information was also specified including a basic list of ‘events’ (essentially causation and contributory factors). Approximately 100 variables in total for each case were agreed as being ‘core data elements’ that should be collected for all cases. Moreover, the data were not selected according to a 'lowest common denominator' approach; instead the parties involved were challenged to gather a variety of information types from different sources if required, and according to a rather strict framework of data representativity and reliability.

Table 2 provides an overview of the variables and values collected in the FAI database. These variables and values conform to common definitions provided in the database Glossary (SafetyNet, 2006). Overall, the FAI dataset it is an independent data set (collected by unbiased parties), of remarkable data completeness, extensively cross-checked for reliability and fully representative of each country. It is the result of the first effort for collecting comparable fatal accident investigation data in Europe.

Table 2 to be inserted here

Methodological Implications

The main interest of this analysis lies in the possibility to exploit the combination of richness and accuracy of information provided by the entire FAI dataset, given that previous analyses of the FAI data were focused on passenger car accidents (Dupont et al. 2010). However, given that the FAI data concern exclusively fatal accidents, it is important that the questions asked of the data are appropriate according to this context. In each one of the accidents included in the FAI data there was at least one fatality, and consequently the baseline fatality and injury risk of road users involved in these accidents is different from the general baseline fatality risk experienced by road users involved in accidents (fatal and non fatal ones).

A first type of bias can be identified when considering the effect of the size of the fatal accident on the fatality risk of the road users involved. In a fatal accident database, a single-vehicle and single-occupant accident would naturally correspond to a fatality risk equal to one for the road user involved. Accordingly, in a two-vehicle accident with one occupant in each vehicle, the baseline fatality risk of each one of the road users involved would be 0.50, and so on. Overall, it can be said that the fewer the vehicles involved in a fatal accident, and the fewer the occupants in these vehicles, the higher the fatality risk for the road users involved. This "fatal accident size" effect is demonstrated in Figure 1, which shows that the proportion of fatally injured road users decreases with the number of vehicles involved in the accident. A similar pattern is obtained when examining the number of occupants in the vehicle. In order to correct for this effect, it is necessary to include in the FAI data analysis variables indicating both the number of vehicles involved in the accident and the number of occupants in each vehicle (Dupont et al. 2010).

Figure 1 to be inserted here

Another type of bias can be identified when considering the baseline fatality risk of road users involved in fatal accidents in relation to the degree of protection of the road users. Given that there will be at least one fatality in each one of the examined accidents, it is reasonable to assume that pedestrians suffer an increased baseline risk, whereas HGV occupants have a reduced baseline risk, as has been established in several previous studies. This is fully confirmed by the FAI data, in which very few pedestrians were not killed and very few HGV occupants were killed (see Figure 2). For instance, given that an accident will be fatal, if the two opponents are a pedestrian and a passenger car, the baseline risk of the opponents would be 1 and 0 respectively, whereas if the two opponents are a passenger car and a truck, the baseline risk of the opponents would be 1 and 0 respectively. On the other hand, if the two opponents are passenger cars, a baseline fatality risk of 0.50 could be reasonably assigned to each of them. Overall, the more vulnerable a road user is, and the heavier the accident opponent is, the higher is the baseline fatality risk for the more vulnerable road user once involved in a fatal accident.

Figure 2 to be inserted here

In order to account for this effect, it is necessary to include in the analysis variables related to both the vulnerability of the road user and the type of accident opponent (Dupont et al. 2010). However, determining the type of opponent can be a very complex task, given that the FAI data do not actually include only two-opponent accidents. Such an analysis for two-vehicle accidents is presented in Dupont et al. (2010). In this analysis, this incomparability of baseline risk of fatal accidents participants will be dealt with by explicitly accounting for the road user vulnerability. On that purpose, variables indicating whether the road user is a pedestrian, a motorcyclist or a HGV occupant will be examined, in order to account for the most obvious source of baseline risk incomparability.

Analysis Techniques

In order to model the fatality and injury risk of road users involved in fatal accidents in the FAI data, binomial and multinomial logistic regression models are tested, in which the hierarchical structure of accident data is accounted for. The hierarchical structure results from the fact that road users are nested into vehicles and vehicles are nested into accidents (Lenguerrand et al., 2006; Dupont and Martensen, 2007; Jones & Jørgensen, 2003). These models are known as multilevel models or random effects models (Goldstein, 2003; Hox, 2002), and they capture the random variation in road safety outcomes due to dependences among road users; for example, the fatality risk in an accident is more similar for two road users involved in the same accident than for road users involved in different accidents, and even more similar for two road users that are in the same vehicle than for road users in different vehicles.

