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Analysis of injury severity and vehicle occupancy in truck- and non-truck-involved accidents

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Abstract

The impact that large trucks have on accident severity has long been a concern in the accident analysis literature. One important measure of accident severity is the most severely injured occupant in the vehicle. Such data are routinely collected in state accident data files in the U.S. Among the many risk factors that determine the most severe level of injury sustained by vehicle occupants, the number of occupants in the vehicle is an important factor. These effects can be significant because vehicles with higher occupancies have an increased likelihood of having someone seriously injured. This paper studies the occupancy/injury severity relationship using Washington State accident data. The effects of large trucks, which are shown to have a significant impact on the most severely injured vehicle occupant, are accounted for by separately estimating nested logit models for truck-involved accidents and for non-truck-involved accidents. The estimation results uncover important relationships between various risk factors and occupant injury. In addition, by comparing the accident characteristics between truck-involved accidents and non-truck-involved accidents, the risk factors unique to large trucks are identified along with the relative importance of such factors. The findings of this study demonstrate that nested logit modeling, which is able to take into account vehicle occupancy effects and identify a broad range of factors that influence occupant injury, is a promising methodological approach.

Keywords: Trucks; Accident severity; Occupant injury; Risk factors; Logit modeling

1. Introduction

The impact that traffic accidents have on society is significant. Individuals injured (or killed) in traffic accidents must deal with pain and suffering, medical costs, wage loss, higher insurance premium rates, and vehicle repair costs. For society as a whole, traffic accidents result in enormous costs in terms of lost productivity and property damage. Clearly, efforts to improve our understanding of the factors that influence accident severity are warranted.

Although there have been numerous research efforts to understand traffic accident severity, the relationships between risk factors and accident severity are still not completely understood. One of the major reasons for this is that the causes leading to accident severity levels are always complicated by presence of multiple factors, including characteristics of the individual (e.g. gender, age and use of restraint systems), of the vehicle (e.g. vehicle type), of the environment (e.g. weather conditions), of the roadway (e.g. geometric designs) and of others (e.g. collision types). Most previous studies have focused on some risk factors, such as restraint systems use or drinking and driving, and tried to determine their relationship with accident severity. However, isolating some factors for analysis and treating others as fixed does not allow one to obtain a complete understanding of the underlying causes of traffic accident severity.

In assessing accident severity, the level of injury sustained by individual vehicle occupants is one obvious measure. Unfortunately, State accident databases often do not have accurate injury information on all occupants. Research has shown that accurate injury information is typically available only for the most severely injured vehicle occupants (Shankar et al., 1996). To avoid possible measurement errors resulting

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from collected data, a more reasonable measure of accident severity is the level of injury sustained by the most severely injured occupant in the vehicle. This type of injury data is routinely and accurately collected. However, use of most severe injury data complicates the statistical analysis because vehicle occupancy effects must be explicitly addressed. Vehicle occupancy is an important concern in determining the most severe injury in a vehicle because an increase in the number of people in an accident-involved vehicle increases the likelihood of someone in the vehicle being injured, perhaps seriously, because of structural intrusions into the vehicle and so on (i.e. occupancy is an 'exposure' effect). Therefore, it is important to develop a methodological approach that is able to take into account vehicle occupancy effects and also identify a broad range of risk factors that impact the level of injury sustained by the most severely injured vehicle occupant.

In terms of traffic safety, issues relating to large trucks have drawn considerable attention from highway engineers, policy makers, and the general public. Large trucks have many unique operating characteristics such as high gross weight, long vehicle length, and poor stopping distance, which have an impact on accident severity. Aggregate data and previous research has shown that accidents involving trucks have an increased likelihood of producing a severe injury or fatality due to the car/truck size disparity and other factors. However, the relative impact that various factors relating to the accident (e.g. roadway geometrics, roadway conditions, etc.) have on the likelihood of a severe injury or fatality has not been satisfactorily quantified.

The objective of this research is to account for the relationship between the level of injury sustained by the most severely injured vehicle occupant and vehicle occupancy and to statistically assess most severely injured occupant differences between truck- and non-truck-involved accidents. This is done by using a nested logit modeling approach and a series of computations to determine the magnitude of the influence that specific factors have on injury severity in both truck- and non-truck-involved accidents.

2. Literature review

Previous research on accident severity has been diverse both empirically and methodologically. From an empirical standpoint, numerous research studies have focused on the casualty of accidents and attempted to isolate the risk factors that contribute to accident severity. Among them, a majority of studies concentrated on the impacts of drinking and driving as well as restraint device use (Evans, 1986a; Mercer, 1987; Lloyd, 1992; Holubowycz et al., 1994; Huelke and Compton, 1995; Kim et al., 1995a; Evans, 1996). The findings consistently indicated that drinking and driving and not using restraint devices significantly increase the severity of traffic accidents. Also, a number of studies have attempted to identify the driver characteristics (e.g. age and gender) that influence accident severity (Jonah, 1986; Mayhew et al., 1986; Levy, 1990; Laberge-Nadeau et al., 1992; Brorsson et al., 1993). Young drivers are believed the group at greater risk of being involved in casualty accidents. Several studies examined particular severity types such as fatalities (Shibata and Fukuda, 1994), or crashes involving certain types of vehicles such as trucks (Chirachavala et al., 1984; Alassar, 1988) or motorcycles (Langley et al., 1994; Shankar and Mannering, 1996). Other studies emphasized particular accident characteristics (e.g. collision types, occupant ejection) on accident severity (Good et al., 1987; Kim et al., 1995b; Viner, 1995; Malliaris et al., 1996).

From a methodological standpoint, a variety of statistical approaches have been applied to study accident severity. The simplest is to use the mean and variance of specific factors (e.g. blood alcohol concentration, percentage of seat belt use, occupant ejections and so on) and to test for significant differences among accident severity levels (Malliaris et al., 1996). Another simple method that has been widely used is to examine the correlation among accident severity levels and factors of interest (e.g. restraint device use) to identify the factors significantly contributing to specific severity levels (Mercer, 1987). Cross-tabulation methods or χ^2 tests have also been used to compare the distributional difference between different groups (e.g. gender and age) and accident severity levels to identify high risk groups (i.e. those that have greater risk of being involved in a certain severity level) (Brorsson et al., 1993; Holubowycz et al., 1994). Multivariate analysis techniques have also been undertaken to identify a set of variables that can be used to distinguish accident severity levels (Shao, 1987). Other statistical techniques include time-series approaches (Lassarre, 1986) and double pair comparison (Evans, 1986b).

Many of the above analysis methods were applied using aggregate data. The disadvantage of using aggregate data is that it can result in a loss of information on the relationships between accident severity and contributing factors. The advantages of using disaggregate data not only include the capability of testing a broad range of factors that influence accident severity but also the capability of capturing powerful disaggregate information about how individual factors influence accident severity. Disaggregate analysis techniques theoretically can lead to more detailed and meaningful findings.

