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Comprehensive analysis of single- and multi-vehicle large truck at-fault crashes on rural and urban roadways in Alabama

Samantha Islam[a,*], Steven L. Jones[b,1], Daniel Dye[b,1]

[a] Department of Civil Engineering, University of South Alabama, 150 Jaguar Drive, Shelby Hall, Suite 3142, Mobile, AL 36688, United States
[b] Department of Civil, Construction & Environmental Engineering, University of Alabama, Box 870205, Tuscaloosa, AL 35487, United States

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ABSTRACT

The research described in this paper analyzed injury severities at a disaggregate level for single-vehicle (SV) and multi-vehicle (MV) large truck at-fault accidents for rural and urban locations in Alabama. Given the occurrence of a crash, four separate random parameter logit models of injury severity (with possible outcomes of major, minor, and possible or no injury) were estimated. The models identified different sets of factors that can lead to effective policy decisions aimed at reducing large truck-at-fault accidents for respective locations. The results of the study clearly indicated that there are differences between the influences of a variety of variables on the injury severities resulting from urban vs. rural SV and MV large truck at-fault accidents. The results showed that some variables were significant only in one type of accident model (SV or MV) but not in the other accident model. Again, some variables were found to be significant in one location (rural or urban) but not in other locations. The study also identified important factors that significantly impact the injury severity resulting from SV and MV large truck at-fault accidents in urban and rural locations based on the estimated values of average direct pseudo-elasticity. A careful study of the results of this study will help policy makers and transportation agencies identify location specific recommendations to increase safety awareness related to large truck involved accidents and to improve overall highway safety.

1. Introduction

According to the data maintained by the United States Department of Transportation and the Department of Commerce (USDOT/USDOC, 2010), trucks moved some 71% of all goods by value and 70% by weight in the United States in 2007. In recent years, the use of larger trucks has been increasing because of its economic and environmental benefits (Abdel-Rahim et al., 2006). The use of large trucks (e.g., greater than 26,000 lbs) results in reduced overall transportation costs and fuel emissions due to fewer truck trips (Caltrans, 2009). Regardless of the economic benefits, the high volume of large truck traffic, the unique operating characteristics of these trucks, the size/weight related issues of large trucks and the demand they place on drivers all contribute to a large number of crashes every year (Zhu and Srinivasan, 2011). The Federal Motor Carrier Safety Administration (2013) reported that 3757 people were killed and another 88,000 were injured in the United States (U.S.) in accidents involving large trucks in 2011. According to the same report, the large truck accident related fatalities in the U.S. rose 11% from 2009 to 2011. According to Zaloshnja and Miller (2006), the estimated average cost of a police reported crash involving large truck is $91,112 (based on 2005 U.S. dollars). In addition, the estimated average costs (in 2005 U.S. dollars) per fatality, non-fatal injury, and property-damage-only (PDO) are $3,604,518, $195,258 and $15,114 respectively. The high costs associated with the large-truck involved crashes have potential significant monetary impact on the society.

To date, researchers have explored the effects of a variety of factors, such as vehicle and driver characteristics, environmental factors, restraint usage, alcohol impairment, roadway geometrics and other related factors on injury severities in accidents involving large trucks (Chirachavala et al., 1984; Alassar, 1988; Campbell et al., 1988; Joshua and Garber, 1992; Brown and Bass, 1997; Chang and Mannering, 1999; Khorashadi et al., 2005; Starnes, 2006; Chen and Chen, 2011; Lemp et al., 2011). In the majority of the above studies, the injury severities of both single-vehicle (SV) and multi-vehicle (MV) accidents were studied as a whole. As a result, these studies could not identify some important factors unique to SV

* Corresponding author. Tel.: +1 251 460 6955; fax: +1 251 461 1400.
E-mail addresses: sislam@southalabama.edu (S. Islam), sjones@eng.ua.edu (S.L. Jones), dctdye@gmail.com (D. Dye).
[1] Tel.: +1 205 348 3137; fax: +1 205 348 6862.

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and MV accidents involving large trucks. Recently, Chen and Chen (2011) investigated difference in driver injury severities between SV and MV crashes involving large trucks. By analyzing injury severities of SV and MV accidents separately, they revealed some new and comprehensive information unique to these two types of accidents. Although a significant portion of accidents involving large trucks occur in urban locations, their study, however, focused exclusively on accidents in rural locations. Recent data (USDOT, 2011), however, show that 36% of all fatal crashes involving large trucks occurred in urban locations. Lee and Mannering (2002) found that rural and urban locations produce different effects on accident injury severities. They attributed these differences to factors such as driver behavior and, in particular, the effect of visual "noise" in certain roadway environments on driver behavior. Therefore, greater understanding of the location specific factors associated with large truck involved crashes is required to develop effective highway safety countermeasures and safety campaigns.

An important issue related to injury severity analyses of accidents involving large trucks is that majority of the severity models from previous research are based on the restrictive assumption that the effect of various factors is equally distributed (or fixed) across all observations. Anastasopoulos and Mannering (2011) showed statistical superiority of the random-parameter (or mixed) logit model compared to the traditional fixed-parameter logit model. Their analysis showed that the random-parameter logit models provide a reasonable level of accuracy even using less detailed crash-specific data than that required by the fixed-parameter models. Very few past studies have considered the randomness or variability across observations while analyzing injury severity resulting from large truck involved crashes. In modeling CMV crash severity in rural locations, Chen and Chen (2011) showed that the random-parameter logit model formulations better modeled the complex interactions of different variables and the nature of injuries.

