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Wrong-way driving crashes: A random-parameters ordered probit analysis of injury severity

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ABSTRACT

In the context of traffic safety, whenever a motorized road user moves against the proper flow of vehicle movement on physically divided highways or access ramps, this is referred to as wrong-way driving (WWD). WWD is notorious for its severity rather than frequency. Based on data from the U.S. National Highway Traffic Safety Administration, an average of 355 deaths occur in the U.S. each year due to WWD. This total translates to 1.34 fatalities per fatal WWD crashes, whereas the same rate for other crash types is 1.10. Given these sobering statistics, WWD crashes, and specifically their severity, must be meticulously analyzed using the appropriate tools to develop sound and effective countermeasures. The objectives of this study were to use a random-parameters ordered probit model to determine the features that best describe WWD crashes and to evaluate the severity of injuries in WWD crashes. This approach takes into account unobserved effects that may be associated with roadway, environmental, vehicle, crash, and driver characteristics. To that end and given the rareness of WWD events, 15 years of crash data from the states of Alabama and Illinois were obtained and compiled. Based on this data, a series of contributing factors including responsible driver characteristics, temporal variables, vehicle characteristics, and crash variables are determined, and their impacts on the severity of injuries are explored. An elasticity analysis was also performed to accurately quantify the effect of significant variables on injury severity outcomes. According to the obtained results, factors such as driver age, driver condition, roadway surface conditions, and lighting conditions significantly contribute to the injury severity of WWD crashes.

1. Introduction

Since the advent of the interstate highway system in the 1950s, crashes associated with driving in the wrong direction on freeways have created a critical issue for transportation agencies (Finley et al., 2014). Wrong-way driving (WWD), by definition, occurs when a motorized road user turns against the proper flow of travel along a physically divided highway (e.g., freeway, expressway, or interstate highway) or its access ramp (Zhou et al., 2014). Typically, there are several reasons a driver might enter the road in the wrong direction, including human factors (e.g., impaired driving, fatigue, distraction, and confusion) and roadside features (e.g., lack of traffic control devices, such as signs and pavement markings). Although this type of crash occurs relatively rarely, in many cases, they have severe outcomes, due to their being mostly head-on or opposite-direction sideswipe collisions. An investigation of fatal WWD crashes over a span of ten years, using the Fatality Analysis Reporting System (FARS) database of the National Highway Traffic Safety Administration (NHTSA)'s found that an average of 355 people die annually across the nation, due to 265 fatal WWD crashes (National Highway Traffic Safety Administration (NHTSA, 2017). This sobering statistic highlights the fact that WWD crashes require special attention due to their greater severity despite their lower frequency. Without a comprehensive analysis of causal factors, any effort to implement WWD countermeasures to prevent or mitigate the frequency and severity of WWD crashes may be misguided. Therefore, the first step is to identify the contributing factors that cause WWD crashes and fatalities.

In recent years, a number of studies have focused on determining the factors that contribute to WWD crashes, with most taking an empirical rather than theoretical approach. Jalayer et al. (2016, 2017)

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examined the significant factors associated with WWD crashes using multiple correspondence analysis. The authors thoroughly investigated combinations of confounding factors contributing to WWD crashes and their association. Ponnaluri (2016) identified the critical contributing factors to WWD crashes using binomial logistic regression models, along with a survey questionnaire. This author found that driver age and condition, driver seatbelt use, lighting conditions, facility type, license state, and the number of vehicles involved in the crash significantly contributed to fatal WWD crashes. Based on Firth's penalized-likelihood logistic regression model, Pour-Rouholamin et al. (2016) presented a comprehensive analysis of the injury severity of WWD crashes on interstates. The authors' obtained results showed that driver age, driver condition, time of day, and driver residency can best characterize WWD crashes. In their study, Lathrop et al. (2010) identified the contributing factors to WWD crashes in New Mexico. The authors showed that factors such as darkness, older drivers, intoxicated drivers, male drivers, passenger cars, the month of November, and non-Hispanic and native drivers were associated with an increased likelihood of WWD crashes. Kemel (2015) investigated WWD crashes on French divided roads and found that the majority of WWD crashes occurred during nighttime hours and on non-freeway roads. Furthermore, the author found impaired drivers, older drivers, older vehicles, and passenger cars to have the highest involvement rates in all types of crashes, including WWD. Zhou et al. (2012a,b) reported that darkness, older drivers, intoxicated drivers, time of day, day of the week, and type of interchange significantly contribute to WWD crashes. Several previous studies have also demonstrated that driving under the influence, older drivers, and driving fatigue were the primary causes of wrong-way crashes (Baratian-Ghorghi et al., 2014). Braam (2006) reported that poor lighting conditions and lack of signage and pavement markings at interchanges may also be contributing factors to wrong-way crashes.