In particular, a three-level structure is considered, according to which road users (i) are nested into vehicles (j) and vehicles are nested into accidents (k):

$$\text{logit}(\pi_{ijk}) = \beta_{0jk} + \beta_{1i} x_i$$

$$\beta_{0jk} = \beta_0 + u_{0jk} + v_{0k}$$

$$u_{0jk} \sim N(0, \sigma^2_{u0})$$

$$v_{0k} \sim N(0, \sigma^2_{v0})$$

Another type of hierarchical dependence that may be hidden in the FAI data is geographical dependence, resulting from the data sampling scheme. As the observations were sampled from seven different countries, it is likely that the fatality risk in fatal accidents sampled from the same country is more similar than the fatality risk in fatal accidents coming from different countries. In this case, a related two-level structure would be considered.

For this type of model, Bayesian estimation is recommended (Dupont and Martensen, 2007), which is based on Markov Chain Monte Carlo (MCMC) simulation techniques and in which an iterative sampling from prior parameter distributions is applied in order to obtain more accurate (interval) estimates for the parameters ("posterior" distribution) and the likelihood statistic. The starting values of the process are those obtained through the conventional estimation method, whereas specific criteria are used to determine the number of iterations required for the convergence of posterior parameter estimates to a given confidence level (Browne, 2003).

RESULTS

Fatality Risk

The dependent variable considered is a binary one (1: fatality, 0: non fatality) of the injury severity of each road user in the FAI data. A multilevel binomial logistic regression model was fitted to the data. Initially, an "empty" single-level model (i.e. including an intercept only) is created. This model will be taken as a basis for comparing more explanatory models in terms of performance. The first step is to examine the presence of dependences in the data due to the hierarchical nature of the accident process. Table 3 includes the results of testing for hierarchies in the data.

Model 1 is the baseline empty model. In Model 2, the possible hierarchies in the FAI data are tested in terms of geographical dependences, through a two-level model in which road users are nested into countries. The results show that the random variation at the country level is not significant upon convergence. On the other hand, Model 3 examines the dependences due to the accident process and therefore has a three-level structure. In this case, the random variation at the accident level (level

3) is not significant; however the variation at the vehicle level (level 2) is very significant. The improvement of the likelihood statistic compared to Model 1 is also important. It is thereby indicated that the fatality risk in a fatal accident does vary systematically across different vehicles and that the consideration of such a hierarchical structure may improve the model.

Table 3 to be inserted here

The building of a model with explanatory variables for fatality risk, given that one is involved in a fatal accident is presented in Table 4.

Table 4 to be inserted here

Model 4 only includes the variables meant to capture the accident size and the relative vulnerability effects, correcting thus for the initial incomparability of the risk ran by different types of road-users (HGV and car occupants, motorcycle riders, pedestrians and bicyclists) involved in fatal accidents. The parameter estimates correspond to what could intuitively be expected, suggesting that, compared to passenger car occupants, vulnerable road users (i.e. pedestrians and bicyclists) have an impressively increased (50 times higher) probability of being the fatalities in fatal accidents, whereas motorcycle riders also have increased probability (8 times higher) of being the fatalities in fatal accidents. On the other hand, HGV occupants have a 5 times lower baseline fatality risk than passenger car occupants in fatal accidents. As regards accident size, the negative parameter estimates for the variables “number of vehicles” and “number of occupants” indicate that the baseline fatality risk is lower (about half) for road users involved in fatal accidents with two or more vehicles (as compared to single vehicle accidents) and for road users in vehicles containing two occupants or more (as those being the sole car occupant).

In Model 5, the additional explanatory variables that were found to be significant, among the numerous variables examined, are presented. These were selected after careful consideration of all possible correlations (multicollinearity) and were initially tested individually (i.e. in the "empty" model), in order to make sure that their parameter estimates are stable, whereas particular focus is put on these parameters which are seldom available in macroscopic databases and for which less information is available in the international literature. The main additional explanatory effects identified can be summarized as follows.

Senior road users (i.e. with more than 65 years of age) have almost five times higher fatality risk when involved in a fatal accident, obviously due to their physical vulnerability.

As regards the variables related to the chain of accident events, fatality risk given that one is involved in a fatal accident is 3.5 times higher when there is more than one event for the road user's vehicle in the accident. Given that this effect is obtained in a model accounting for the accident size effect, it suggests that there is a higher probability for more than one fatality in a fatal accident including more than one event. Furthermore, fatality risk almost doubles when the most harmful event of the accident is not the first event of the chain. This may also reflect the fact that in most cases in the FAI data the first event was not the actual collision, but a loss of vehicle control or other inappropriate manoeuvre recorded, followed by other events resulting in and including one or more collisions.