One commonly used disaggregate model is the logistic regression as applied by Jones and Whitfield (1988), Shibata and Fukuda (1994), Lui et al. (1988). In other work, O'Donnell and Connor (1996) estimated an ordered logit model and an ordered probit model to identify risk factors that increase the probabilities of serious injury and death. Shankar and Mannering (1996) applied multinomial logit model to analyze single-vehicle motorcycle accident-injury severity and Shankar et al. (1996) employed a nested logit model to study a broad range of variables that are significant in determining the accident-injury severity probabilities.

There have also been a number of research studies that have specifically examined accident characteristics for large trucks. Most of these have focused on safety issues for truck configurations. For example, Polus and Mahalel (1985), Chirachavala and Cleveland (1985), Carsten (1987), Stein and Jones (1988), Jovanis et al. (1989), Blower et al. (1993) and Braver et al. (1997) examined the accident involvement rates for different truck configurations (e.g. singles and doubles) to identify whether or not one configuration is significantly safer than the other. Jovanis and Delleur (1983) statistically compared the accident involvement rates for motor vehicle accidents to identify whether or not large trucks have higher fatality and/or injury rates than those for other types of vehicles. Saccomanno and Buyco (1988) used generalized log linear models and Joshua and Garber (1990) applied multiple linear and Poisson regression analyses to estimate truck accident rates. Miaou (1994) applied Poisson and negative binomial regression models to explore the relationships between truck accident occurrence and highway geometric designs and other factors (e.g. traffic characteristics). In other work, Khasnabis and Lyoo (1989) used time series analysis to forecast truck accidents. Finally, Campbell (1991) addressed the issue of minimum age for drivers of large trucks by comparing the fatal accident involvement rates by driver age.

Most research dealing with the analysis of large tucks in accidents has focused on the occurrence of truck accidents (e.g. Jovanis and Delleur, 1983; Miaou, 1994). There have been relatively few studies that have concentrated on the severity of accidents involving trucks. In one of these, Golob et al. (1987) statistically compared the mean number of injuries and fatalities by collision types and the number of involved vehicles for truck-involved freeway accidents. Alassar (1988) used log-linear modeling approach to examine accident severity of truck-involved accidents and identified the contributing factors (e.g. collision types and road class) for fatal and injury accidents. Finally, Chirachavala et al. (1984) estimated logit models to study the factors that increase accident severity for four different truck types. They found that collisions with passenger cars, collisions on dry road surfaces at night, and collisions on undivided rural roads usually resulted in highest fatality and injury ratios.

As the above discussion shows, there have been a number of studies that have analyzed the relationships between risk factors and accident severity for all motor vehicle accidents and some specifically for large truck accidents. However, there is still much to be learned because most of these previous studies focused only on a few risk factors. As a result, the underlying causes for severe accidents and the differences in severities for truck-involved and non-truck-involved are still not completely understood.

3. Methodological approach

As previously discussed, our measure of accident severity is, for each vehicle, the level of injury sustained by the most severely injured vehicle occupant. Because this measure is affected by the number of occupants in the vehicle (i.e. more occupants make a higher injury severity more likely because more people are exposed to possible injury), the relationship between vehicle occupancy and the level of injury sustained by the most severely injured vehicle occupant must be explicitly accounted for by analyzing injury severity jointly with vehicle occupancy. Injury severity levels are property damage only (no one in the vehicle is injured), possible injury (the most severely injured occupant has a possible injury), evident and disabling injury (the most severely injured occupant has an evident or disabling injury), and fatality (the most severely injured occupant was fatally injured). Fig. 1 gives the nested structure describing the analysis of accident severity (in this case property damage only, possible injury, and injury/fatality) conditioned on vehicle occupancy[1]. This structure assumes the number of occupants in the vehicle affects the level of injury sustained by the most severely injured vehicle occupant as discussed above. An appropriate method of modeling the process indicted in Fig. 1 is the nested logit formulation previously applied to accident severity by Shankar et al. (1996). The model assumes that unobserved effects that influence occupancy and severity are generalized extreme value (GEV) distributed. Using the GEV distribution, the severity probabilities can be written in the following nested logit model form (see McFadden, 1981; Shankar et al., 1996).

[1] Note, in Fig. 1, that the severity of an accident is specified to be one of three discrete categories: (1) property damage only; (2) possible injury; (3) injury/fatality (injury here includes both evident and disabling injuries). The reason for combining evident injury, disabling injury and fatality into a single category is to increase the number of observations to reduce the variability caused by random effects when statistical methods are applied. This is necessary because the data that we will use in this study had too few observations on disabling and fatal acidents to separate out their individual effects. Likewise, occupancy levels at four and above are combined into one discrete category due to their being too few observations of vehicles involved in accidents with four or more occupants.

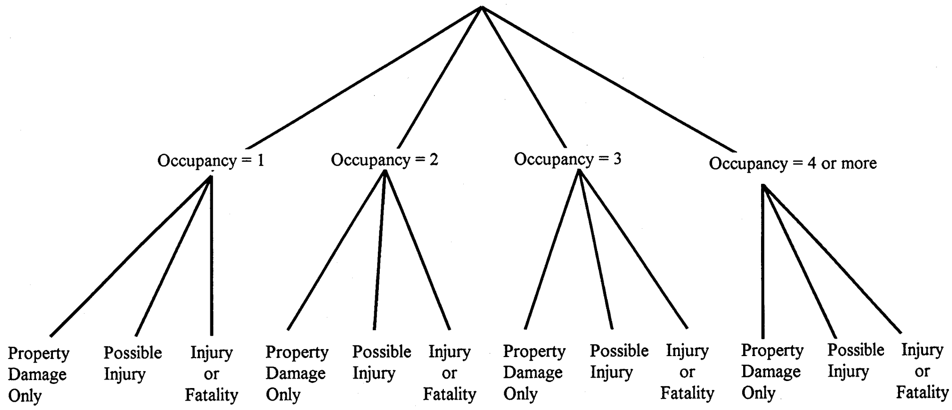

Fig. 1. Nested structure of vehicle occupancy and level of injury sustained by the most severely injured vehicle occupant.

$$\mathrm{Pr}_n(k) = \exp[\beta_k Z_n + \Theta_k L_{kn}] / \sum_K \exp[\beta_k \mathbf{Z}_n + \Theta_k L_{kn}], \quad (1)$$

$$\mathrm{Pr}_n(i|k) = \exp[\beta_{i|k} \mathbf{X}_n] / \sum_I \exp[\beta_{i|k} \mathbf{X}_n], \quad (2)$$

$$L_{kn} = \ln\left[\sum_I \exp(\beta_{i|k} \mathbf{X}_n)\right], \quad (3)$$

$$\mathrm{Pr}_n(i) = \mathrm{Pr}_n(k) \cdot \mathrm{Pr}_n(i|k), \quad (4)$$

where $\mathrm{Pr}_n(k)$ is the unconditional probability of the involved vehicle n having occupancy k (e.g. single occupant), $\mathbf{Z}_n$ is a vector of variables that determine vehicle occupancy, $\mathrm{Pr}_n(i|k)$ is the probability of the involved vehicle n having injury severity i conditioned on the vehicle occupancy k (e.g. the probability of having property damage only given that there was single-occupant in the vehicle), $\mathbf{X}_n$ is a vector of measurable characteristics that determine injury severity (e.g. driver age, driver gender, weather conditions, vehicle type, and so on), β is a vector of statistically estimable coefficients, I is the conditional set of injury severity categories (conditioned on k), and K is the unconditional set of vehicle occupancy, L_{kn} is the inclusive value (log sum) which is interpreted as the expected value of the attributes that determine injury severity probabilities in severity category i, Θ_k is an estimable coefficient with a value between zero and one to be consistent with the model derivation (see McFadden, 1981). The model structure in Eqs. (1)–(4) can be estimated by standard maximum likelihood methods.

