INVESTIGATION OF INIJURY SEVERITIES OF TRUCK DRIVERS ON RURAL HIGHWAYS

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Submitted to the 3rd International Conference on Road Safety and Simulation, 14 September 14-16, 2011, Indianapolis, USA

Note: This paper is NOT pursing possible publication on any journal

ABSTRACT

Trucks are often involved in single-vehicle (SV) accidents in addition to multi-vehicle (MV) accidents in adverse driving conditions, such as inclement weather and/or complex terrain. Ten-year accident data involving trucks on rural highway from the Highway Safety Information System (HSIS) is studied to investigate the difference in driver-injury severity between SV and MV accidents by using mixed logit models. Injury severity from SV and MV accidents involving trucks on rural highways is modeled separately and their respective critical risk factors such as driver, vehicle, temporal, roadway, environmental and accident characteristics are evaluated. It is found that there exists substantial difference between the impacts from a variety of variables on the driver-injury severity in MV and SV accidents. By conducting the injury severity study for MV and SV accidents involving trucks separately, some new or more comprehensive observations, which have not been covered in the existing studies can be made. Estimation findings indicate that the snow road surface and light traffic indicators will be better modeled as random parameters in SV and MV models respectively. As a result, the complex interactions of various variables and the nature of truck-driver injury are able to be disclosed in a better way.

Keywords: **t**rucks; injury severity; rural highway; mixed logit model

INTRODUCTION

Truck drivers experience significantly higher risk of suffering serious injury and fatality than passenger vehicle drivers (USDOT 2005). In the United States, commercial truck drivers face huge risk of injury and death from crashes – as much as 7 times more likely to die and 2.5 times more likely to suffer an injury than the average worker (NIOSH 2007). Given the high number of trucks on highways around the country every day, how to protect truck drivers from serious

injury in traffic crashes has become not only an occupational safety issue, but also critical to the overall traffic safety and efficiency of the highway network as a whole in the nation.
It is known that SV and MV accidents have different mechanisms of occurrence (Chen and Chen, 2010; Baker, 1991), critical risk factors (Savolainen and Mannering, 2007) and accordingly different injury mitigation strategies (NIOSH, 2007). Although the absolute number of SV accidents is often lower than that of MV accidents, SV accidents usually result in more serious injury (The National Academies, 2006). For example, SV accidents were responsible for 57.8% of all crash fatalities in 2005 (USDOT, 2005). Therefore, to investigate injury severity and associated risk factors in both SV and MV accidents of trucks is crucial to implementing more effective injury prevention strategy for truck drivers in their daily work. Moreover, the findings from such an investigation will provide scientific basis to improve the current highway design and traffic management policy, and propose next-generation safety initiatives in order to reduce the injury severity, live and financial losses of truck-involved accidents.

Different from a number of studies on accident frequencies (or rates), there are only limited studies specifically focusing on injury severity of truck drivers or occupancies in truck-involved accidents. Golob et al. (1987) and Alassar (1988) investigated the influence of some risk factors such as collision type, the number of involved vehicles and road class on injury severity of truck drivers using log-linear models. Chirachavala et al. (1984) studied the factors that increase accident severity for different truck types based on discrete multivariate analysis. Duncan (1998) studied the injury severity of passenger occupancy caused by truck-passenger-car rear-end collisions using ordered logit models. Chang and Mannering (1999) analyzed the accident severity of occupancy in truck-involved and non-truck-involved accidents using nested logit models. Some risk factors were found unique to truck-involved accidents. Khorashadi et al. (2005) compared the difference of driver-injury severities from truck-involved accidents in rural and urban roads using multinomial logit models. In addition to injury severity, there are also some studies focusing on the fatality of occupants related to trucks (Shibata and Fukuda, 1994; Lyman and Braver 2003). Most of the existing studies with a focus on severity of truck-involved accidents, as summarized above, covered all types of accidents as a whole without separating MV and SV accidents.

In recent years, there are a few studies which have started investigating injury severity from SV and MV accidents separately. For example, Kockelman and Kweon (2002) used ordered probit models to investigate injury severity in two-vehicle crashes and single-vehicle crashes datasets separately. They found that there is large difference of injury severity behavior for SV and MV accidents involving different vehicle types such as pickups and sport utility vehicles. In the work conducted by Ulfarsson and Mannering (2004), single-vehicle and two-vehicle accidents were studied using separate models because it was found a single model cannot accurately tell the different characteristics of these accidents. Savolainen and Mannering (2007) estimated the probabilistic models of motorcyclists' injury severity by separating SV and MV crashes using multinomial and nested logit models. Different risk factors on the injury severity of motorcyclists in SV ad MV crashes were found. In realizing the considerably different causality mechanisms of SV and MV accidents, some other studies investigated SV accidents only (e.g. Shankar and Mannering, 1996; Islam and Mannering, 2006). So far, however, no study has been reported on investigating the injury severity of truck drivers in SV and MV crashes separately. For thousands of truck drivers working around the country every day, the lack of such a vital piece of