A speed limit higher than 50 km/h was found to increase fatality risk when involved in a fatal accident by around 40%. This variable reflects increased travel speeds and rural road environments, resulting in either increased probability of single vehicle accidents (e.g. run off-road) or higher impact speeds in multi-vehicle accidents. It is also noted that the speed limit variable was found to be strongly correlated to numerous roadway and traffic variables (e.g. traffic volume, road type, carriageway divided etc.) and thus partly accounts for these effects as well. Unfortunately, adequate information about the actual pre-impact speed of the vehicles was not available in the FAI data.

On the other hand, road users in a vehicle that braked before the collision have a lower fatality risk, once involved in a fatal collision. It is noted that this effect is significant in all vehicle types. A vehicle braking results in lower impact speed for its occupants, probably also resulting from a crash avoidance manoeuvre included in the chain of accident events, making the impact less severe.

It is interesting to note that front damage of the vehicle is significantly associated with a lower fatality risk for its occupants. This effect reflects the improved protection offered to car occupants (improved cabin design, airbag deployment etc.) in front impacts. Accordingly, more fatalities are to be expected from side or rear impacts, due to the reduced protection offered to car occupants in such impacts. This effect is partly confirmed by the fact that a variable related to airbag deployment was tested and found to be correlated with front damage and not significant in the final model.

The effect of passenger cars safety equipment was further investigated by means of three more variables. These variables were available only for passenger cars, and were recoded to include a "not applicable" value for the other types of vehicles. As regards seat belt use, it was found that road users who did not use a seat belt have more than double risk of being the fatalities in fatal accidents; it is likely that this effect is also associated with the increased fatality risk of rear seat car occupants mentioned above. The related effect for unknown use of seat belt is non significant.

Finally, occupants of cars equipped with ABS have 25% lower fatality risk when involved in fatal accidents. Moreover, occupants of cars equipped with ESP have 65% lower fatality risk when involved in fatal accidents. It is underlined that, in the FAI data, all vehicles equipped with ESP were also equipped with ABS (whereas the opposite was not the case) and therefore the effect of ESP can be considered to be a cumulative safety effect of ABS and ESP. It is also interesting to note that the combined effect of vehicle braking before the accident and ABS results in 60% lower fatality risk, whereas the main effect of vehicle braking before the accident was equal to 45% lower fatality risk. It is noted that ABS and ESP are typically associated with accident occurrence, for which several studies are available (Broughton & Boughan, 2002; Sagberg et al. 1997; Page & Cuny, 2006; Erke, 2008). The estimated effects of ABS and ESP on accident severity available from a few studies mostly suggest negative or no effects; however in the present research they were found to be positive and statistically significant. For this reasons, the effects were extensively tested for possible confounders. In particular, it was tested whether they could be in fact reflecting vehicle age effects (i.e. new vehicles are more likely to be equipped with ABS) and the related correlation coefficient was calculated equal to -0.112, suggesting a non significant correlation. Moreover, it was tested whether accident type effects could be involved, but the proportion of vehicles equipped with ABS was found to be similar in both single and multi-vehicle accidents in this sample. The lack of obvious confounders was further suggested by the respective univariate models (i.e. including ABS and ESP as the only variables), where the estimated effects were also negative. A more detailed interpretation of these new effects, within the context of previous related studies, is presented in the discussion section of this paper.

The reduction of the likelihood statistic of Model 5 is important compared to Model 4, confirming the additional explanatory effect offered by the new variables. Useful information on the model's performance is also obtained through the number of correctly classified outcomes. In particular, Model 5 correctly classifies 79% of fatalities and 75% of non-fatalities in the FAI data.

The vehicle-level random variation was found to be non significant in the last two models, not confirming the initially important difference in the fatality risk of road users in different vehicles. It is possible that most of the random variation identified in the "empty" models of Table 2 is captured by the explanatory effects, and probably especially those related to vehicles (e.g. number of events, braked, safety equipment etc.).

Injury Risk

The next stage of the analysis concerns the development of a multinomial model, in which the road user risk in fatal accidents can be considered in more detail. In this case, the dependent variable is a multinomial one (fatality, serious injury, slight injury, no injury) and therefore the slight, serious, or fatal injury risks are examined. The main objective of this part of the analysis is to test whether explanatory variables have a different effect on these different casualty risks in fatal accidents. However, the interpretation is expected to be less straightforward in this case; given that every accident includes at least one fatal injury, the serious and slight injuries in the FAI data are additional casualties in fatal accidents, and are possibly of a more random nature. Variation in the respective injury risk will therefore be explained in this particular context.

