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Detecting unforgiving roadside contributors through the severity analysis of ran-off-road crashes

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ABSTRACT

The objective of this paper is to study the contributors influencing ran-off-road (ROR) crash severities in a setting that has not been analysed in the literature, namely on freeways not designed according to the "*forgiving roadside*" concept. To accomplish the analysis, ROR crash data were collected on freeway road sections in Portugal and multinomial and mixed logit models were estimated using the driver injury and the most severely injured occupant as outcome variables. Our results are in line with previous findings reported in the literature on ROR crash severity in a number of distinct settings. Most importantly, this study shows the contribution of critical slopes and vehicle rollover towards fatal injuries and highlights the importance of introducing the "*forgiving roadside*" concept to mitigate ROR crash severity in Portuguese freeways. The study also indicates the importance of protecting errant vehicles particularly in horizontal curves, as these are linked with fatalities. Finally, the empirical findings from the developed models revealed problems in current Portuguese roadside design, especially with regards to criteria for forgiving slopes provision and warrants for safety barrier installation.

1. Introduction

Highway crash injuries are a major burden on modern societies throughout the world. Single-vehicle crashes accounted for 32% of the total number of registered crash fatalities in the European Union during the period 2001–2010 (ERSO, 2012), and single-vehicle off-roadway crashes were linked to 42% of the total fatalities registered in the American FARS in the period 2010–2012 (NHTSA, 2014). In Portugal, single-vehicle ran-off-road (ROR) crashes result in ten thousand crashes with roadside features every year and account for approximately half of all freeway fatalities. Portuguese crash data (2007–2010) indicate that roadside geometry – including slopes, embankments, and ditches – contributes to more than half of all ROR accidents involving serious injury or death (Roque and Cardoso, 2012).

Safety in ROR crashes can be improved by having knowledge of the underlying factors involved in ROR crash occurrences and resulting injuries, so as to develop sound methods to support road design and efficient road operation decision making. The knowledge on ROR crashes on Portuguese roads was recently increased by a roadside safety research project (called SAFESIDE) carried out by the Laboratório Nacional de Engenharia Civil (Roque and Cardoso, 2013). SAFESIDE aimed at developing a procedure for supporting cost-effective decisions with regard to roadside safety benefits, based on cost–benefit analysis (CBA) and statistical methods, to be used in roadside design and redesign. In the US, where the concept of roadside clear zones has been in use since the early 1970s to increase the likelihood that a roadway departure results in a safe recovery rather than a crash (Donnell and Mason, 2006), a cost effectiveness analysis procedure – the Roadside Safety Analysis Program (RSAP) – is currently used for assessing roadside safety improvements (Ray et al., 2012).

Using data based on detailed accident information, the decisive factors in ROR crash frequency and severity can be analysed using statistical methods. A number of ROR crash prediction models exist in road safety literature: for instance, Lee and Mannering (2002), Geedipally and Lord (2010) and Roque and Cardoso (2014) all used Poisson and Negative Binomial regression models to develop ROR crash prediction models. However, the factors that influence accident frequency may differ from those that affect crash severity. For this reason, it is reasonable to analyse the two separately (Savolainen et al., 2011).

A comprehensive and systematic review of the road safety literature shows that no analysis of crash severity on Portuguese

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roads has been carried out thus far. Furthermore, whilst international literature on the severity of ROR crashes is not scarce, only five studies were identified that specifically addressed the modelling of the effect that roadside conditions have on ROR crash severity.

Lee and Mannering (2002) defined guidelines for identifying cost-effective countermeasures that would improve US highway designs by reducing the severity of crashes involving vehicles leaving the roadway. Indeed, ROR crash severity is a complex interaction of roadside features, such as the presence of guardrails, miscellaneous fixed objects, sign supports, trees and utility poles along the roadway. They noted: "*Some of these roadside features contribute to severity as the result of vehicle–object impact whereas others appear to mitigate severity, presumably by altering driver behaviour (e.g. speed, awareness) in the roadway section*" (Lee and Mannering, 2002).

Holdridge et al. (2005) analysed the in-service performance of roadside hardware in urban areas along the Washington State Route system by developing multivariate nested logit models of injury severity in fixed-object crashes. The study shows the contribution of safety barrier terminals to fatal injuries, and highlights the importance of using well-designed leading ends, as well as the need to upgrade substandard safety barrier terminals on bridges and near other dangerous obstacles. The study also points out the importance of protecting vehicles from crashes with rigid poles and tree stumps, as these objects are linked to greater injury severity and fatalities.