Despite the existence of numerous WWD studies (Jalayer et al., 2016, 2017; Zhou et al., 2016; Rogers et al., 2015; Simpson and Bruggeman, 2015; Baratian-Ghorghi et al., 2015; Morena and Leix, 2012; Zhou et al., 2012a,b; North Texas Tollway Authority (NTTA, 2009; Moler, 2002; and Copelan, 1989), very few studies have identified and compared the factors affecting the injury severity of WWD crashes. More specifically, no studies have investigated the effect of various confounding variables on the injury severity sustained by at-fault drivers in WWD crashes while also considering the effects of unobserved factors associated with driver characteristics, vehicle characteristics, temporal variables, and crash variables, which we address in this paper. The objectives of this paper are to present an in-depth review of WWD crashes that occurred in the states of Alabama and Illinois and to inform the development of more cost-effective safety countermeasures for reducing the frequency of this crash type. To do so, a random-parameters ordered probit model was utilized to more accurately identify the impacts of numerous factors on the severity of injuries sustained by WWD crashes. Random-parameters ordered probit models have been successfully applied to other crash types, including large truck crashes (Lemp et al., 2011; Zhu and Srinivasan, 2011; Islam and Hernandez, 2013; Islam, 2015), intersection-related crashes (Tay, 2015), angle collisions (Russo et al., 2014), and run-off-road crashes (Al-Bdairi and Hernandez, 2017). Identifying the factors affecting the injury severity of WWD crashes will provide valuable information for federal, state, and local agencies regarding the variables contributing to WWD crashes and the most appropriate safety countermeasures that can be taken. This is especially necessary given the increasing number of WWD incidents. The organization of this paper is as follows. The WWD-crash-data collection process is described in Section 2. Section 3 outlines and discusses the methodology we employed. The statistical analysis results are presented in Section 4. Finally, Section 5 draws the conclusions and make appropriate recommendations.

2. Data

Since WWD crashes are relatively rare, to enhance the study sample size and thereby improve the accuracy of our analysis and quality of our results, WWD crash data from two states: Alabama (2009–2013) and Illinois (2004–2013), were compiled in this study. Based on our knowledge and familiarity with the crash data from these two states, developed in our previous crash research work, we considered the crash data from these two states to be essentially are comparable. Notably, based on our comprehensive review of the WWD crashes in the states of California, Texas, Michigan, Florida, and New Mexico, WWD crashes in all these states have the same or very similar characteristics, despite variations in weather, driver behavior, demographics, and roadway design codes. To achieve the highest possible comparability between crashes, the same variables, formats, and definitions for both state datasets were employed. Additionally, hard copies of the crash reports were reviewed to confirm that the factors being analyzed were analogous in both states. Based on these efforts, we considered it reasonable to combine the WWD crash data of the two states (i.e., Illinois and Alabama) to increase the sample size and obtain more accurate and reliable results.

Unlike other crash types that require only the development of specific filters to prepare the final dataset for analysis, WWD crashes require some extra steps prior analysis to ascertain that the dataset has the highest possible accuracy. Specifically, possible WWD crashes were identified by defining several filters and then additional steps were taken to verify the actual occurrence of WWD crashes. The first filter phase produced several crashes that did not actually include WWD. For example, occasionally, cross-median crashes on divided highways are recorded as WWD since they occur on the opposite side of the road. Therefore, hard copies of the crash reports were reviewed to verify that actual WWD crashes had occurred, to cross check the information provided in narratives and crash diagrams and to locate crashes on Web map services to verify that they occurred on divided highways. For further details of these data collection processes, readers are referred to Zhou et al. (2012a,b, 2016) for Illinois and Alabama WWD crash data, respectively. After filtering out non-WWD crashes via the above-mentioned steps, our final WWD dataset included 398 crash records, 305 crashes in Illinois and 93 crashes in Alabama, for further severity analysis. Table 1 lists the explanatory variables used in this study, which are cross-tabulated with three-levels of injury severities (i.e., severe injury, minor injury, and no/possible injury). It should be noted that the severity in this paper refers to the at-fault driver's injury severity reported up to 30 days after the crash. In this context, property damage only (PDO) crashes and possible injury (C-injury) crashes are categorized as "no/possible injury," B-injury crashes are categorized as "minor injury," and incapacitating injury (A-injury), and fatalities are categorized as "severe injury." Based on this table, 221 (55.5%) drivers were not injured, 61 (15.3%) drivers sustained minor injuries, and 116 (29.1%) drivers sustained severe injuries. It should be noted that the Other/Unknown category of explanatory variables are not presented in this table, so, the total number of some variables may not add up to 398 WWD crashes.

3. Method

Traditional methods for modeling injury severity (e.g., the multinomial and nested logit models) assume that the effect of each parameter is fixed across all observations (Kim et al., 2013; Wu et al. (2014). These methods cannot capture the potential correlation between injury severity outcomes and unobserved effects associated with driver behavior, roadway, and vehicle characteristics at the time of the crash. For example, although our final dataset includes data pertaining to the driver, vehicle, and environment, specific driver-related details such as risk perceptions and educational level were not fully captured. Random-parameters model, on the other hand, allows the model