4. Data description

The source of accident data used in this study was the Washington State accident records supplied by the Washington State Department of Transportation. The data were obtained in computer-ready form that included coded information on all reported accidents that occurred on principal arterials, state highways, and interstate highways in King County (which includes the city of Seattle in Washington State) during 1994[2]. Washington State accident records contain a broad range of accident information including injury, weather conditions, alcohol involvement, restraint use, roadway conditions, factors contributing to the accident (e.g. excess speed) and other data.

As previously discussed, we use individual vehicles as the unit of observation and define severity as the injury level of the most severely injured vehicle occupant. Thus, for example, an accident involving a three-occupant vehicle, having two occupants with no injury and a third with a possible injury would be classified as possible-injury accident.

The total reported number of accidents that occurred on principal arterials, state highways, and interstate highways in King County during 1994 was 13 607. In these 13 607 accidents, accident information on a total of 27 410 involved vehicles was recorded. After screening out the vehicles with incomplete information, a database of 17 473 vehicles was used for this analysis[3]. Of the 17 473 vehicles, 12 397 (70.9%) vehicles had property damage only, 3695 (21.1%) vehicles had possible injuries, 1161 (6.6%) vehicles had evident injuries,

[2] We limited our analysis to a single year of King County accident records to avoid possible temporal and spatial variations that may be present in the analysis (see Milton and Mannering, 1998 for an example of such variations). Similarly principal arterials, state highways, and interstate highways were considered to minimize variations across highway functional classes. A promising direction for future research would be to test the temporal and spatial stability of nested-logit severity models by including data from different years and different states.

[3] Missing information in accident records appears to be a random result of poor reporting or errors in data entry and not systematic. A large sample z-test comparison of the means of some variables (e.g. vehicle occupancy) of the data included and excluded in our 17 473-vehicle sample did not yield statistically significant differences. Thus the excluded data do not appear to be introducing a systematic bias in our sample.

199 (1.1%) vehicles had disabling injuries, and 21 (0.1%) vehicles had fatalities. As mentioned in an earlier footnote, to ensure a sufficient number of observations for estimation purposes, severity data are grouped into three severity categories: (1) property damage only; (2) possible injury, and (3) injury/fatality (i.e. evident injury, disabling injury, or fatality).

The data show that average vehicle occupancies for property damage only accidents, possible injury accidents, and injury/fatal accidents are 1.308, 1.526, and 1.630, respectively. These values are significantly different (using a large sample z-test) and underscore the importance of considering the relationship between vehicle occupancy and severity in the model structure.

5. Model estimation results

Separate models were estimated of truck-[4] and non-truck-involved accidents[5]. The nested logit model specified in Fig. 1 was developed to estimate the probabilities of injury severity for the most severely injured vehicle occupant conditioned on vehicle occupancies for non-truck-involved accidents and to identify the factors that increase or decrease the injury severity likelihood. To estimate the nested logit model, the most common estimation technique, the sequential estimation approach, is used. The lower nests (i.e. Eq. (2)) are estimated first as standard multinomial logit (MNL) models using standard maximum likelihood methods. The estimated coefficients are then used to calculate the inclusive value (i.e. L_{kn} in Eq. (3)). The final step is to estimate the upper nest (i.e. Eq. (1)) using standard MNL by including the computed inclusive value (i.e., L_{kn}) from the lower nests as an independent variable.[6]

5.1. Non-truck-involved accidents

Table 1 shows maximum likelihood estimation results of the conditional lower nest model (i.e. conditioned on single occupancy level) for accidents that do not involve a truck. The estimation results of the rest of conditional lower nest models are not shown due to space limitations (see Chang, 1997 for these model estimation results). The models for single-occupant vehicles, two-occupant vehicles, three-occupant vehicles, and four or more occupant vehicles show that a wide range of roadway characteristics, temporal characteristics, environmental characteristics, driver characteristics, vehicle characteristics, and accident characteristics, influence the injury severity level of the accident. The variables included in these models show some general trends in that many have similar effects across occupancy levels. However, there are quite a few variables that differ significantly across occupancy levels (i.e. found to be significant at one occupancy level but not at another) and the relative influence on injury severity probabilities varies across occupancy levels.

To gain a better understanding of marginal effects of the variables included in these conditional lower nests on the most severely injured vehicle occupant, elasticities were computed. In general, the direct elasticity is defined as

$$E_{x_n}^{\Pr_n(i)} = \frac{\partial \Pr_n(i)}{\partial x_n} \cdot \frac{x_n}{\Pr_n(i)}, \tag{5}$$

where E represents the direct elasticity, $\Pr_n(i)$ is the probability of vehicle n having severity category i, and x_n is the variable being considered to have effects on accident severity i. Given Eq. (5), the direct elasticity for the multinomial logit formulation can be shown equal to

$$E_{x_n}^{\Pr_n(i)} = \left[1 - \sum_{I=I_n} \Pr_n(i)\right]\beta_i x_n, \tag{6}$$

where β_i is the estimated coefficient corresponding to the variable and I_n is the set of severity levels that have variable x_n in the severity function (see Eq. (2)).

The elasticity defined in Eq. (6) is used to measure the effect that a 1% change in injury severity determinants will have on injury severity probability. Thus, it is only valid when the severity determinants are continuous variables. It is not applicable for indicator variables. For indicator variables a 'pseudo-elasticity' can be used to give an approximate elasticity of the variable. The pseudo-elasticity gives the incremental change in injury severity probability caused by the indicator variable. The pseudo-elasticity is defined as

$$E_{x_n}^{\Pr_n(i)} = \frac{\exp[\Delta(\beta_i \mathbf{X}_n)]\sum_{I} \exp(\beta_i x_n)}{\exp[\Delta(\beta_i \mathbf{X}_n)] \sum_{I=I_n} \exp(\beta_i x_n) + \sum_{I \neq I_n} \exp(\beta_i \mathbf{X}_n)} - 1, \tag{7}$$

where all the variables are as previously defined.

The elasticities for some key severity determinants are shown in Table 2 for the single occupant non-truck-involved accidents (the estimation results of the rest of

[4] A truck is defined as a single unit or combination truck exceeding 44.5 kN in gross vehicle weight.

[5] We will present a statistical test later in the paper that justifies the estimation of separate models for truck- and non-truck-involved injury severities.

[6] It can be shown that the sequential estimation technique results in an underestimation of the standard errors of the estimated model coefficients. Studies have shown that this results in about a 10–15% overestimation in the t-statistics. Thus some caution should be exercised in interpreting our forthcoming model results with regard to the significance of the estimated coefficients.