Before testing the explanatory variables, a basic modelling structure was created, including the necessary variables to account for accident size and relative vulnerability effects. Moreover, a multilevel structure of road users nested into vehicles was defined. All additional explanatory variables that were found significant in the binomial model were included in the multinomial model and numerous additional variables were tested, while controlling for multicollinearity. The results (Model 6) are presented in Table 5.

Table 5 to be inserted here

One can notice the positive intercept for fatalities, and the negative intercept for serious injuries. They indicate respectively that, overall, the probability of being killed in a fatal accident is larger than the probability of being uninjured, while the probability of being seriously injured is lower than the one of being uninjured. This is reasonable when considering that there was at least one fatality in all the accidents in the FAI data, but not necessarily a serious injury.

As regards the accident size effects, a common negative effect of the number of vehicles was estimated. This suggests that, in multi-vehicle fatal accidents, all injury risks of all road users involved are lower than in single-vehicle accidents. This is reasonable, given that when there is only one vehicle in a fatal accident, all fatalities and additional casualties will be found in this vehicle. Having corrected for the effect of the number of vehicles in a fatal accident, the effect of the number of occupants is less straightforward. The effect on fatality risk in particular is not significant in Model 6. Given that a significant negative effect is obtained when testing the two accident size variables alone, it is deduced that other explanatory variables account for this effect in the final model. Moreover, a positive effect of the number of occupants is obtained for serious and slight injury risk. This suggests that, the more persons in a vehicle involved in a fatal accident, the higher the probability of each one of them being injured, which is intuitive and reflects the accident size effect in any accident, and not just in a fatal one. Therefore, in fatal accidents, the higher the number of occupants, the lower the baseline fatality risk for each one of them (i.e. fatal accidents size effect), but the higher the baseline injury risk for each one of the non fatalities (i.e. general accident size effect).

With regard to relative vulnerability, the results confirm that motorcycle riders have 30 times higher fatality risk in fatal accidents, and that they also have a 6 to 8 times higher probability of being additional non-fatal casualties. On the other hand, HGV occupants are by 85% less likely to be part of the fatalities in a fatal accident, and by 75% less likely to be seriously injured if there are additional casualties in the fatal accident. However, they only have a faintly lower (by 23%) probability of being slightly injured when involved in a fatal accident. It is thereby indicated that the protection offered by a heavy vehicle may not fully prevent slight injuries once involved in a severe accident. As regards vulnerable road users (i.e. pedestrians and bicyclists), they have 33 to 44 times increased serious or slight injury risk in fatal accidents and even more increased fatality risk. Given that only a couple of vulnerable road users were uninjured in the FAI data, not including this variable in the model might have resulted in important bias in the remaining parameter estimates.

Looking at the parameter estimates of the additional explanatory variables, several other effects can be identified. The variable "senior" was found to be significant only for fatality and slight injury risk. Senior road users have a significantly higher probability of being the fatality in a fatal road accident and a higher probability of being slightly injured.

The fact that the vehicle braked before the collision marginally reduces serious injury risk, and does not appear to affect slight injury risk in fatal accidents. Moreover, speed limits higher than 50 km/h were found to double all injury risks; this seems reasonable, for the reasons mentioned in the binomial model. The chain of accident events also affects serious and slight injury risk; these are increased 1.8 and 1.5 times respectively, in case the most harmful event of the accident is not the first event.

Finally, the effects of safety equipment on serious and slight injury risk in fatal accidents are as follows: car occupants not using a seat belt have around 6 times higher fatality risk, 3 times higher serious injury risk and more than 2 times higher slight injury risk, compared to those using a seat belt. Moreover, occupants of cars equipped with ABS have a by 33% lower fatality risk and by 25% lower serious or slight injury risk compared to all other road users. The presence of ABS and ESP (expressed by the 'ESP' variable) reduces fatality risk by around 50% and serious injury risk by around 60%. It is thereby suggested that ABS and ESP have important positive effects not only on fatality risk, but also on injury risk, despite the fact that these system were mainly associated to accident occurrence in the existing literature.

As regards hierarchical dependences, a significant variation of serious and slight injuries across different vehicles in fatal accidents was found, but no respective random variation of fatalities. This is obviously due to the fact that all accidents in the FAI data had one fatality, but not necessarily a serious or slight injury.