knowledge may hinder efforts concerning injury prevention and traffic management on national highways.
Over the past ten years, various disaggregate models have been widely used to compare different datasets due to the unique advantages as compared to the previous methods. These advantages include being able to test a broad range of variables that influence injury severity and capture comprehensive disaggregate information about how the injury severity is influenced by these variables (Chang and Mannering, 1999). Some studies applied ordered logit (Duncan, 1998) or ordered probit models (Abdel-Aty, 2003) to investigate various risk factors associated with injury severity. Multinomial logit models (Ulfarsson and Mannering, 2004) and nested logit models (Chang and Mannering, 1999) have also been frequently used in order to obtain more detailed information about the influence of various risk factors on different injury severity levels.

Although multinomial logit models have been widely applied in injury severity studies during the past years, people find some limitations of this model such as (Jones and Hensher, 2007): (1) questionable assumptions associated with the IID (independently and identically distributed errors) condition and the IIA (independence of irrelevant alternatives) assumption condition; and (2) observed and unobserved heterogeneity in parameter effects are not considered. Most of the approaches used in the existing studies on truck driver injury severity were based on the assumption that the effects of all variables are fixed across observations. Mixed logit models, which can address these limitations and consider the random effects of variables, have recently been adopted in the studies on accident injury (e.g. Milton et al., 2008; Kim et al., 2010; Malyshkina and Mannering, 2010; Moore et al., 2010). With the promising potentials on injury studies as discussed above, mixed logit models will be adopted in the present study to investigate the injury severity of truck drivers in both SV and MV accidents. The complex interactions between roadway characteristics, driver characteristics, accident characteristics, temporal characteristics and environmental characteristics in both SV and MV accidents will be untangled

DATA DESCRIPTION

Highway Safety Information System (HSIS) is a database sponsored by Federal Highway Administration (FHWA) and has detailed traffic accident data from nine states across the United States which contains accident, roadway inventory, and traffic information. The 10-year (1991-2000) detailed accident data on rural highways in Illinois will be utilized in this study.

Three different truck types were classified in the Illinois HSIS database: single-unit truck, tractor with semi-trailer, and tractor without semi-trailer. After removing the accident records with insufficient accident information, there were in total 19,741 truck-involved accidents occurring on the rural highways in Illinois during the 10-year period, which include 6,891 SV accidents and 12,850 MV accidents (only count as one MV accident if there was more than one truck involved in an accident, and only the first truck involved will be considered).

The variable “driver extent of injury” defined in the HSIS database of Illinois is an indicator of driver-injury severity, which is defined as numerical scales from 1-5, representing no injury, possible injury, non-incapacitating injury, incapacitating injury and fatal, respectively. Out of a total of 6,891 SV accidents, 5,539 (80.4%) accidents had no injury, 214 (3.1%) accidents had possible injury, 754 (10.9%) accidents had non-incapacitating injury, 341 (5.0%) accidents had incapacitating injury and 43 (0.6%) accidents had fatal injury. Out of a total of 12,850 MV accidents, 11,811(91.9%) accidents had no injury, 314 (2.5%) accidents had possible injury, 451 (3.5%) accidents had non-incapacitating injury, 249 (1.9%) accidents had incapacitating injury and 25 (0.2%) accidents had fatal injury. In the present study the injury severity of truck drivers is grouped into three categories to ensure a sufficient number of observations are available in each category (it was otherwise not possible to make all five categories statistically different): (1) no injury (same as original Scale 1), (2) possible injury/non-incapacitating injury (including the original Scales 2 and 3), and (3) incapacitating injury/ fatal (including original Scales 4 and 5).

