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Effects of foggy conditions on driver injury levels in U.S. highway-rail grade crossing accidents

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ABSTRACT

Foggy conditions are considered to be potentially dangerous for drivers and have been paid considerable attention recently. However, few studies have addressed the influence of fog-related conditions on injury severity in accidents, particularly at highway-rail grade crossings. This study estimates the effect of foggy conditions on driver injury severity at highway-rail grade crossings. Compared to accidents occurring during clear conditions, fog-related accidents tend to result in more severe injuries. Older drivers are more likely to suffer severe injuries in foggy than in clear conditions as a result of their poorer vision and reaction times. In foggy conditions, drivers were found to be willing to drive at speeds that were too high for them to be able to stop to avoid obstacles that they may be able to identify and react to. In addition, drivers in foggy conditions are more likely to be severely injured in accidents occurring in open space areas with passive control device due to low traffic volumes and higher expected vehicle speeds. Drivers are more likely to experience high level injury in accidents during early morning in winter. Finally, drivers tend to suffer more severe injuries in accidents during peak-hours as a result of the fatigue that they experience at these times.

1. Introduction

The influence of weather conditions on transportation operations and safety is an important research topic. Adverse weather conditions can have significant impacts on visibility distance, driving behavior, vehicle performance, traffic flow characteristics, and traffic safety. The effects of different weather conditions on traffic operations and safety have been paid considerable attention by transportation researchers (Cools et al., 2010)

Among adverse weather conditions, fog is considered to be the most hazardous and the one that drivers most fear. Approximately 600 fatalities and 16,300 injuries occur each year in fog-related crashes as reported by Federal Highway Administration (FHWA) (Brooks et al., 2011). Driving in fog can be risky for drivers of all abilities as it can result in a substantial reduction in visibility. A 16% increase in personal injuries was found to occur in accidents during heavy fog compared with clear weather conditions (Yan et al., 2014).

Vehicle-train collisions at highway-rail grade crossings are considered to be the most dangerous accidents for vehicle drivers because the average weight ratio of trains to motor vehicles is around 4000 to 1 (Yan et al., 2010). The Federal Railroad Administration (FRA) database (FRA, 2011) on which this study is based indicates that there were 381 highway–rail crossing accidents during fog-related weather conditions in the United States between 2002 and 2011.

Several studies have shown that weather conditions have a significant influence on accidents, but few addressed the influence of fog-related weather conditions on the injury severity level in accidents, especially at highway-rail grade crossings. In general, the literature revealed that the risk of traffic fatalities is much higher in accidents occurring during foggy weather conditions. Each of these studies are reviewed next.

Mueller and Trick (2012) studied the influence of driving experience on speed compensation when driving in foggy conditions. It was found that experienced drivers drove faster than novice drivers in clear visibility conditions, however, they reduced their speed more in reduced visibility conditions. Compared to experienced drivers, novice

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drivers had longer response times to hazards and greater speed and steering variability.

Ni et al. (2012) studied age-related differences in collision detection performance influenced by fog conditions. This study found that during inclement weather conditions with bad visibility, especially foggy conditions, older drivers may have an increased crash risk due to a decreased ability to detect impending collisions. In addition, Ni et al. (2010) studied age-related car following performance, which is maintaining a safe distance behind a vehicle, in simulated fog conditions. The study's results show that older drivers may be at greater risk for collisions in high fog density and at moderate speeds.

The influence of visibility obstruction on crashes due to fog and smoke were explored by Abdel-Aty et al. (2011). This study analyzed the effect of fog and smoke using a multilevel ordered logistic model based on accident data from Florida between 2003 and 2007. Crashes occurring in foggy or smoky conditions were found to result in more severe injuries and involve more vehicles than those occurring during clear weather. These crashes occurred more often on high-speed roads, undivided roads, roads with no sidewalks two-lane rural roadways and at night on roads with no street lights.

Brooks et al. (2011) studied speed choice and driving performance in simulated foggy conditions. This study used a driving simulator-based method with simulated fog conditions. It found that drivers were willing to drive at speeds that were too high for them to be able to avoid obstacles that they may have been able to identify and react to. The research concludes by noting that safety could be improved if drivers were convinced to drive at lower speeds than they would choose on their own or the vehicle's ability to identify and react to hazards that the driver cannot see was enhanced

Drivers were found to have decreased car-following performance (failure to maintain a safe following distance) under simulated foggy conditions (Kang et al., 2008). Another study (Edwards, 1998) looked at the relationship between accident severity and recorded weather. The study found that speed was a major contributing factor in many crashes which occur in foggy conditions.