Table 1
Estimation of probabilities of accident severity conditioned on single-occupant vehicles for non-truck-involved accidents

Variable[a]	Estimated coefficient	(t-statistic)
Constant [PI]	−3.002	(−12.11)
Constant [I/F]	−3.821	(−20.15)
Roadway characteristics		
Interstate functional classification indicator (1 if accident occurred on interstate, 0 otherwise) [PDO]	0.010	(2.23)
Rural location indicator (1 if accident occurred in rural area, 0 in urban area) [PDO, PI]	−0.418	(−2.05)
35 mph (56 km/h) posted speed indicator (1 if the posted speed limit was 35 mph (56 km/h) or less, 0 otherwise) [PDO]	0.173	(2.90)
Temporal characteristics		
Winter indicator (1 if accident occurred in December, January and February, 0 otherwise) [PDO, I/F]	0.109	(1.87)
Weekend indicator 1 (1 if accident occurred during weekend, 0 otherwise) [PDO]	0.136	(1.93)
Weekend indicator 2 (1 if accident occurred during weekend, 0 otherwise) [I/F]	0.280	(2.52)
Rush hour indicator 1 (1 if accident occurred in the rush hours, 0 otherwise) [PI]	−0.096	(−1.90)
Rush hour indicator 2 (1 if accident occurred in the rush hours, 0 otherwise) [I/F]	−0.253	(−2.57)
Night time indicator (1 if accident occurred in night time, 0 otherwise) [I/F]	0.448	(4.47)
Environmental characteristics		
Dry road surface indicator 1 (1 if accident occurred on a dry roadway surface, 0 otherwise) [PDO]	0.082	(1.54)
Dry road surface indicator 2 (1 if accident occurred on a dry roadway surface, 0 otherwise) [I/F]	0.216	(2.32)
Driver characteristics		
Driver resident proximity (1 if driver is residing within 15 miles (24 km) and driver was most severely injured occupant, 0 otherwise) [PI, I/F]	0.114	(1.69)
Gender indicator (1 if driver was female and driver was most severely injured occupant, 0 otherwise) [PDO]	−0.547	(−11.85)
Young age indicator (1 if driver is at age of 25 or younger and driver was most severely injured occupant, 0 otherwise) [PDO, I/F]	0.097	(1.62)
Old age indicator (1 if driver is at age of 65 or older and driver was most severely injured occupant, 0 otherwise) [PDO, I/F]	0.382	(3.01)
Driver restraint system indicator 1 (1 if no restraint system was used and driver was most severely injured occupant, 0 otherwise) [PI]	1.063	(7.83)
Driver restraint system indicator 2 (1 if no restraint system was used and driver was most severely injured occupant, 0 otherwise) [I/F]	1.782	(12.16)
Alcohol-impaired driving indicator (1 if driver had been drinking and ability impaired and driver was most severely injured occupant, 0 otherwise) [I/F]	0.784	(5.26)
Vehicle characteristics		
Passenger car indicator (1 if vehicle involved in the accident was a passenger car, 0 otherwise) [PI]	0.902	(4.05)
Small truck indicator 1 (1 if vehicle involved in the accident was a small truck or a pickup truck, 0 otherwise) [PDO]	−0.552	(−2.45)
Small truck indicator 2 (1 if vehicle involved in the accident was a small truck or a pickup truck, 0 otherwise) [I/F]	−0.920	(−3.82)
Accident characteristics		
Number of vehicles involved in the accident 1 [PI]	0.193	(5.87)
Number of vehicles involved in the accident 2 [I/F]	0.343	(6.96)
Driver ejection indicator (1 if driver was partially or totally ejected, 0 otherwise) [I/F]	3.279	(2.95)
Pole struck indicator (1 if sign post or utility pole was struck in the accident, 0 otherwise) [I/F]	0.694	(2.44)
Off roadway indicator (1 if accident occurred off the road, 0 otherwise) [PI, I/F]	1.029	(10.42)
Going straight indicator (1 if accident occurred when the vehicle was going straight, 0 otherwise) [PDO, PI]	−0.415	(−4.30)
Right turn indicator (1 if accident occurred when the vehicle was making right turn, 0 otherwise) [PDO]	0.621	(2.59)
Stopped for traffic indicator (1 if accident occurred when the vehicle was stopped for traffic, 0 otherwise) [PDO]	−0.692	(−8.79)
Stopped at signal or stop sign indicator (1 if accident occurred when the vehicle was stopped at signal or stop sign, 0 otherwise) [PDO]	−0.544	(−3.82)
Changing lane indicator (1 if accident occurred when the vehicle was changing lanes, 0 otherwise) [PI]	−0.239	(−1.48)
Slowing indicator (1 if accident occurred when the vehicle was slowing, 0 otherwise) [PI, I/F]	0.566	(6.92)
Merging indicator (1 if accident occurred when the vehicle was entering traffic, 0 otherwise) [PI]	−0.475	(−1.25)
Speeding indicator (1 if 'exceeding reasonably safe speed' was the primary cause, 0 otherwise) [PDO, I/F]	0.530	(6.36)
Following too closely indicator (1 if 'following too closely' was the primary cause, 0 otherwise) [PDO]	0.808	(8.54)
Failing to grant right of way indicator 1 (1 if 'didn't grant right of way to vehicle' was the primary cause, 0 otherwise) [PDO]	0.518	(3.84)

Table 1 (*Continued*)

Variable[a]	Estimated coefficient	(t-statistic)
Failing to grant right of way indicator 2 (1 if 'didn't grant right of way to vehicle' was the primary cause, 0 otherwise) [I/F]	0.944	(4.37)
Inattention indicator (1 if 'inattention' was the primary cause, 0 otherwise) [PI, I/F]	−0.626	(−4.71)
Defective equipment indicator (1 if 'operating defective equipment' was the primary cause, 0 otherwise) [PI, I/F]	−0.704	(−2.85)
Same-direction sideswipe indicator (1 if the collision type was same-direction sideswipe, 0 otherwise) [PDO, PI]	1.297	(6.22)
Rear end indicator 1 (1 if the collision type was rear end, 0 otherwise) [PDO]	0.443	(3.79)
Rear end indicator 2 (1 if the collision type was rear end, 0 otherwise) [PI]	0.739	(6.15)
Entering/leaving driveway indicator 1 (1 if accident occurred when vehicle collided with other vehicle entering or leaving driveway, 0 otherwise) [PDO]	0.717	(2.87)
Entering/leaving driveway indicator 2 (1 if accident occurred when vehicle collided with other vehicle entering or leaving driveway, 0 otherwise) [PI]	1.057	(3.96)
Opposite direction angle collision indicator 1 (1 if the collision type was opposite-direction angle collision, 0 otherwise) [PI]	0.658	(5.05)
Opposite direction angle collision indicator 2 (1 if the collision type was opposite-direction angle collision, 0 otherwise) [I/F]	0.436	(2.48)
Number of observations		12 172
Log-likelihood at zero		−13 372
Log-likelihood at convergence		−7829.8
ρ^2		0.41

[a] Characters in the brackets indicate variables defined for: [PDO] property damage only, [PI] possible injury, [I/F] injury/fatality.

the conditional lower nest models are not shown due to space limitation, see Chang, 1997). The values in this table can be readily interpreted. For example, the elasticity for the functional classification variable shown in Table 2 for a single-occupant vehicle is 0.027 for property damage only. This means that, given a single-occupant vehicle is involved in an accident, the involved single occupant, the driver, is 2.7% more likely to have property damage only if the accident occurs on an interstate highway. As shown in these tables, driver restraint systems, driver ejection, and alcohol-impaired driving can increase likelihood of having an injury dramatically. For example, the elasticity for the driver restraint systems variable shown in Table 2 is 1.174 for possible injury and 3.692 for injury/fatality. This means that, given a single-occupant vehicle is involved in an accident, the involved driver is two times more likely (a 117.4% increase in the probability) to have a possible injury and about four times more likely (a 369.2% increase in the probability) to have a injury/fatality if a restraint system is not used. The driver ejection variable shows an 1134.0% increase in the probability of the driver being injured or killed.