The HSIS data contains very detailed information related to truck-involved accidents, which can be separated into following groups such as roadway characteristics, driver characteristics, vehicle characteristics, temporal characteristics, environmental characteristics and accident characteristics. The specifications of some selected indicators for some groups are given as follows. Driver characteristics: the young driver (≤ 25 years old) and old driver (≥ 50 years old) indicator. Vehicle characteristics: the carrying hazardous material indicator shows if the truck is carrying hazardous material or not. Temporal characteristics: the rush hour indicator refers to the accidents occurring between 6:00 am and 9:59 am. Road characteristic: the light traffic indicator and Class I designated truck route indicator. The light traffic indicator implies that the AADT divided by the number of the lanes is less than or equal to 2,000. Illinois-designated truck routes include Class I designated truck route (approved for all load widths of 8 foot 6 inches or less), Class II designated truck route (approved for all load widths of 8 foot 6 inches or less and a wheel base no greater than 55 feet) and Class III designated truck route (approved for all load widths of 8 foot 0 inches or less and a wheel base no greater than 55 feet). Environmental characteristics: one example is the darkness light indicator, which shows that the light condition was dark when the accident occurred. Accident characteristics: for example, the ran off the roadway indicator suggests that the truck ran off the roadway when the accident happened. These indicators as shown above were selected in the present study based on the hypothesis that they would affect injury severity of truck drivers. The hypothesis of no significant difference from zero for each parameter of severity category will be tested using the likelihood ratio t-test and the parameters not significantly different from zero at the 90% level will be restricted to zero.

Table 1 and 2 give the number of observations and the percentage distribution across the injury severity of truck drivers for SV and MV accidents involving at least one truck, respectively. As compared to the SV accident datasets (Table 1), the MV accident datasets have more indicators with percentages less than 5% for incapacitating injury/fatal (27 indicators (MV) vs 9 indicators (SV)) and less than 10% for possible injury/non-incapacitating injury (24 indicators (MV) vs 4 indicators (SV)). The difference of the aggregated data between the datasets of SV and MV accidents indicates possible difference in terms of driver-injury severity, which will be studied in the following sections comprehensively.

Table 1 Driver-injury frequency and percentage distribution for SV model

	No injury		Possible injury/non-incapacitating injury		Incapacitating injury/fatal		Total
Driver characteristics							
Young driver (age<=25)	421	77.8%	100	18.5%	20	3.7%	541
Old driver (age>=50)	1503	81.7%	225	12.2%	112	6.1%	1840
Female driver	183	76.3%	38	15.8%	19	7.9%	240

Driver trapped/extract	3	2.9%	41	40.2%	58	56.9%	102
Driver safety belt not used	48	24.1%	79	39.7%	72	36.2%	199
Driver was asleep/fainted	112	54.1%	62	30.0%	33	15.9%	207
Driver was fatigued	76	65.5%	28	24.1%	12	10.3%	116
Vehicle characteristics							
Single unit truck	710	74.4%	187	19.6%	57	6.0%	954
Truck brakes defect	64	63.4%	28	27.7%	9	8.9%	101
Truck tires defect	70	64.2%	23	21.1%	16	14.7%	109
Truck cargo defect	22	57.9%	11	29.0%	5	13.2%	38
Carrying hazardous material	67	62.6%	17	15.9%	23	21.5%	107
Temporal characteristics							
Rush hour (6:00am-9:59am)	954	75.8%	222	17.7%	82	6.5%	1258
Roadway characteristics							
Light traffic (AADT/number of lanes<=2k)	1518	79.1%	291	15.2%	109	5.7%	1918
Class I designated truck route	3137	80.2%	552	14.1%	221	5.7%	3910
Stop sign/flasher	141	86.5%	17	10.4%	5	3.1%	163
Traffic signal	60	95.2%	2	3.2%	1	1.6%	63
Sharp curve (degree of curve>=5)	64	59.8%	31	29.0%	12	11.2%	107
Steep grade (vertical curve grade>=2.2)	41	66.1%	10	16.1%	11	17.7%	62
Environmental characteristics							
Wet road surface	728	77.0%	171	18.1%	46	4.9%	945
Snow/slush road surface	399	87.5%	45	9.9%	12	2.6%	456
Ice road surface	437	84.9%	61	11.8%	17	3.3%	515
Fog/smoke/haze	128	78.1%	28	17.1%	8	4.9%	164
Severe cross wind	161	62.7%	81	31.5%	15	5.8%	257
Accident characteristics							
Truck ran off the roadway	1800	69.6%	549	21.2%	236	9.1%	2585
Truck overturn	250	57.5%	139	32.0%	46	10.6%	435
Truck jackknife	322	90.2%	34	9.5%	1	0.3%	357
Exceeding speed limit	44	58.7%	23	30.7%	8	10.7%	75
Improper lane usage	322	62.0%	137	26.4%	60	11.6%	519
Hitting animal	1538	96.6%	42	2.6%	13	0.8%	1593
Exceeding safe speed for conditions	207	72.6%	61	21.4%	17	6.0%	285
Failing to reduce speed to avoid crash	101	60.5%	41	24.6%	25	15.0%	167
Truck was passing/overtaking	38	76.0%	5	10.0%	7	14.0%	50
Truck was turning left	102	73.9%	29	21.0%	7	5.1%	138
Truck was skidding/control loss	825	69.2%	262	22.0%	106	8.9%	1193
Truck was merging	11	55.0%	8	40.0%	1	5.0%	20