Although recent studies on highway crashes have paid attention to drivers' safety in foggy conditions, most have focused on a particular driving scenario and lack a systematic analysis of driver's injury severity according to different weather conditions. To overcome previous limitations in the literature, this study aims to estimate the effect of fog conditions on driver's injury severity using data from the FRA database. Using a mixed logit modeling approach, the current research finds the determinants of driver injury severity in fog conditions at highway-rail grade crossings compared with clear weather conditions.

The steps undertaken in this study are as follows.

(1) A crash characteristics analysis examines the characteristics of fog-related crashes compared to crashes which occur in clear visibility conditions. The factors investigated include temporal distribution, crash types and various geometric, traffic, and human factors and environmental conditions.
(2) An injury severity modeling analysis estimates the effects of various traffic situations and environmental conditions on injury severity given that a fog-related crash has occurred.

2. Methodology descriptions

The methodology in this research includes developing, estimating and analyzing statistical models that predict the probability of injury severity levels in highway-rail grade crossing accidents. Many methodological techniques have been applied to analyze crash-severity data. A comprehensive study of injury severity level models and approaches can be found in Savolainen and Mannering (2007). The following subsections discuss the mixed logit model methodology used in the current study, as well as the calculation of elasticity, and the likelihood ratio test.

2.1. Mixed logit model

Mixed logit models are utilized to calculate the probability of discrete driver-injury severity outcomes conditioned on a highway-rail grade crossing accident having happened and having been reported to police (Mannering and Bhat, 2014). The mixed logit model (Mannering and Bhat, 2014) addresses several limitations: 1) it allows for a comprehensive and total relaxation of the independent and identically distributed (IID) condition, 2) it avoids the violation of the independence from irrelevant alternatives (IIA) condition, and 3) it allows for heterogeneity in parameter effects.

The data provide three injury severity outcomes: PDO (Property Damage Only), injury, and fatality. To derive an estimated model's discrete outcomes, this study follows the approaches of Milton et al. (2008), Brooks et al. (2011), Morgan and Mannering (2011), and begins with the following function for determining driver-injury severity:

$$S_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{1}$$

Where, S_{in} is a severity function determining the driver-injury severity category i in highway-rail grade crossing accident n, X_{in} is a vector of explanatory variables which affect driver-injury severity category i in highway-rail grade crossing accident n, β_i are the coefficients of the explanatory variables, and ε_{in} is an error term which is assumed to be generalized extreme value distributed. In order to obtain the mixed logit model, random parameters are introduced with $f(\beta_i|\varphi)$, where φ is a vector of variables of the chosen probability density function using mean and variance. As in McFadden and Train (2000), the resulting mixed-logit injury-severity probabilities are:

$$P_n(i|\varphi) = \int \frac{e^{\beta_i X_{in}}}{\sum_{\forall I} e^{\beta_i X_{in}}} f(\beta_i|\varphi) d\beta_i \tag{2}$$

Where, $P_n(i|\varphi)$is the probability of injury severity i conditional on $f(\beta_i|\varphi)$. If the variance in φ is determined to be significantly different from zero, and it will be accident-specific variations of the effect of X on injury severity across each crash observation n, with the density function $f(\beta_i|\varphi)$used to determine the values of β_i across crashes (Train, 2003).

Maximum likelihood estimation of mixed logit models is computationally cumbersome because of the required numerical integration of the logit model over the distribution of the random, unobserved parameters (Milton et al., 2008). As a consequence, simulation-based maximum likelihood approaches are typically employed using Halton draws, which have been proven to give a more useful distribution of draws for numerical integration than purely random draws (see Bhat, 2003; Train, 2003). Details of the evolution of simulation-based maximum likelihood methods for estimating mixed logit models can be found in McFadden and Ruud (1994), Geweke et al. (1994).

To evaluate the effects of individual parameter estimates on injury-severity outcome probabilities, elasticities can be calculated from the partial derivative for each individual observation n (n subscripting omitted) as:

$$E_{X_{ki}}^{P(i|\varphi)} = \frac{\partial P(i|\varphi)}{\partial X_{ki}} \times \frac{X_{ki}}{P(i|\varphi)} \tag{3}$$

Where, $P(i|\varphi)$is the probability of injury-severity outcome i and X_k is the value of variable K. Elasticity values can be roughly interpreted as the percent effect that a 1% change in X_{ki} has on the injury-severity outcome probability$P(i|\varphi)$. For indicator variables, a pseudo elasticity could be calculated which gives the percent change on the injury-severity outcome probability of the parameters with values ranging from zero to one (Morgan and Mannering, 2011).

2.2. Likelihood ratio tests

To test if there are significant differences between parameter