Finally, Table 3 presents the estimation results of the overall model (upper nest). The inclusive value coefficients are 0.247, 0.249, 0.198, and 0.230 for one, two, three, and four or more occupant vehicles respectively and all these coefficients are significantly different from zero and one. This provides a statistical validation of the nested logit structure.

5.2. *Truck-involved accidents*

Table 4 shows maximum likelihood estimation results of the conditional lower nest models (i.e. conditioned on occupancy level) for accidents that involve a truck and corresponding elasticity estimates are given in Table 5 (the estimation results of the rest of the conditional lower models are not shown due to space limitations, see Chang, 1997). Due to the lower number of truck-involved accidents in our database, we were only able to estimate severity models for two occupancy levels (single occupant, and two or more occupants). Finally, Table 6 gives the overall model estimates (upper nest). The inclusive value coefficients are 0.472, and 0.231 for one, and two or more occupant vehicles respectively and these coefficients are significantly different from zero and one. This again provides support for the nested logit structure.

Because of the lower number of observations relative to non-truck-involved accidents, the number of variables found statistically significant in the truck-involved accident model are fewer than the number found in the non-truck-involved accident model. It is interesting that most of the variables determining injury severity, in terms of their tendency, give generally similar findings between truck- and non-truck-involved accidents. The difference in injury level of the most severely injured occupant between these two types of accidents is largely reflected by specific accident characteristics. Some variables implicitly capture the effects of trucks on injury severity. For example, 55 mph (88 km/h) speed limit indicator was not found to be statistically significant in the non-truck-involved accident model but was statistically significant in truck-involved accident model giving an increased likelihood of possible injury and injury/fatality. However, in non-truck-involved accidents a functional indicator variable, which is correlated with this speed limit variable, showed an increased likelihood of no injury. With greater vehicle weight, longer stopping distance, and high speeds, truck-involved collisions are expected to result in severe injury. This finding suggests that higher speed limits have potential impacts on severity levels for accidents with truck involvement but less of an impact on accidents without truck involvement.

Table 2
Elasticity estimates for key variables conditioned on single-occupant vehicles for non-truck-involved accidents

Variable[a]	Elasticity
Interstate functional classification indicator [PDO]	0.027
Rural location indicator [PDO, PI]	−0.031
35 mph (56 km/h) posted speed indicator [PDO]	0.043
Winter indicator [PDO, I/F]	0.025
Weekend indicator 1 [PDO]	0.034
Weekend indicator 2 [I/F]	0.297
Rush hour indicator 1 [PI]	−0.075
Rush hour indicator 2 [I/F]	−0.212
Night time indicator [I/F]	0.512
Dry road surface indicator 1 [PDO]	0.067
Dry road surface indicator 2 [I/F]	0.198
Driver resident proximity indicator [PI, I/F]	0.088
Gender indicator [PDO]	−0.150
Young age indicator [PDO, I/F]	0.018
Old age indicator [PDO, I/F]	0.066
Driver restraint system indicator 1 [PI]	1.174
Driver restraint system indicator 2 [I/F]	3.692
Alcohol-impaired driving indicator [I/F]	1.044
Passenger car indicator [PI]	0.956
Small truck indicator 1 [PDO]	−0.152
Small truck indicator 2 [I/F]	−0.584
Number of vehicles involved in the accident 1 [PI]	0.360
Number of vehicles involved in the accident 2 [I/F]	0.753
Driver ejection indicator [I/F]	11.340
Pole struck indicator [I/F]	0.887
Off roadway indicator [PI, I/F]	0.973
Going straight indicator [PDO, PI]	−0.031
Right turn indicator [PDO]	0.140
Stopped for traffic indicator [PDO]	−0.193
Stopped at signal or stop sign indicator [PDO]	−0.149
Changing lane indicator [PI]	−0.179
Slowing indicator [PI, I/F]	0.487
Merging indicator [PI]	−0.329
Speeding indicator [PDO, I/F]	0.087
Following too closely indicator [PDO]	0.175
Failing to grant right of way indicator 1 [PDO]	0.119
Failing to grant right of way indicator 2 [I/F]	1.352
Inattention indicator [PI, I/F]	−0.390
Defective equipment indicator [PI, I/F]	−0.428
Same-direction sideswipe indicator [PDO, PI]	0.054
Rear end indicator 1 [PDO]	0.104
Rear end indicator 2 [PI]	0.749
Entering/leaving driveway indicator 1 [PDO]	0.158
Entering/leaving driveway indicator 2 [PI]	1.165
Opposite direction angle collision indicator 1 [PI]	0.652
Opposite direction angle collision indicator 2 [I/F]	0.496

[a] Characters in the brackets indicate variables defined for: [PDO] property damage only, [PI] possible injury, [I/F] injury/fatality.

Two other variables, vehicles making right turns and vehicles making left turns, are worthy of note. For non-truck-involved accidents, the left turn variable is statistically insignificant and right turn variable shows increased likelihood of property damage only. But for truck-involved accidents, the right-turn variable shows an increased likelihood of possible injury and the left-turn variable shows a decreased likelihood of property damage only and possible injury. Impact point and speed at collision are usually the most important factors in determining the severity outcome when a vehicle is making a turn. The impact points for vehicles making a turn are usually both sides of the vehicle. If a truck from either side strikes a car, the severity is expected to be high because of truck weight.

5.3. Additional comparisons of non-truck- and truck-involved accidents

The elasticities of the estimated models also provide insight into the difference between truck- and non-truck-involved accidents. Table 7 gives elasticity variables that are common to truck and non-truck-involved, single occupant injury-severity models.