Overall, the performance of Model 6 (likelihood statistic equal to 1318.00) is satisfactory compared to the respective single-level "empty" model (likelihood statistic equal to 7833.40). Model 6 correctly classifies 86% of fatalities, and 58% and 51% of serious and slight injuries respectively. Hence, part of the variation in injury risk when involved in fatal accidents remains unexplained, suggesting in particular that serious injuries can not be fully distinguished from slight injuries by the specific model. The results of the multinomial model confirm to a significant degree the findings of the binomial model for fatality risk in fatal accidents, and it also reveals a few interesting effects on injury risk. This could be due to the fact that serious and slight injuries of persons involved in fatal accidents are to a significant degree random, as initially suspected in this analysis.

It is noted that Bayesian estimation was proved to be less efficient in the multinomial multilevel modelling, providing substantially higher and unstable estimates of the random parameters compared to the standard estimation methods, which is a known problem that occurs in this case (Browne, 2003). For this reason, the standard estimation methods were considered to be more reliable and are the only ones presented here. The likelihood statistic, however, is quite approximate in this case and can only be taken as a rough measure of model's fit.

DISCUSSION

In this research, models for estimating the fatality and injury risk of road users involved in fatal accidents were developed by means of a European in-depth road accident investigation dataset. In this framework, a primary objective of the analysis was the exploitation of the whole set of FAI data for addressing general questions related to the effects of various factors on fatality and injury risk. Factors such as the availability and use of safety equipment, the position in the vehicle etc., although specific to car occupants, were properly coded and included in the model and proved to have important explanatory power for all levels of injury severity. The analysis allowed to confirm some known effects on accident severity, and to identify some new ones. It is noted that, unless these known effects were controlled for in the statistical analysis, the effects of the new variables examined (e.g. ABS, chain of accident events) might have been wrongly estimated.

The results of the present analysis suggest that several factors affect the fatality risk of road users involved in fatal accidents. On the other hand, non-fatalities among road users involved in fatal accidents are more difficult to distinguish in statistical analysis. It appears that injury risk in fatal accidents is to a large extent random, at least in this sample. In order to interpret the effects related to injury risk, it should be kept in mind that, in the FAI data, although injuries indicate a less severe consequence than that of a fatality at the road user level, at the accident level they are associated with a more severe accident, because there is an additional casualty.

Overall, fatality and injury risk in fatal accidents is largely defined by the type of road user: pedestrians, bicyclists and motorcyclists experience an impressive baseline fatality risk, compared to car occupants, whereas the opposite is the case for HGV occupants, also according to previous research. Consequently, upgrading the protection of vulnerable road users (i.e. pedestrians, bicyclists, and motorcyclists) may balance their baseline risk with considerable benefit in the road safety of these road users.

On the other hand, speed limits and the chain of accident events (number, severity etc.) are 'external' risk factors affecting the risk of all road users involved in the accident. Fatality risk increases when the number of events in the accident chain increases, and also further increases when the severity of consecutive accident events increases. It is suggested thus that the accident consequences are more severe when the most harmful event of the accident occurs later within the accident chain.

Moreover, the presence and use of safety equipment such as seat belt, ABS and ESP are important additional protection factors for car occupants, and especially for those seated at the front seats, as they also benefit from improved cabin design, airbag deployment etc. It is important to note that ABS and ESP systems are primarily designed to prevent accident occurrence. Existing results, particularly within earlier studies, suggest mostly negative effects of ABS and ESP on accident severity (see for instance the related review and discussion in Evans & Gerrish, 1991), and these were attributed to either compensatory effects or improper use of these systems (Harless & Hoffer, 2002). It is noted, however, that somewhat different trends were identified in more recent studies. Farmer (2001) reports that based on fatal crash experience up to 1995, vehicles with ABS were more likely to be involved in crashes fatal to their own occupants, but less likely to be involved in crashes fatal to occupants of other vehicles. However, similar analyses based on fatal crash experience during 1996-1998, yielded very different results, according to which vehicles with ABS were no longer over-involved in accidents fatal to their own occupants. Moreover, Scully and Newstead (2008) found that ESP reduced the risk of driver injury in single vehicle accidents by 68% for 4WDs compared with 27% for passenger cars. In any case, research results on this question are far from conclusive, and therefore the results of the present study may be considered as a contribution to an ongoing scientific discussion on this important road safety question.

