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Improving roadside design policies for safety enhancement using hazard-based duration modeling

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ABSTRACT

Roadway departure (RwD) crashes, comprising run-off-road (ROR) and cross-median/centerline head-on collisions, are one of the most lethal crash types. Nationwide, from 2014 to 2016, annual RwD crashes accounted for 53% of all motor vehicle traffic fatalities. Several factors may cause a driver leave the travel lane, including an avoidance maneuver and inattention or fatigue. Roadway and roadside geometric design features (e.g., lane widths and clear zones) play a significant role in whether human error results in a crash. In this paper, we present a hazard-based duration model to investigate the distance traveled by an errant vehicle in a run-off-road crash, the stopping hazard rates, and associated risk factors. For this study, we obtained five years' (2010–2014) of crash data related to roadway departures (i.e., overturn and fixed-object crashes) from the Federal Highway Administration's Highway Safety Information System Database. The results indicate that over 50% of the observed vehicles traveled no more than 36 ft. in a ROR crash and 25% of the observed vehicles traveled at least 78 ft. We also found that seasonal, roadway, and crash variables, along with vehicle information and driver characteristics significantly contributed to the distances traveled by errant vehicles in ROR crashes. This paper presents methodological empirical evidence that the Cox proportional-hazards model is appropriate for investigating the distances traveled by errant vehicles in ROR crashes. In addition, it also provides valuable information for traffic design and management agencies to improve roadside design policies and implementing appropriately forgiving roadsides for errant vehicles.

1. Introduction

Roadway departure (RwD) crashes occur when a vehicle departs from the traveled way either by crossing an edge line or a centerline. RwD events comprise both run-off-road (ROR) and cross-median/centerline head-on collisions. These crashes are known for their tendency to be more severe than other crash types and result in more fatalities by virtue of being mostly head-on crashes, opposite-direction sideswipe collisions, and fixed object crashes. According to the Federal Highway Administration (FHWA) Roadway Departure Safety Program, this crash type accounts for the majority (more than 50%) of traffic fatalities in the United States. More specifically, overturns (30%), opposite direction (23%), and trees/shrubs (19%) crashes account for more than 70% of all roadway departure crashes. Given these sobering statistics, developing greater insight into the crash contributing factors and mitigation strategies will be valuable.

There are a number of reasons a driver may leave the travel lane, such as an avoidance maneuver, inattention, or fatigue. Roadway and roadside geometric design features (e.g., lane and shoulder widths, sideslope, fixed-object density, and offset from fixed objects) play a significant role in whether human error will result in a crash.

Only in the late 1960s, roadside safety design (as the design of the area outside the traveled way) became a discussed aspect of highway design, and it was in the decade of the 1970s that this type of design was regularly incorporated into highway projects (AASHTO, 2011). Clear zones were created since the early 1970s to increase the likelihood that a roadway departure results in a safe recovery rather than a crash, and mitigate the severity of crashes that do occur (Donnell and Mason, 2006). Under this philosophy, roadside hazards within the clear zone are either eliminated or moved. When hazards cannot be removed or relocated, a determination needs to be made if a safety device (e.g., using an appropriate breakaway device, guardrail or crash cushion) is warranted to protect occupants from the roadside obstacle. The forgiving roadside concept has guided the development of design policies to the present day, such as the fourth edition of American Association of State Highway and Transportation Officials' Roadside Design Guide

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(RDG) (AASHTO, 2011).

Information collected between the 1960′s and early 80′s in North America are still the main source of roadside encroachment data (Hutchinson and Kennedy, 1966; Cooper, 1980; Graham and Hardwood, 1982). The data used to define the clear-zone distances suggested in RDG are based on limited empirical data that were extrapolated to provide information for a wide range of conditions (Graham and Hardwood, 1982; AASHTO, 2011). Current international practice for determining clear-zone widths is also largely based on the research and practices discussed in AASHTO (2011).

A considerable number of studies have identified various contributing factors to ROR crashes based on a variety of data collection and data analysis methods. Lord et al. (2011) investigated the factors contributing to ROR crashes on two-way two-lane rural roads in the state of Texas. The authors divided the contributing factors into three groups, comprising highway design characteristics (i.e., lane width, shoulder width and type, roadside design, pavement edge drop-off, horizontal curvature and grades, driveway and pavement surfaces, and traffic volume), human factors (i.e., speeding, alcohol and drug use, and age and gender), and other factors (i.e., time of day, vehicle type). The results revealed that, compared to tangent sections, wider shoulders yielded greater safety on horizontal curves. Additionally, most ROR crashes occurred on weekends, which is attributed to people driving under the influence (DUI). Unlike driveway density, which had a little impact on ROR crashes, lighting conditions had a significant influence on the probability of a ROR crash occurrence. Liu and Subramanian (2009) evaluated various contributing factors associated with single-vehicle ROR crashes. Their results showed that horizontal road alignment, area type, speed limit, roadway geometric characteristics, and lighting conditions significantly affect the frequency and severity of ROR crashes. In an attempt to identify the factors contributing to ROR crashes, McLaughlin et al. (2009) obtained the dataset of a 100-car naturalistic driving study. In each car, several software and hardware instruments had been installed to collect data. In the study, a ROR event was identified as having occurred when the subject vehicle passed or touched a roadway boundary (e.g., edge line marking and pavement edge). The study results revealed that a single factor contributed to 75% of the ROR events, followed by two other factors contributing 22%. The analysis results showed that the most common factors contributing to ROR events included: distraction, following at a short distance, low friction, narrower lane, and roadside geometric configurations. Additionally, 36% of the ROR events involved distractions due to non-driving tasks and 30% of the ROR events happened on road curves.