This table shows that accidents involving trucks almost always have higher elasticities (absolute value) relative to accidents that do not involve trucks. For example, the increase in probability of an injury or fatality for drivers not using a restraint system was about twice as high if a truck was involved in the accident (a 369 vs 738%). In opposite direction angle collisions, accidents involving trucks had an increase in the probability of an injury or fatality that was almost five times as high as the increase for non-truck-involved accidents (49.6 vs 229.1%). And, for accidents that occurred on dry roads, the probability of an injury or fatality was 19.8% higher for non-truck accidents (relative to all other road conditions) and 84.2% higher for truck-involved accidents, making the relative increase over four times higher for truck-involved accidents. One notable exception to the higher elasticities for truck-involved accidents is for accidents that occur during the night. For these accidents, the probability increases are virtually identical with non-truck-involved accidents having a 51.2% higher probability of an injury or fatality and truck-involved accidents have a 50% higher probability of an injury or fatality. These findings, for the most part, show dramatic differences in the extent to which specific factors affect the probability of

Table 3
Estimation of overall nested logit model of accident severity for non-truck-involved accidents

Variable[a]	Estimated coefficient	(t-statistic)
Constant [2]	−1.745	(−28.22)
Constant [3]	−3.469	(−36.22)
Constant [4+]	−3.895	(−27.16)
Roadway characteristics		
Rural location indicator 1 (1 if accident occurred in rural area, 0 in urban area) [2]	0.986	(8.65)
Rural location indicator 2 (1 if accident occurred in rural area, 0 in urban area) [3, 4+]	1.528	(11.97)
Interstate highway 5 indicator (1 if accident occurred on Interstate highway 5, 0 otherwise) [3, 4+]	0.179	(2.85)
Interstate highway 90 indicator (1 if accident occurred on Interstate highway 90, 0 otherwise) [1]	0.259	(2.97)
Interstate highway 405 indicator (1 if accident occurred on Interstate highway 405, 0 otherwise) [1]	0.227	(3.82)
Temporal characteristics		
Spring indicator (1 if accident occurred in March, April and May, 0 otherwise) [1]	0.097	(2.05)
Summer indicator (1 if accident occurred in June, July and August, 0 otherwise) [4+]	0.314	(3.12)
Autumn indicator (1 if accident occurred in September, October and November, 0 otherwise) [1]	0.068	(1.54)
Weekend indicator 1 (1 if accident occurred during weekend, 0 otherwise) [2]	0.761	(15.61)
Weekend indicator 2 (1 if accident occurred during weekend, 0 otherwise) [3]	0.868	(10.72)
Weekend indicator 3 (1 if accident occurred during weekend, 0 otherwise) [4+]	1.145	(12.74)
Rush hour indicator (1 if accident occurred in the rush hours, 0 otherwise) [1]	0.181	(4.66)
Night time indicator (1 if accident occurred in night time, 0 otherwise) [4+]	0.244	(2.58)
Environmental characteristics		
Clear/cloudy weather indicator 1 (1 if accident occurred in the clear or cloudy weather condition, 0 otherwise) [1]	0.117	(1.17)
Clear/cloudy weather indicator 2 (1 if accident occurred in the clear or cloudy weather condition, 0 otherwise) [2, 3]	0.324	(3.03)
Driver characteristics		
Gender indicator (1 if driver was female, 0 otherwise) [2]	−0.076	(−1.61)
Young age indicator 1 (1 if driver is at age of 25 or younger, 0 otherwise) [2]	0.455	(9.45)
Young age indicator 2 (1 if driver is at age of 25 or younger, 0 otherwise) [3]	0.659	(8.35)
Young age indicator 3 (1 if driver is at age of 25 or younger, 0 otherwise) [4+]	0.218	(2.24)
Old age indicator 1 (1 if driver is at age of 65 or older, 0 otherwise) [1]	0.325	(1.98)
Old age indicator 2 (1 if driver is at age of 65 or older, 0 otherwise) [2]	1.004	(5.84)
Vehicle characteristics		
Passenger car indicator 1 (1 if vehicle involved in the accident was a passenger car, 0 otherwise) [2]	0.306	(4.99)
Passenger car indicator 2 (1 if vehicle involved in the accident was a passenger car, 0 otherwise) [3, 4+]	0.558	(6.22)
Small truck indicator (1 if vehicle involved in the accident was a small truck or a pickup truck, 0 otherwise) [4+]	0.364	(2.99)
Nested logit structure statistics		
Inclusive value of vehicles with 1 occupant [1]	0.247	(5.36)
Inclusive value of vehicles with 2 occupants [2]	0.249	(4.91)
Inclusive value of vehicles with 3 occupants [3]	0.198	(4.15)
Inclusive value of vehicles with 4 + occupants [4+]	0.230	(2.29)
Number of observations		16 394
Log-likelihood at zero		−22 727
Log-likelihood at convergence		−12 427
ρ^2		0.45

[a] Numbers in the brackets indicate variables defined for: [1] single−occupant vehicles, [2] two-occupant vehicles, [3] three-occupant vehicles, [4+] 4 or more occupant vehicles.

various injury outcomes for truck- and non-truck-involved accidents. From a policy perspective, these differences can be used to point the direction for future accident countermeasures. For example, the importance of driver restraints in preventing injuries or fatalities is important in both truck- and non-truck-involved accidents but plays a much bigger role when a truck is involved in an accident. Public awareness campaigns that stress this point may have some value in increasing seat and shoulder belt usage.

Another way to examine the effects of trucks on most severe occupant injury is to conduct an enumeration analysis to compare the level of injury of the most severely injured vehicle occupant for an accident under the same circumstances, with and without the involvement of a truck. This kind of analysis is particularly

Table 4
Estimation of probabilities of accident severity conditioned on single-occupant vehicles for truck-involved accidents

Variable[a]	Estimated coefficient (t-statistic)	
Constant [PI]	−5.563	(−10.39)
Constant [I/F]	−5.549	(−8.06)
Roadway characteristics		
Rural location indicator (1 if accident occurred in rural area, 0 in urban area) [PI]	−1.093	(−1.68)
55 mph (88 km/h) posted speed indicator (1 if the posted speed limit was 55 mph (88 km/h) or higher, 0 otherwise) [PI, I/F]	1.060	(3.38)
Temporal characteristics		
Weekend indicator (1 if accident occurred during weekend, 0 otherwise) [PDO]	0.737	(1.57)
Rush hour indicator (1 if accident occurred in the rush hours, 0 otherwise) [PI]	−0.524	(−2.17)
Night time indicator (1 if accident occurred in night time, 0 otherwise) [PI, I/F]	0.509	(2.03)
Environmental Characteristics		
Dry road surface indicator (1 if accident occurred on a dry roadway surface, 0 otherwise) [I/F]	0.641	(1.58)
Driver characteristics		
Driver resident proximity (1 if driver is residing within 15 miles (24 km) and driver was most severely injured occupant, 0 otherwise) [I/F]	1.286	(2.60)
Gender indicator (1 if driver was female and driver was most severely injured occupant, 0 otherwise) [I/F]	0.850	(2.44)
Young age indicator (1 if driver is at age of 25 or younger and driver was most severely injured occupant, 0 otherwise) [PI]	0.580	(2.01)
Driver restraint system indicator (1 if no restraint system was used and driver was most severely injured occupant, 0 otherwise) [I/F]	2.407	(4.39)
Vehicle characteristics		
Passenger car indicator (1 if vehicle involved in the accident was a passenger car, 0 otherwise) [PI]	2.271	(7.95)
Small truck indicator (1 if vehicle involved in the accident was a small truck or a pickup truck, 0 otherwise) [PI]	1.853	(5.31)
Truck indicator (1 if vehicle involved in the accident was a truck or a tractor-trailer, 0 otherwise) [PDO, PI]	1.695	(3.57)
Accident characteristics		
Number of vehicles involved in the accident [PI]	0.534	(3.79)
Off roadway indicator (1 if accident occurred off the road, 0 otherwise) [I/F]	2.502	(4.37)
Right turn indicator (1 if accident occurred when the vehicle was making right turn, 0 otherwise) [PI]	1.098	(1.47)
Left turn indicator (1 if accident occurred when the vehicle was making left turn, 0 otherwise) [PDO, PI]	−1.490	(−1.97)
Speeding indicator (1 if 'exceeding reasonably safe speed' was the primary cause, 0 otherwise) [I/F]	0.709	(1.67)
Failing to grant right of way indicator (1 if 'didn't grant right of way to vehicle' was the primary cause, 0 otherwise) [PI]	−0.917	(−2.26)
Inattention indicator (1 if 'inattention' was the primary cause, 0 otherwise) [PI, I/F]	−0.917	(−1.36)
Defective equipment indicator (1 if 'operating defective equipment' was the primary cause, 0 otherwise) [PI]	1.876	(3.15)
Rear end indicator (1 if the collision type was rear end, 0 otherwise) [PI, I/F]	0.737	(3.33)
Entering/leaving driveway indicator (1 if accident occurred when vehicle collided with other vehicle entering or leaving driveway, 0 otherwise) [PI]	1.462	(1.71)
Opposite direction angle collision indicator (1 if the collision type was opposite-direction angle collision, 0 otherwise) [PI, I/F]	1.585	(2.03)
Number of observations		967
Log-likelihood at zero		−1062.4
Log−likelihood at convergence		−431.97
ρ^2		0.59