In particular, the results of this research revealed significant positive effects of ABS and ESP on accident severity, in cases the accident occurrence was not prevented. This severity effect is attributable to improved vehicle performance during the accident, through more efficient braking or better manoeuvres, in other words improved management of the accident itself, resulting in a less harmful impact for the occupant of the vehicle. When interpreting these effects, it should be kept in mind that the results concern the very particular case of fatal accidents only. Therefore, what they suggest is that, in an accident that will be fatal, it is less likely that the fatality will occur into a vehicle equipped with ABS/ESP. They do not suggest that ABS/ESP reduce accident fatality risk in general. It is also noted that, in the present research, these results are controlled not only for the incomparability of baseline risks of road users, but also for numerous other effects, which was seldom the case in previous studies on these factors.

The age and the size of the vehicle, as well as the accident type could be additional factors indirectly associated with ABS and ESP effects; however, this was not found to be the case in the specific dataset. It is also noted that the effect was stable in different model structures (e.g. univariate models). Therefore, these new ABS and ESP effects can be considered to highlight the need for more efforts for improved vehicle technology and safety equipment for other, less protected vehicles, such as motorcycles and mopeds.

Consequently, there are several encouraging findings in the proposed models for road users involved in fatal accidents; the variable effects identified are reasonable and include several variables which are seldom reliable in national databases, such as the chain of accident events, the pre-impact vehicle manoeuvre and the availability / use of vehicle safety equipment. Due to the fact that the data used are an original, high quality and representative dataset of fatal accidents in seven European countries, following common definitions and collection procedures, the results are considered to reflect the factors affecting fatality and injury risk in fatal accidents in the examined group of countries.

Generally, using such a dataset of an 'intermediate' level of detail, one may obtain much more detailed and reliable information compared to e.g. national statistics. The proposed method is advantageous as per the use of a quite standard statistical technique for analyzing a variety of information related to fatal accidents. On the other hand, the data are somewhat less detailed compared to 'pure' in-depth accident investigation data. The effects of safety equipment (seat belts, ABS/ESC etc.) as well as of accident events (chain of events, collision type, injury type) may be further evaluated by other more microscopic methods.

Finally, it is important to note that some particularities were involved in addressing such questions in a fatal accidents context, mainly concerning the incomparability of the baseline risk of road users, reflected in an "accident size" effect and a "relative vulnerability" effect, which were appropriately handled. However, an additional potentially important factor concerns the collision opponent, which may further correct for the baseline risk of road users involved in fatal accidents. Existing results on passenger car occupants have demonstrated the importance of this effect (Dupont et al. 2009), whose identification should be sought in future research.

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Table 1. FAI data collection features by country

Country	Institute	Number of cases	Data sources
France	INRETS - French National Institute for Transport and Safety research	140	Police fatal accident investigation reports
Netherlands	TNO - Netherlands Organisation for Applied Scientific Research	50	Accident Investigation Police Force reports
Italy	DITS - Department of "Idraulica, Trasporti, Strade", University of Rome	479	Insurance companies accident investigation reports
Finland	VALT - The Finnish Motor Insurers' Centre	60	Finnish Accident Investigation Organisation reports
Sweden	Chalmers University of Technology	125	Police fatal accident investigation reports
UK	VSRC - Vehicle Safety Research Centre - Loughborough University	268	Police fatal accident investigation reports
Germany	ARU-MUH - Accident Research Unit at Medical University Hanover	174	Police fatal accident investigation reports, In-depth-investigations by scientific teams (GIDAS).