In another study conducted by the National Highway Traffic Safety Administration (NHTSA), driver inattention, driver fatigue, roadway surface conditions, driver blood alcohol presence, drivers' level of familiarity with the roadway, and driver gender were identified as the most significant factors contributing to ROR crashes (Liu and Ye, 2011). Jalayer and Zhou (2016a) presented a new approach for evaluating the safety risk of roadside features for rural two-lane roads based on reliability analysis. The authors confirmed that reliability indices could serve as indicators to gauge safety levels. Eustace et al. (2014) used generalized ordered logit regression to identify the most significant factors contributing to severe ROR crashes (i.e., injury and fatal). Their results demonstrated that driver conditions (e.g., impaired drivers), road alignments (e.g., curves), roadway characteristics (e.g., grade), gender (e.g., male), and roadway surface conditions (e.g., wet) increased the likelihood of severe ROR crashes. Roque and Cardoso (2014) investigated the relationship between ROR crash frequency and traffic flows with different functional forms. In an attempt to determine the contributing factors to unforgiving roadsides, Roque et al. (2015) collected ROR crash data on freeway road sections in Portugal and developed multinomial and mixed logit regression models. The empirical findings of their study indicated that critical slopes and horizontal curves significantly contributed to fatal ROR crashes. In 2015, the American Traffic Safety Services Association (ATSSA) published an executive summary booklet of various case studies to educate transportation practitioners regarding ROR crashes and associated safety countermeasures (American Traffic Safety Services Association (ATSSA, 2015). In this booklet, countermeasures are categorized as signs (e.g., chevron pattern), pavement safety (e.g., high friction surface treatments), and roadside design (e.g., clear zone improvements). The study results revealed pavement safety countermeasures, compared to other categories, to be the most effective in reducing total ROR crash frequency and severity. Gong and Fan (2017) used mixed logit models to model single-vehicle ROR crashes on rural highways. Rusli et al. (2017) employed a random parameters negative binomial model to explore single-vehicle crashes on mountainous roads.

Few studies have looked at the probability of vehicles involved in run-off-road events exceeding different encroachment distances. Zegeer et al. (1987) reported that for generally unobstructed flat ground, a provision of 5 to 20 feet for the roadside safety recovery corridor width might reduce accident rates from 13% to 44%. Lee and Mannering (2002) showed that ROR crash frequencies can be reduced by decreasing the distance from outside shoulder edge to guardrail, and increasing the distance from outside shoulder edge to light poles. Using crash data on rural roads in Victoria, Jurewicz and Pyta (2010) showed that even for very wide clear zones (> 29.5 feet) there were still a significant number of ROR crashes. Doecke and Woolley (2011) used in-depth crash investigation data of 132 Australian ROR crashes and computer simulation modelling to assess clear-zone widths and the appropriateness of barrier protection. This study showed that when a vehicle is out of control it will travel well beyond a 29.5 feet clear zone if it is not impeded by a roadside hazard. More recently, Jamieson (2012) showed similar results, using the same method and New Zealand data to investigate vehicle encroachments on horizontal curves.

Regarding the methodology used in this study, few past studies have applied a hazard-based duration model to highway safety. Duration models have been extensively used in fields such as biometrics, social sciences, and industrial engineering to determine causality in duration data. Sharman et al. (2012) compared parametric and non-parametric hazard-based duration models to evaluate the stop duration of commercial vehicles in urban areas. Lin et al. (2016) employed a combined M5P tree and hazard-based duration model for predicting urban freeway accident duration. Using a hazard-based duration model, Yang et al. (2015a) investigated the crossing behavior of cyclists and electric bike riders at signalized intersections. In another study, Yang et al. (2015b) used a joint hazard-based duration model to explore various covariates related to pedestrian crossing behavior and pedestrian waiting times at signalized intersections. Using an accelerated failure time (AFT) hazard-based model, Li et al. (2017) investigated the significant contributing factors associated with the duration of crashes. Fu et al. (2016) also used a parametric duration model to describe and model drivers' brake perception–reaction times with respect to the yellow signal at signalized intersections equipped with and without a countdown timer.

We note that although a large number of studies are related to ROR crashes, to our knowledge, no previous studies have investigated the effects of various factors such as roadway and roadside geometric design features on the distance traveled by an errant vehicle in a ROR crash, which we address in this paper. We use an efficient and practical methodology, the hazard-based duration model, to gain a better understanding of the distance traveled by errant vehicles in ROR crashes and their associated factors. Of particular interest to this study are overturn and fixed-object crashes.

Our study findings provide valuable insights into the underlying relationship between risk factors, crash injury, and the distance traveled by an errant vehicle in a ROR event. These findings will also help to promote the implementation of more efficient roadside safety countermeasures to mitigate ROR crash severity.