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Analysis of driver injury severity in wrong-way driving crashes on controlled-access highways

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ABSTRACT

For more than five decades, wrong-way driving (WWD) has been notorious as a traffic safety issue for controlled-access highways. Numerous studies and efforts have tried to identify factors that contribute to WWD occurrences at these sites in order to delineate between WWD and non-WWD crashes. However, none of the studies investigate the effect of various confounding variables on the injury severity being sustained by the at-fault drivers in a WWD crash. This study tries to fill this gap in the existing literature by considering possible variables and taking into account the ordinal nature of injury severity using three different ordered-response models: ordered logit or proportional odds (PO), generalized ordered logit (GOL), and partial proportional odds (PPO) model. The findings of this study reveal that a set of variables, including driver's age, condition (i.e., intoxication), seatbelt use, time of day, airbag deployment, type of setting, surface condition, lighting condition, and type of crash, has a significant effect on the severity of a WWD crash. Additionally, a comparison was made between the three proposed methods. The results corroborate that the PPO model outperforms the other two models in terms of modeling injury severity using our database. Based on the findings, several countermeasures at the engineering, education, and enforcement levels are recommended.

1. Introduction

Controlled-access highways are designed to provide high-speed vehicular traffic flows and maximize mobility by eliminating the potential conflicts between moving vehicles and driveways using grade-separated interchanges. Despite all the benefits in terms of vehicular throughput, this highway system is prone to a rare, but severe, kind of crash, which is caused by wrong-way driving (WWD). This type of crash happens when a driver, inadvertently or deliberately, drives against the main direction of traffic flow on a controlled-access highway. According to the National Transportation Safety Board (NTSB) Special Investigation Report, three possible mechanisms describe how a driver can end up driving in the wrong direction on controlled-access highways: (1) entering an exit ramp, (2) making a U-turn on the mainline, and (3) using an emergency turnaround through the median (NTSB, 2012). In addition to these mechanisms, a driver who crosses over the median and travels for some distance is also considered to make a WWD movement, despite accounting for a small number of WWD events. Even a short distance traveled means the movement is categorized separately from a cross-median crash where, instead, the driver collides with other vehicle(s) immediately after crossing over the median to an opposing traffic lane.

Regardless of the type of entrance, WWD crashes tend to be more severe and have a greater likelihood of resulting in death or injury when compared to other types of crashes on controlled-access highways. The reason is the high speed of traffic flow on these facilities and the nature of WWD crashes, which is mostly head-on. Past studies (Copelan, 1989; Cooner et al., 2004) showed that although a very small percentage of overall traffic crashes were caused by WWD, they result in a relatively large percentage of fatal crashes. In a recent study, Pour-Rouholamin et al. (2016) reported 1.34 fatalities per fatal WWD crashes in the U.S. from 2004 to 2013, while fatalities per fatal crash rate of 1.10 is observed for all other crash types during the same time period. Drivers and passengers in both wrong-way (WW) and right-way (RW) vehicles can be killed in WWD crashes. For example, of the 49 fatal WWD crashes on the New Mexico interstate highway system between 1990 and 2004, 35 drivers and 11 passengers in the WW vehicles were killed, and 18 drivers and 15 passengers in vehicles traveling in the correct direction were killed, as well (Lathrop et al., 2010). These statistics

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and accompanying safety issues corroborate the need for analyzing the injury severity of WWD crashes more in depth.

This study analyses the injury severity sustained by the WW (at-fault) drivers in a WWD crash considering the inherently ordered nature of injury severity. To this end, 398 WWD crashes[1] on controlled-access highways were investigated from the states of Illinois (10 years of data) and Alabama (5 years of data), based on the availability of the data. Three ordered-response models, including ordered logit, generalized ordered logit, and partial proportional odds models were nominated as possible analysis tools. A comparison between these three nominated models was also made to select the best modeling approach for WW driver injury severity analysis. Hence, the main objective of this study is to identify the factors that significantly affect the injury severity of WW drivers in such events. These factors fall under four major categories, which include responsible driver characteristics, temporal variables, vehicle information, and crash variables. The results of this study can provide useful insights into this safety issue and provide appropriate safety countermeasures to address this rare, particular traffic safety problem.

The rest of this paper is organized as follows: A review on the prior research on WWD crashes as well as methodological approaches is provided in Section 2. Section 3 elaborates on the databases used for analysis along with descriptive statistics of the multiple possible contributing factors. Ordered-response models (i.e., ordered logit, generalized ordered logit, and partial proportional odds model), their formulations, assumptions, and applications are discussed in Section 4. In Section 5, the proposed model is applied to the WWD crash dataset and parameter estimates and average direct pseudo-elasticities as well as model goodness-of-fit tests are presented. Finally, section 6 concludes this paper and provides safety recommendations.