Another issue related to the aforementioned past studies on large truck involved accidents is that none of them focused explicitly on crashes in which only the large trucks were at fault. A study of injury severities resulting from such accidents may provide valuable information unique to large trucks. Such information will help designing and implementing effective truck safety policies and driver education programs addressing the type of accidents truck drivers are more likely to be at fault.

The current study addresses such issues by analyzing injury severities resulting from large truck at-fault accidents in both rural and urban locations. This study incorporated the effects of randomness across the observations by developing separate random-parameter logit models for SV and MV accidents for rural and urban conditions. The objective of this study was to determine the factors influencing injury severity of at-fault large truck SV and MV crashes in rural and urban locations. A disaggregate level study of this sort is expected to identify location specific recommendations to increase safety awareness related to large truck involved accidents and to improve overall highway safety.

2. Methodology

There have been myriad previous works exploring crash risk factors and severity outcomes employing a range of tools from fault-tree analysis to predictive models using probit and logit formulations (Joshua and Garber, 1992; Shankar et al., 1996; Duncan et al., 1998; Chang and Mannering, 1999; Khattak, 2001; Kockelman and Kweon, 2002; Lee and Mannering, 2002; Abdel-Aty, 2003; Kweon and Kockelman, 2003; Ulfarsson and Mannering, 2004; Yamamoto and Shankar, 2004; Khorashadi et al., 2005; Wang and Kockelman, 2005; Islam and Mannering, 2006; Hill and Boyle, 2006; Milton et al., 2008; Malyshkina and Mannering, 2009; Xie et al., 2009; Haleem and Abdel-Aty, 2010; Malyshkina and Mannering, 2010; Christoforou et al., 2010; Anastasopoulos and Mannering, 2011; Hu and Donnell, 2011; Morgan and Mannering, 2011; Savolainen et al., 2011; Kaplan and Prato, 2012; Haleem and Gan, 2013). The current research employed a mixed-logit model approach to capture the randomness associated with some parameters necessary to understand injury severities attributable to at-fault truck crashes. This study used three injury-severity categories: possible/no injury, minor injury, and major injury (more discussions on the selection of these three categories are provided later in this paper). Given that three discrete outcomes were possible, an appropriate statistical modeling approach would be to use an ordered discrete probability model. This modeling approach would explicitly recognize the increasing severity of the three categories in the model estimation (from possible/no injury to major injury). Previously, researchers have applied this type of approach to accident severity models (Kockelman and Kweon, 2002; Abdel-Aty, 2003). However, a major limitation of the traditional ordered models is that they can restrict the influence of explanatory variables on severity outcomes (Khorashadi et al., 2005; Kim et al., 2013; Yasmin and Eluru, 2013). These models restrict variables to either increase the highest severity category and decrease the lowest, or increase the lowest severity category and decrease the highest. Although it is possible to use random parameter ordered models, the aforementioned limitation still exists (Kim et al., 2013). Therefore, the traditional simple ordered models may not always be appropriate for accident severity data. As a result, it is more appropriate to use either the generalized ordered logit model (Yasmin and Eluru, 2013) or the unordered discrete outcome model approach. In this paper, we employed the latter approach.

Table 1
Equations used in mixed logit model formulation.

Equation	Description
$S_{in} = \beta_i X_{in} + \varepsilon_{in}$	S_{in} = function of severity category i in crash n X_{in} = injury severity explanatory variables β_i = estimable parameter vector for injury severity category i ε_{in} = error term
$P_n(i) = \frac{e^{\beta_i X_{in}}}{\sum_{\forall I} e^{\beta_I X_{In}}}$	$P_n(i)$ = standard multinomial logit model probability of ith outcome for nth observation (Washington et al., 2011). Error term assumed to be generalized extreme value distributed as set out by McFadden (1981)
$P_n(i\|\phi) = \int \frac{e^{\beta_i X_{in}}}{\sum_{\forall I} e^{\beta_I X_{In}}} f(\beta_i\|\phi) d\beta_i$	$P_n(i\|\phi)$ = probability of injury severity i conditional on $f(\beta_i\|\phi)$ ϕ = parameter vector with known density function (McFadden and Train, 2000; Train, 2003).

The current study followed the mixed logit model approach reported by Milton et al. (2008), Washington et al. (2011) and Morgan and Mannering (2011). Details of the mixed logit model formulation are summarized in Table 1. The mixed logit model is a generalization of the multinomial logit model. It allows the parameter vector β_i to vary across each observation so that the injury outcome-specific constant and each element of the parameter vector β_i can be fixed or randomly distributed with fixed means. Random parameters are introduced with $f(\beta_i|\phi)$, where ϕ represents a parameter vector with a known density function. Statistically significant variance in ϕ indicates that the modeled injury severity varies with respect to X across individual observations as defined by $f(\beta_i|\phi)$ (Train, 2003). In the current study, the mixed logit probabilities were estimated by simulated maximum likelihood method using the Halton sequence approach (Halton, 1960; Bhat,