[a] Characters in the brackets indicate variables defined for: [PDO] property damage only, [PI] possible injury, [I/F] injury/fatality.

interesting because it allows one to compare the injury severity directly caused by trucks while accounting for all other variables such as environment factors, driver characteristics, and accident characteristics. A simple way to do such an enumeration analysis is to apply the severity models (i.e. lower nests) for non-truck-involved accidents to predict severity for the truck-involved accidents (i.e. what would have been the severity if a truck had not been involved). This will estimate severity for the truck-involved accidents as if there had been no truck involved in the accident. Conversely, severity models (i.e. lower nests) for the truck-involved accidents can also be applied to predict severity for the non-truck-involved accidents (i.e. what would have been the severity if a truck had been involved). This will estimate severity for non-truck-involved accidents as if there had been a truck involved in the accident.

The results of the enumeration analysis are shown Tables 8 and 9. Table 8 shows the predicted severity for truck-involved accidents as if there had been no truck involved. This table shows that the level of injury of the most severely injured vehicle occupant is significantly reduced if there had been no truck involved in the accident, except for three occupant vehicles[7]. For example, for the single occupant vehicles, the actual distribution of severity is 81.7, 13 and 5.3% for property damage only, possible injury and injury/fatality, respectively. But if there was no truck involved in the accident, property damage only accidents would increase from 81.7 to 83.9% but possible injury and injury/fatal accidents would decrease to 11.3 and 4.8%.

Table 5
Elasticity estimates for key variables conditioned on single-occupant vehicles for truck-involved accidents

Variable[a]	Elasticity
Rural location indicator [PI]	−0.628
55 mph (88 km/h) posted speed indicator [PI, I/F]	1.271
Weekend indicator [PDO]	0.121
Rush hour indicator [PI]	−0.372
Night time indicator [PI, I/F]	0.500
Dry road surface indicator [I/F]	0.842
Driver resident proximity [I/F]	2.258
Gender indicator [I/F]	1.204
Young age indicator [PI]	0.636
Driver restraint system indicator [I/F]	7.378
Passenger car indicator [PI]	4.868
Small truck indicator [PI]	3.382
Truck indicator [PDO, PI]	0.055
Number of vehicles involved in the accident [PI]	1.022
Off roadway indicator [I/F]	8.034
Right turn indicator [PI]	1.484
Left turn indicator [PDO, PI]	−0.122
Speeding indicator [I/F]	0.938
Failing to grant right of way indicator [PI]	−0.562
Inattention indicator [PI, I/F]	−0.542
Defective equipment indicator [PI]	3.455
Rear end indicator [PI, I/F]	0.786
Entering/leaving driveway indicator [PI]	2.286
Opposite direction angle collision indicator [PI, I/F]	2.291

[a] Characters in the brackets indicate variables defined for: [PDO] property damage only, [PI] possible injury, [I/F] injury/fatality.

[7] Both three and four occupant results should be viewed with some caution due to the low number of observations.

Table 9 shows the predicted severity for non-truck-involved accidents as if there had been at least one truck involved. For the single-occupant vehicles, if there is a truck involved in the accident, property damage accidents will decrease from 74.6 to 64.5%, while possible injury accident will increase from 19.0 to 23.5% and injury/fatal accidents will increase from 6.4 to 12%. This increased severity is also found for multi-occupant vehicles. It is also interesting to note that truck involvement has greater impact on multi-occupant vehicles than single-occupant vehicles showing not only the relationship between severity and vehicle occupancy but also the impact that large trucks on severity due to increased occupant 'exposure' as measured by the number of vehicle occupants.

6. Model specification tests

One concern with our study is the statistical justification for separately estimating truck and non-truck involved accidents. To test the validity of this model structure, a likelihood ratio test was conducted to test the significance of the difference between a constrained model (i.e. one combined model for all vehicles) and an unconstrained model (two separate models, one for non-truck-involved accidents and the other for truck-involved accidents). The likelihood ratio test statistic is,

$$-2[\mathrm{L_N}(\beta) - \mathrm{L_{Nnt}}(\beta^{nt}) - \mathrm{L_{Nt}}(\beta^{t})], \tag{8}$$

where $\mathrm{L}_N(\beta)$ is the log-likelihood at convergence of the model estimated on all data, N, with a single coefficient vector β, $\mathrm{L}_{N\mathrm{nt}}(\beta^{\mathrm{nt}})$ is the log-likelihood at convergence of the model estimated on the non-truck (nt) subset of the data, and $\mathrm{L}_{N\mathrm{t}}(\beta^{\mathrm{t}})$ is the log-likelihood at convergence of the model estimated on the truck (t) subset of the data. This test statistic is χ^2 distributed with the degrees of freedom equal to the sum of the number of estimated coefficients in truck and non-truck models minus the number of coefficients in the model estimated on all data (both truck and non-truck).