2. Literature review

Previous research has focused on identifying which factors are correlated with the occurrence of WWD crashes on freeways. Many States have conducted studies on WWD crashes, including California, Texas, North Carolina, New Mexico, Michigan, Illinois, Alabama, and Florida. In addition to the studies in the U.S., other countries such as Finland, Switzerland, Netherlands, Japan, and France have also worked on WWD issues. The results of these efforts are summarized in Table 1.

Based on these studies, WWD crashes are more prevalent during non-daylight hours, particularly in the early morning. In Texas, 52% of all WWD crashes occurred during the six hours from 12:00 midnight to 6:00 a.m.; however, only 10.4% of overall freeway crashes occurred during that time period. Past studies (Copelan, 1989; Cooner et al., 2004; Braam, 2006; NTTA, 2009) indicated that WWD crashes occurred more frequently during the weekends; however, the monthly distribution of WWD crashes varies among different states (Braam, 2006; Cooner and Ranft, 2008; Pour-Rouholamin et al., 2016) and countries (ITARDA, 2002), showing no consistent trend.

Past research conducted in both Illinois (Zhou et al., 2012) and Texas (Cooner et al., 2004) found that WWD crashes occur in urban areas more often than in rural areas. Studies in Texas also found that most of the WWD collisions occurred in the inside lane of the correct direction and at locations with left-side exit ramps or one-way streets that transitioned into a freeway section. A study in the Netherlands from 1996 to 1998 found that 79% of WWD crashes took place on the main line of the freeway, 5% on merge/diverge lanes, and 17% on ramps (SWOV, 2009).

The characteristics of WW drivers, such as driver sobriety, age, and gender, have been discussed in many past studies. A significant portion of WWD crashes on freeways was caused by those who were driving under the influence (DUI) of alcohol or drugs. Most past studies concluded that young drivers and older drivers are overrepresented in the WWD crashes. Most of the crashes caused by drivers in the young and middle-age range occurred because of distraction (Haendeler et al., 2014; Pour-Rouholamin et al., 2016), while most crashes caused by drivers in the senior age range occurred because of some physical illnesses such as dementia or confusion (ITARDA, 2002). The findings of a study by Gibbons et al. (2012) established a relationship between aging and nighttime driving behaviors, signifying that older drivers have more difficulty detecting objects than younger drivers when the roadway is not lit well. An overwhelming majority of WWD crashes involved male drivers, and most of the female drivers were in young age groups (ITARDA, 2002).

Despite all the efforts to characterize WWD crashes and delineate between these types of crashes and the others, there is no research into the factors that affect the driver's injury severity within the WWD domain. Along with recognizing the factors that affect the probability of WWD crashes, it is also crucial to identify the extent to which these factors might affect the severity of injuries sustained by the WW driver in terms of safety implications. To this end, several methods have already been used whether they consider the ordered nature of severities or not.

Over the past years, numerous disaggregate modeling approaches have been employed to quantify the effect of several contributing factors on various levels of injury severity. Given the ordered nature of the injury severity in crashes (representing an ordinal outcome), these methodological approaches generally fall under two main categories (based on whether this nature is considered or not): ordered-response models and unordered-response models. Ordered logit/probit (Khattak and Rocha, 2003; Lee and Li, 2014), generalized ordered logit (Wang and Abdel-Aty, 2008; Abegaz et al., 2014), and mixed generalized ordered logit (Eluru and Bhat, 2007; Eluru et al., 2008) models are among the models that do consider the ordered nature of crash severity. However, there is an increasing tendency towards using unordered response models, as well. Nested logit (Haleem and Abdel-Aty, 2010; Hu and Donnell, 2010), multinomial logit (Celik and Oktay, 2014; Xie et al., 2012), and mixed logit models (Kim et al., 2013; Klassen et al., 2014) have also been used to provide in-depth insight into significant contributing factors to crash injury severities. This study considers the ordered nature of crash injury severity; thus, it employs ordered-response models to examine the effect of various contributing factors to the driver injury severity in WWD crashes on controlled-access highways (freeways, expressways, Interstate highways).

3. Data

The WWD crash records in this study mainly come from the results of two major WWD studies in Illinois (Zhou et al., 2012, 2015; Zhou and Pour-Rouholamin, 2015) and Alabama (Zhou et al., 2016). The Illinois crash data was accessed through the Illinois Department of Transportation (IDOT) crash database. This database combines the crash data from three separate text files (crash, person, and vehicle). Crash records in these three files can be linked together using a numerical variable unique to each crash record, called the Illinois Case Number (ICN). The Alabama crash data was also accessed through the Critical Analysis Reporting Environment

[1] While the sample size might look small, it should be noted that several studies have already used small sample sizes mainly because of the rareness of this kind of crash. For instance, Kemel (2015), Zhou et al. (2012), and Lathrop et al. (2010) used sample sizes of 266, 217, and 49 for their analyses, respectively.