Table 2. Variables available in each area of the FAI database

AccidentDetail_ID CaseNumber	RoadwayDetails_ID CaseNumber VehicleNumber	VehicleDetails_ID CaseNumber VehicleNumber	RoadUserDetails_ID CaseNumber VehicleNumber	
CentreName	CarriagewayType	NumOfOccupants	RoadUserClass	PoliceRepOtherDrug
AccidentDate	NumberOfLines	VehicleType	Age	FailureOfDriverRider
AccidentDay	Motorway	VehicleMake	Gender	ChildRestrFitted
TimeOfDay	SpeedLimit	VehicleModel	Impairment	ChildRestrUsed
HitAndRun	TypeOfSpeedLimit	CarBodyStyle	IsAResident	CRSType
AnimalInvolved	Junction	DrivenWheels	IsFamiliar	MCycleHelmetWorn
AccidentTypeClass	LocalArea	DriveOfVehicle	CrashAvoidMan	MHelmetType
FirstEvent	VerticalAlignment	VehicleColour	SeatPos	PartialLeathersProtJack
RelatedFactors	HorizontalAlignment	VehicleLength	SeatDir	PartialLeathersProtJackTrou
CrashParticipants	ConstrMaintZone	VehicleWidth	SeatBelt	MGloves
CarMPV	RoadwaySurfaceType	WasVehicleTowing	AirbagAvail	MBoots
Van	PedestrianFacility	EnginePower	AirbagDeploy	MReflItemWorn
BusMinibus	CycleFacilities	YearOfManufacture	PoliceInjuryseverity	BHelmetWorn
Truck	RoadConditions	KerbWeight	SafetyNetMedicalOutcome	BHelmetType
AgriculturalVehicle	LightConditions	NumberOfAxles	BodyRegionMostInjured	HighVisCloth
MotorcycleMoped	TrafficFlow	PassedInspection	Ejection	ThickCloth
Bicycle	WeatherConditions	DriverManoeuvre	EntrapmentExtrication	PedVehInteraction
TrainTram	StrongWinds	TransientFactors	TakenToHospital	PedCompany
ShoeVehiclePedestrian	Fog	VehicleHeading	HospDuration	PedDisabilities
Other	SurfaceContaminents	HazardousCargo	DiedAtScene	PReflectiveItemsWorn
UnknownVehicle	TrafficCalming	CargoDischarged	NDaysUntilDeath	
AccidentSummary	NumOfSigns	PreImpactSpeed	SuspicionAlcohol	
	Sign1-5	NumberOfEvents		
	ProblemWithSign1-5	MostHarmfulEvent		
	NotWorking1-5	AreaOfMostDamage		
		EventType1-6		
		EventDetail1-6		
		InteractedWith1-6		
		CollisionType1-6		
		ABS /BAS /ACS/ ESP/ LDW/CSS/TCS		

Table 3. Testing hierarchical dependences in the FAI data

	Model 1	Model 2	Model 3
Fixed effects			
Intercept	-0.260 (0.037)	-0.255 (0.071)	-0.219 (0.046)
Random effects			
σ^2_{u0} (country level)		0.022 (0.030)	
σ^2_{u0} (vehicle level)			0.934 (0.243)
σ^2_{v0} (accident level)			0.004 (0.006)
-2*loglikelihood	4208.6	4198.7	3678
Number of iterations	15,000	80,000	300,000

Note: Numbers in brackets are standard errors of parameter estimates

Table 4. Models for fatality risk in fatal accidents (binomial two-level models)

		Model 4		Model 5		
Fixed effects		B	(std.error)	B	(std.error)	expB
Intercept	1	0.931	(0.155)	-1.587	(0.271)	
Number of vehicles	One Vehicle	0.000		0.000		1.00
	Two or More	-1.623	(0.171)	-0.533	(0.171)	0.59
Number of occupants	One occupant	0.000		0.000		1.00
	Two or more	-0.634	(0.106)	-0.846	(0.121)	0.43
Motorcycle	Yes	2.128	(0.198)	2.065	(0.224)	7.89
	No	0.000		0.000		1.00
Heavy vehicle	Yes	-1.461	(0.195)	-1.487	(0.229)	0.23
	No	0.000		0.000		1.00
Vulnerable	Yes	3.693	(0.285)	4.046	(0.327)	57.17
	No	0.000		0.000		1.00
Senior	> 65 years old			1.513	(0.185)	4.54
	Younger			0.000		1.00
Speed limit	> 50 Km/h			0.322	(0.125)	1.38
	=< 50 Km/h			0.000		1.00
Number of Events	More than one			1.243	(0.159)	3.47
	One			0.000		1.00
Most Harmful event is the 1st	Yes			0.000		1.00
	No			0.717	(0.162)	2.05
Vehicle Braked	Yes			0.000		1.00
	No			0.591	(0.141)	1.81
ABS	Yes			-0.313	(0.136)	0.73
	No / Unknown / N.A			0.000		1.00
ESP	Yes			-1.083	(0.371)	0.34
	No / Unknown / N.A			0.000		1.00
Front dammage	Yes			-0.174	(0.116)	0.84
	No			0.000		1.00
Seat belt	Used / use claimed			0.000		1.00
	Not used			0.787	(0.187)	2.20
	Unknown / N.A			*-0.216*	-0.134	0.81
Random effects						
σ^2_{u0} (vehicle level)		0.353	(0.229)	0.211	-0.237	
-2*loglikelihood		3018.36		2345.8		
Number of iterations		300,000		100,000		

N.A: Not applicable

Table 5. Model for fatality, serious and slight injury risk in fatal accidents (multinomial two-level model)

