Impact of roadway geometric features on crash severity on rural two-lane highways

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ABSTRACT

This study examines the impact of a wide range of roadway geometric features on the severity outcomes of crashes occurred on rural two-lane highways. We argue that crash data have a hierarchical structure which needs to be addressed in modeling procedure. Moreover, most of previous studies ignored the impact of geometric features on crash types when developing crash severity models. We hypothesis that geometric features are more likely to determine crash type, and crash type together with other occupant, environmental and vehicle characteristics determine crash severity outcome. This paper presents an application of multilevel models to successfully capture both hierarchical structure of crash data and indirect impact of geometric features on crash severity. Using data collected in Illinois from 2007 to 2009, multilevel ordered logit model is developed to quantify the impact of geometric features and environmental conditions on crash severity outcome. Analysis results revealed that there is a significant variation in severity outcomes of crashes occurred across segments which verifies the presence of hierarchical structure. Lower risk of severe crashes is found to be associated with the presence of 10-ft lane and/or narrow shoulders, lower roadside hazard rate, higher driveway density, longer barrier length, and shorter barrier offset. The developed multilevel model offers greater consistency with data generating mechanism and can be utilized to evaluate safety effects of geometric design improvement projects.

1. Introduction

Motor vehicle crashes impose enormous economic and social losses on society, vehicle manufactures, and transportation agencies. In 2010 alone, the economic losses due to motor vehicle crashes accounted for $242 billion which is equivalent to 1.6 percent of the U.S. Gross Domestic Product (GDP) (NHTSA, 2015). The death toll due to motor vehicle crashes was 35,092 people during 2015, equivalent to 96 death per day nationwide (NHTSA, 2016).

Previous studies identified a myriad of factors that may affect both the frequency and severity of motor vehicle crashes (Abdel-Aty and Radwan, 2000; Cafiso et al., 2010; Chen et al., 2016; de Ona et al., 2013; Lord et al., 2005; Siskind et al., 2011; Zegeer et al., 1981). These factors can be classified as roadway characteristics (e.g. pavement surface, roadside condition, number of lanes, lane width, shoulder width), occupant attributes (e.g. seat belt use, driver attention, driver eyesight, age, gender), vehicle characteristics (e.g. vehicle weight, vehicle height, vehicle class), crash characteristics (e.g. crash type, impact speed), and environmental conditions (e.g. weather condition, light condition, visibility).

Numerous studies examined the impact of roadway features on crash frequency (Ye et al., 2013; Yu and Abdel-Aty, 2013; Castro et al., 2012; Bella, 2013; Park et al., 2012; Zegeer et al., 1988; Lee and Mannering, 2002; Zegeer and Deacon, 1987; Vogt and Bared, 1998; Karlaftis and Golias, 2002; Shankar et al., 1995). However, very few have investigated the influence of roadway features on the crash injury severity outcome. Most of the available studies developed distinct crash severity models for different crash types but since roadway features have significant impact on crash type, these models do not completely reflect the safety effect of roadway features (Duncan et al., 1998; Krull et al., 2000; Lee and Mannering, 2002; Yamamoto and Shankar, 2004).

In the meantime, crash severity data have a hierarchical structure which needs to be addressed in modeling procedure. A hierarchy implies that lower-level observations are clustered within higher level(s). In crash data for example, occupants are clustered within vehicles in which they are located, vehicles are clustered within road segments where the crash occurred, and road segments are clustered within geographical regions. Therefore, crashes occurred on the same segments tend to share similar severity outcomes. Most of previous studies overlooked such hierarchical structure of crash data and used

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traditional regression models (Duncan et al., 1998; Eluru, 2013; Haleem and Abdel-Aty, 2010; Boodlal et al., 2015; Krull et al., 2000; Lee and Mannering, 2002; Yamamoto and Shankar, 2004; Peek-Asa et al., 2010; Ye and Lord, 2011; Yasmin and Eluru, 2013; Ye and Lord, 2014; Schneider and Savolainen, 2011; Wu et al., 2013). The problem with these models is that they assume the residuals are independent across observations. Disregarding such hierarchical structure, when present, may result in models with biased parameter estimates and biased standard errors. This might as well explain several inconsistencies among previous studies on safety effect of roadway features. For instance, upgrading roadway features such as increasing number of travel lanes, widening lanes and shoulders, reducing number of curves, and reducing roadside hazards are generally considered viable solutions to fatality and injury reductions associated with motor vehicle crashes (Hadi et al., 1995; Gross et al., 2009). Yet several studies reported that some upgrades may increase frequency and severity of motor vehicle crashes (Ivan et al., 2000; Karlaftis and Tarko, 1998; Milton and Mannering, 1998; Sawalha and Sayed, 2001; Shankar et al., 1995; Vitaliano and Held, 1991).

To address these research gaps, this study attempts to assess the impact of a wide range of roadway geometric features on the severity of crashes occurred on rural two-lane highways. The contribution of this paper is threefold. First, to address hierarchical structure of crash data, a multilevel modeling approach is developed for analyzing crash severity. Second, the setting of multilevel model is configured to successfully capture the indirect impact of geometric features. Third, this study does not limit the impact of roadway geometric features by conditioning severity models on any specific crash type. To estimate the proposed models, crash data recorded on rural two-lane highway segments in Illinois from 2007 to 2009 were used. The developed crash severity models can be utilized to evaluate safety effects of geometric design improvement projects.