The results of the test indicate that there is significant difference of severity likelihoods between truck-involved accidents and non-truck-involved accidents ($P < 0.001$) for single-occupant vehicles ($\chi^2 = 97.34$, degrees of freedom = 50). The test results do not show significant differences in severity likelihoods between truck-involved accidents and non-truck-involved accidents for two or more occupant vehicles ($\chi^2 = 57.06$, degrees of freedom = 46, $P = 0.127$, for two occupants; $\chi^2 = 9.90$, degrees of freedom = 28, $P = 0.999$, for three occupants; $\chi^2 = 11.42$, degrees of freedom =

Table 6
Estimation of overall nested logit model of accident severity for truck-involved accidents

Variable[a]	Estimated coefficient	(t-statistic)
Constant [2+]	−1.719	(−8.58)
Roadway characteristics		
Rural location indicator (1 if accident occurred in rural area, 0 in urban area) [2+]	0.601	(1.96)
Interstate highway 405 indicator (1 if accident occurred on Interstate highway 405, 0 otherwise) [1]	0.317	(1.16)
Temporal characteristics		
Weekend indicator (1 if accident occurred during weekend, 0 otherwise) [2+]	1.011	(3.13)
Autumn indicator (1 if accident occurred in September, October and November, 0 otherwise) [1]	0.244	(1.23)
Driver characteristics		
Gender indicator (1 if driver was female, 0 otherwise) [2+]	0.291	(1.37)
Young age indicator (1 if driver is at age of 25 or younger, 0 otherwise) [2+]	0.869	(3.73)
Old age indicator (1 if driver is at age of 65 or older, 0 otherwise) [2+]	0.914	(2.42)
Vehicle characteristics		
Truck indicator (1 if vehicle involved in the accident was a truck or a tractor-trailer, 0 otherwise)	0.876	(2.27)
Nested logit structure statistics		
Inclusive value of vehicles with 1 occupant [1]	0.472	(2.19)
Inclusive value of vehicles with 2 or more occupants [2+]	0.231	(2.71)
Number of observations		1079
Log-likelihood at zero		−747.91
Log-likelihood at convergence		−412.06
ρ^2		0.45

[a] Numbers in the brackets indicate variables defined for: [1] single-occupant vehicles, [2+] 2 or more occupant vehicles.

25, $P = 0.990$, for four or more occupants). This finding is likely due to there being too few observations of two or more occupant vehicles in truck-involved accidents (only 177, 32, and 13, for two, three, and four or more occupants, respectively). The significant difference in the single-occupant model supports the contention that truck and non-truck involved accidents should be modeled separately.

7. Summary and discussion

Data were collected from reported traffic accidents occurring on principal arterials, state highways, and interstate highways in King County, Washington during 1994. To account for vehicle occupancy effects that influence the level of injury sustained by the most severely injured vehicle occupant, this study applied nested logit modeling techniques to study injury severity conditioned on different vehicle occupancies. The results demonstrate that nested logit modeling of the injury sustained by the most severely injured vehicle occupant accounts for vehicle occupancy effects and thereby provides additional insight into the factors determining accident severity. This represents an important methodological step in studying traffic accident-injury severity. The findings obtained here, by exploring a broad range of variables including characteristics of individual, environment, vehicle, accident, and others, provide a better understanding the underlying relationships between risk factors and accident-injury severity for truck-involved and non-truck-involved accidents.

The comparison of the factors determining accident-injury severity between truck-involved accidents and non-truck-involved accidents showed that the difference in severity likelihoods between these two types of accidents is influenced by a variety of variables. The comparison results indicate that several variables which significantly increase injury severity were found only for truck-involved accidents, including high speed limits, and accidents occurring when a vehicle is making right or left turn, rear-end type of collision. An elasticity analysis of a number of variables common to both truck-involved and non-truck-involved accidents revealed that such variables generally had a much bigger impact on injury/fatality probabilities in the truck-involved case. This underscores the importance that specific countermeasures (e.g. increased use of diver restraint systems) can assume when trucks are involved. In addition, an enumeration analysis, designed to examine the direct effects of trucks on accident severity, indicated that accident-injury severity is noticeably worsened if the accident has a truck involved. The results further indicate that the effects of trucks on accident-injury severity are more significant for multi-occupant vehicles than single-occupant vehicles.

In terms of future work, an application of the methodological approach used in this paper to a more expansive database would be valuable. The small number of observations of multi-occupant vehicles in truck-involved accidents made separate models with the same specification impossible for truck-involved accidents and non-truck-involved accidents. It is hoped that a similar study could be conducted with data that include a large number of multi-occupant vehicles for truck-involved accidents. This would allow a more comprehensive comparison of accident characteristics between truck-involved accidents and non-truck-involved accidents.

In addition, there has been a long argument about the safety issues relating to different types of trucks, especially singles and twins. It would be quite interesting for future studies, using a larger database, to apply nested logit modeling techniques to explore the factors that affect the severity levels for the accidents involving different types of trucks (i.e. conditioned on different types of trucks for this case). This would be helpful in improving truck safety as well as guiding regulations for large trucks.

Table 7
Elasticity comparisons of common variables for single-occupant vehicles for truck- and non-truck-involved accidents

Variable[a]	Non-truck-elasticity	Truck-elasticity
Rural location indicator [PI]	−0.031	−0.628
Weekend indicator [PDO]	0.034	0.121
Rush hour indicator [PI]	−0.075	−0.372
Night time indicator [I/F]	0.512	0.500
Dry road indicator [I/F]	0.198	0.842
Driver resident proximity [I/F]	0.088	2.258
Driver restraint system [I/F]	3.692	7.378
Passenger car indicator [PI]	0.956	4.868
Number of vehicles involved in the accident [PI]	0.360	1.022
Off roadway indicator [I/F]	0.973	8.034
Speeding indicator [I/F]	0.870	0.938
Inattention indicator [PI, I/F]	−0.390	−0.542
Defective equipment indicator [PI]	−0.428	3.455
Rear end indicator [PI]	0.749	0.786
Entering/leaving driveway indicator [PI]	1.165	2.286
Opposite direction angle collision indicator [PI]	0.652	2.291
Opposite direction angle collision indicator [I/F]	0.496	2.291

[a] Characters in the brackets indicate variables defined for: [PDO] property damage only, [PI] possible injury, [I/F] injury/fatality.

Table 8
The distribution of predicted accident severity for truck-involved accidents by the enumeration analysis

	Predicted by non-truck model	Actual distribution
Single-occupant		
Property damage only	83.9%	81.7%
Possible Injury	11.3%	13.0%
Injury/fatality	4.8%	5.3%
Number of observations	917	917
Two occupants		
Property damage only	73.0%	67.5%
Possible Injury	19.6%	23.9%
Injury/fatality	7.4%	8.6%
Number of observations	117	117
Three occupants		
Property damage only	64.7%	68.8%
Possible Injury	25.5%	15.6%
Injury/fatality	9.7%	15.6%
Number of observations	32	32
Four or more occupants		
Property damage only	63.3%	38.5%
Possible Injury	23.8%	46.2%
Injury/fatality	12.8%	15.4%
Number of observations	13	13

Table 9
The distribution of predicted accident severity for non-truck-involved accidents by the enumeration analysis

	Predicted by truck model	Actual distribution
Single occupant		
Property damage only	64.5%	74.6%
Possible Injury	23.5%	19.0%
Injury/fatality	12.0%	6.4%
Number of observations	12 172	12 172
Two or more occupants		
Property damage only	42.0%	58.5%
Possible Injury	35.9%	28.9%
Injury/fatality	22.1%	12.6%
Number of observations	4222	4222

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