		Model 6								
		Fatality			Serious injury			Slight injury		
Fixed effects		B	(std.error)	expB	B	(std.error)	expB	B	(std.error)	expB
Intercept	1	0.312	(0.140)	1.37	-0.616	(0.190)	0.54	*0.232*	*(0.175)*	*1.26*
Number of vehicles	One Vehicle			1.00			1.00			*1.00*
	Two or More	-1.758	(0.031)	0.17	-1.758	(0.031)	0.17	-1.758	(0.031)	0.17
Number of occupants	One occupant			*1.00*			1.00			1.00
	Two or more	*0.012*	*(0.090)*	*1.01*	1.551	(0.134)	4.72	0.845	(0.122)	2.33
Motorcycle	Yes	3.391	(0.169)	29.70	2.118	(0.221)	8.31	1.747	(0.266)	5.74
	No			1.00			1.00			1.00
Heavy vehicle	Yes	-1.805	(0.175)	0.16	-1.371	(0.225)	0.25	-0.261	(0.166)	0.77
	No			1.00			1.00			1.00
Vulnerable	Yes	5.864	(0.252)	352.13	3.786	(0.358)	44.08	3.507	(0.367)	33.35
	No			1.00			1.00			1.00
Senior	> 65 years old	1.514	(0.133)	4.54	*0.213*	*(0.199)*	*1.24*	0.438	(0.197)	1.55
	Younger			1.00			*1.00*			1.00
Speed limit	> 50 Km/h	0.686	(0.030)	1.99	0.686	(0.030)	1.99	0.686	(0.030)	1.99
	=< 50 Km/h			1.00			1.00			1.00
ABS	Yes	-0.414	(0.102)	0.66	-0.293	(0.134)	0.75	-0.282	(0.135)	0.75
	No / Unknown / N.A			1.00			1.00			1.00
Vehicle Braked	Yes			1.00			1.00			*1.00*
	No	0.474	(0.098)	1.61	0.210	(0.130)	1.23	*0.014*	*(0.129)*	*1.01*
Most Harmful event is the 1st	Yes			1.00			1.00			1.00
	No	1.512	(0.089)	4.54	0.604	(0.120)	1.83	0.449	(0.124)	1.57
ESP	Yes	-0.738	(0.265)	0.48	-0.565	(0.363)	0.57	*0.230*	*(0.297)*	*1.26*
	No / Unknown / N.A			1.00			1.00			*1.00*
Seat belt	Used / use claimed			1.00			1.00			1.00
	Not used	1.845	(0.131)	6.33	1.147	(0.172)	3.15	0.867	(0.175)	2.38
	Unknown / N.A	-0.214	(0.103)	0.81	*0.001*	*(0.128)*	*1.00*	-0.487	(0.130)	0.61
Random effects										
σ^2_{u0} (vehicle level variances)		0.000	(0.000)		0.552	(0.108)		0.650	(0.135)	
σ_{u0} (vehicle level covariance)							-0.392 (0.105)			
-2*loglikelihood						1318.00				

N.A: Not applicable

Figure 1. Proportion of road users killed in fatal accidents per number of vehicles in the accident in the FAI data - The "accident size" effect.

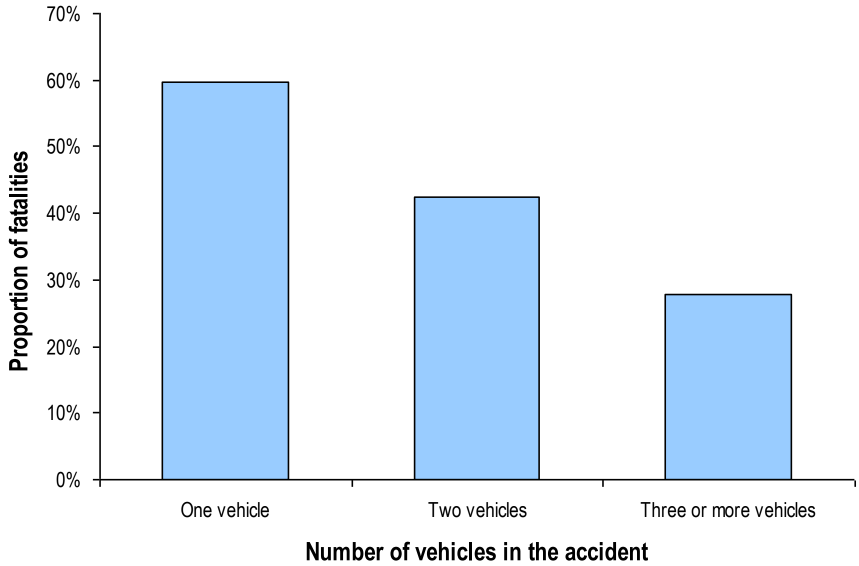

Figure 2. Proportion of road users killed in fatal accidents per road user type in the FAI data - The "vulnerability" effect