A study conducted by Schneider et al. (2009) shows that ROR crashes resulting in collisions with dangerous roadside objects increase injury severity significantly. Trees were found to be the cause of the greatest increase in incapacitating and fatal injuries. The study concludes that introducing geometric design improvements on curves along rural two-lane highways can help to mitigate the effects of curvature and collisions with roadside objects.

More recently, Xie et al. (2012) analysed injury severity in single-vehicle crashes on rural roads, utilizing a latent class logit (LCL) model. Key injury severity impact factors were identified for rural ROR crashes, including trees, utility poles and concrete barriers.

Finally, Wu et al. (2014) developed mixed logit models to analyse driver injury severity in single-vehicle and multi-vehicle crashes on rural two-lane highways. For single-vehicle crashes with fixed objects, they concluded that the likelihood of being severely injured increased for almost a quarter of drivers involved in such crashes on rural two-lane highways, whereas for a large majority of drivers in other crashes, the likelihood of severe injury decreased. This result indicates the non-uniform effect of fixed roadside objects on driver injury severity and the need for further investigation to analyse the impacts of different types of fixed objects on driver injury outcomes with a view to developing effective countermeasures.

Furthermore, some researchers have documented statistical models that include factors associated with median crash severity in the model specification. Hu and Donnell (2010) found that collisions with cable median barriers tend to result in less severe injuries than collisions with concrete or guardrail median barriers. The study also indicates that increasing the median barrier offset decreases the probability of severe crash outcomes.

Another study conducted by Hu and Donnell (2011) shows that flatter cross-slopes and narrower medians are associated with more severe cross-median crash outcomes, and steeper cross-slopes and narrower medians considerably increase rollover crash severity outcomes. The presence of horizontal curves was associated with increased probabilities of high-severity outcomes in a median rollover crash.

A more recent study on inter-city motorways in France shows that concrete barriers are less effective than W-beam guardrails in reducing cross-median crashes (Martin et al., 2013).

Finally, the NCHRP project 17-44 (2014) conducted research into the factors that contribute to median-related crashes with a view to identifying design treatments and countermeasures that can be applied to improve median safety on divided highways. The research confirms the importance of the traditional approach to improving median safety, which involves design improvements to reduce the consequences of median encroachments (e.g. removing, relocating, or using breakaway design for fixed objects in medians). According to NCHRP project 17-44 (2014), median safety can also be improved by design treatments and countermeasures to make it less likely that motorists will run off the roadway into the median (e.g. providing wider median shoulders).

Roadside design consists in defining the characteristics of the area between the carriageway edges and roadway right-of-way limits and is an important component of the road design process. Concern with roadside characteristics and their influence in road safety is not new. In the US the "*forgiving roadside*" concept has been in use since the 1960s. The studies described above were all carried out in countries where this concept has already been adopted. However, in Portugal, the approval process is still ongoing for new Portuguese roadside design guidelines that integrate this concept within the scope of benefit–cost analysis decision-making (Roque and Cardoso, 2011).

Important data and methodological concerns have been identified in the crash-severity literature over the years as potential sources of error in statistical model specification. They may lead to erroneous crash-severity explanations or predictions, as argued by Savolainen et al. (2011). Omitted-variable bias, endogeneity and underreporting of crashes are examples of those issues. To deal with these data-related problems, state-of-the-art methodological approaches have been incorporated in the statistical methods employed by researchers in an attempt to improve their statistical validity and robustness. However, it is important to keep in mind that these models are intrinsically case specific because they are limited and constrained by the available data, which may be improved over time.

Several researchers have investigated the severity of crashes by considering the injury severity of the driver (Kockelman and Kweon, 2002; Ulfarsson and Mannering, 2004; Wu et al., 2014), whilst others have considered the injury severity of the most severely injured vehicle occupant (Chang and Mannering, 1999; Yamamoto and Shankar, 2004). In this paper we use and compare both. Accordingly, two outcome variables are used: the severity of the injury of the most severely injured occupant (the MSIO models); and the injury severity of the driver of the errant vehicle (the DI models). In both cases, four classes of injury severity are considered: fatal injury, severe injury, minor injury, and no injury – i.e. property damage only (PDO). Detailed information on roadside features and PDO crashes are obtained from a different database and matched to our accident data.

The objective of this paper is to study the factors influencing ROR crash severity in a setting that has not been looked at in the literature, namely on freeways that were not designed in line with the "*forgiving roadside*" concept. Both left-side and right-side carriageway departures are considered, as very few Portuguese dual carriageway medians can be crossed by errant vehicles, thus effectively ruling out frontal collisions between vehicles travelling in opposite directions.

This made it possible to have analysing factors in common with those found in similar studies, whilst also keeping alternative factors within the scope of the study. Accordingly, our modelling approach is mainly explanatory (based on past observations) rather than predictive (predicting new values for the future).