2. Literature review

Several studies have investigated the influence of roadway features on the crash injury severity outcome. Lee and Mannering (2002) used a nested logit model to predict the severity of run-off roadway crashes. Data from State Route 3 in Washington State was used to develop the crash severity model. The presence of horizontal curve was found to have significant impact on crash severity. Khorashadi et al. (2005) explored the difference between urban and rural driver injuries in crashes involving large trucks. Using accident data from 1998 to 2000 in California, two multinomial logit models were developed separately for rural and urban environments. Results revealed that number of lanes, highway terrain, median barrier type and road lighting have significant impact on rural crash severity. In urban area, highway type, median type, presence of construction zone, and weather were found to significantly influence crash severity. Moreover, the presence of concrete median barriers was found to reduce the risk of severe/fatal injury by 68.7%. Duncan et al. (1998) used ordered probit model to assess the impact of occupant characteristics, roadway features, and environmental conditions on injury severity. Their study focused on rear-end crashes involving truck-passenger car collisions. Results revealed that roadway features do not have significant impact on crash severity. Krull et al. (2000) developed logit models to predict injury severity of drivers involved in single-vehicle crashes. They used three years crash data from Michigan and Illinois to evaluate the impact of rollover, while controlling for roadway, vehicle, and driver factors. The roadway features found to increase the probability of severe injury are higher speed limits and dry pavement (as opposed to slick pavement). Yamamoto and Shankar (2004) used a bivariate ordered probit model to analyze driver injury severity and most severely injured passenger's severity in collisions with fixed objects. The study used 4-year statewide crash data in Washington State. Results revealed that icy roadway surface and rain decrease the risk of more severe driver injury crashes. They also found

that while collision with guardrail face decreases the probability of severe driver injury, collision with guardrail end increases the risk of severe driver injury.

Most of these studies only investigated the relationship between roadway features and injury severity for a specific crash type. Moreover, previous studies often describe the relationship between geometric features and injury severity as a direct effect. Yet it is difficult to explain the underlying reason why such direct effect would exist. For example, the presence of a median barrier influences the type of crashes − preventing head-on collisions but increasing barrier collisions. It appears more likely that roadway geometric features directly impact crash type. And crash type, together with occupant and vehicle characteristics determine crash severity. Therefore, the safety effect of roadway geometric features on crash severity is not fully captured by these studies due to the negligence of this intermediate layer. Recently, some researchers used crash severity models without focusing on specific crash types. Boodlal et al. (2015) analyzed the safety effects of lane width and shoulder width combination on rural two-lane highways. The study used 3-year crash data collected in Illinois and Minnesota. They developed two multinomial logit models to predict the probability of total and fatal-plus-injury crashes. No significant relationship was found between geometric features and crash severity. They reported that geometric features are not expected to directly affect severity outcome and it is more likely that they just impact likelihood of crash occurrence. Chen et al. (2016) used a hierarchical Bayesian model to investigate the impact of occupant characteristics, roadway features, and vehicle characteristics on driver injury severity. They used 2-year rural interstate crash data from New Mexico. They found significant relationship between the presence of curve and driver injury severity.

From a methodological standpoint, a wide range of econometric modeling approaches including binary logit/probit (Haleem and Abdel-Aty, 2010; Peek-Asa et al., 2010; Kononen et al., 2011; Santolino et al., 2012), multinomial logit (Ye and Lord, 2011; Yasmin and Eluru, 2013; Ye and Lord, 2014; Schneider and Savolainen, 2011), ordered logit/probit (Abay, 2013; Eluru, 2013; Jiang et al., 2013a,b; Mergia et al., 2013), nested logit (Abdel-Aty, 2010; Patil et al., 2012; Wu et al., 2013), bivariate/multivariate ordered probit (de Lapparent, 2008; Abay et al., 2013), copula based (Rana et al., 2010; Yasmin et al., 2014; Eluru et al., 2010), latent class (Xie et al., 2012; Eluru et al., 2012; Shaheed and Gkritza, 2014; Behnood et al., 2014; Behnood and Mannering, 2016), and mixed logit/probit (Aziz et al., 2013; Morgan and Mannering, 2011; Manner and Wünsch-Ziegler, 2013; Paleti et al., 2010) were used to analyze crash severity outcome. Most of these methods are based on the assumption that the model residuals are independent. However, very few of them are able to capture correlation across observations. Multivariate and copula-based methods are mostly used to jointly model multiple dependent variables that are inter-related with one another. For example Eluru et al. (2010) used a copula-based multivariate model to simultaneously examine injury severity experienced by drivers, front-seat passengers, and rear-seat passengers. Latent class models are mostly used when there is correlation across observations but the source of correlation is unknown to the analyst. They attempt to identify groups of observations with homogenous variable effects within each group. The model requires analyst to specify the number of groups. However, in some cases, analyst is aware (or at least partially aware) of the source of correlation and homogenous groups. For instance, it is known that hierarchical structure of data may cause some observations to share similar unobserved characteristics. Recently, studies started to use multilevel models to address this issue. Multilevel modeling approach allows modeling the hierarchical structure of data and capturing correlation at different levels of hierarchy. The application of multilevel models is appropriate when correlation exists within clusters in different levels of hierarchy; otherwise traditional models are sufficient. Jones and Jørgensen (2003) developed a multilevel binary logit model to assess the impact of occupant and vehicle characteristics on fatality risk on Norwegian public roads.