Table 2 Driver-injury frequency and percentage distribution for MV model

	No injury		Possible injury/non-incapacitating injury		Incapacitating injury/fatal		Total
Driver characteristics							
Old driver (age>=50)	3170	91.8%	221	6.4%	61	1.8%	3452
Female driver	386	88.9%	31	7.1%	17	3.9%	434
Driver trapped/extract	4	9.3%	13	30.2%	26	60.5%	43
Driver safety belt not used	96	59.3%	37	22.8%	29	17.9%	162
Driver was asleep/fainted	18	56.3%	8	25.0%	6	18.8%	32
Driver was fatigued	29	82.9%	1	2.9%	5	14.3%	35
Vehicle characteristics							
Single unit truck	2542	89.0%	233	8.2%	81	2.8%	2856
Tractor with semi-trailer	8974	92.8%	505	5.2%	189	2.0%	9668
Truck brakes defect	167	79.2%	32	15.2%	12	5.7%	211

Truck tires defect	98	96.1%	1	1.0%	3	2.9%	102
Carrying hazardous material	115	82.1%	10	7.1%	15	10.7%	140
Roadway characteristics							
Light traffic (AADT/number of lanes<=2k)	3092	89.8%	267	7.8%	86	2.5%	3445
Low truck percentage (percentage [a] <=0.1)	3061	91.8%	199	6.0%	74	2.2%	3334
Class I designated truck route	4379	93.9%	208	4.5%	78	1.7%	4665
Class II designated truck route	6367	90.9%	485	6.9%	156	2.2%	7008
Wide lane(lane width>=13ft)	1669	92.5%	96	5.3%	39	2.2%	1804
Wide median (median width>=60ft)	1833	94.5%	70	3.6%	36	1.9%	1939
Unprotected median	4627	93.7%	220	4.5%	91	1.8%	4938
Painted median	307	88.5%	34	9.8%	6	1.7%	347
Stop sign/flasher	2015	90.1%	169	7.6%	53	2.4%	2237
No passing zone sign	254	85.2%	37	12.4%	7	2.4%	298
Environmental characteristics							
Darkness light condition	1945	90.3%	154	7.2%	56	2.6%	2155
Snow/slush road surface	1045	94.8%	48	4.4%	9	0.8%	1102
Ice road surface	591	94.1%	26	4.1%	11	1.8%	628
Accident characteristics							
Number of vehicles in accident >=3	909	86.2%	111	10.5%	34	3.2%	1054
Truck ran off the roadway	155	78.3%	29	14.7%	14	7.1%	198
Truck overturn	7	35.0%	9	45.0%	4	20.0%	20
Exceeding speed limit	190	89.6%	18	8.5%	4	1.9%	212
Failing to yield right-of-way	776	88.7%	80	9.1%	19	2.2%	875
Driving on wrong side/wrong way	110	77.5%	26	18.3%	6	4.2%	142
Driver influenced by alcohol/drugs	136	85.5%	17	10.7%	6	3.8%	159
Truck was turning left	723	93.5%	41	5.3%	9	1.2%	773
Truck was turning right	414	96.5%	12	2.8%	3	0.7%	429
Truck slowed/stopped in traffic	732	94.3%	39	5.0%	5	0.6%	776
Truck was avoiding vehicle/objects	489	85.9%	62	10.9%	18	3.2%	569
Truck was skidding/control loss	401	82.3%	54	11.1%	32	6.6%	487

[a] truck percentage is equal to commercial volume/AADT

STATISTICAL METHOD

In the present study, base multinomial logit models and subsequently, mixed logit models, will be developed (Moore et al., 2010). Mixed logit models allow for the possibility that the influence of variables affecting injury-severity levels may vary across observations. We follow the works by Revelt and Train (1998), McFadden and Train (2000) and Bhat (2001), which have demonstrated the effectiveness of this approach to explore the variations of the effects (across observations) that variables can have on injury-severity levels.

Let $P_n(i)$ be the probability of the accident *n* causing the injury severity category *i* (Ulfarsson and Mannering, 2004):

$$P_n(i) = P(\beta_i X_n + \varepsilon_{ni} \geq \beta_{i'} X_n + \varepsilon_{ni'}) \quad \forall i' \in I, \quad i' \neq i \tag{1}$$

where I is a set of all possible discrete outcomes, mutually exclusive severity categories. i and i' are different injury severity categories. β_i and $\beta_{i'}$ are vectors of estimated parameters of severity category i and i', respectively. X_n is the vector of characteristics (e.g. driver, vehicle, roadway and environmental) for the accident observation *n* that influences the injury severity category i and i'. ε_{ni} and $\varepsilon_{ni'}$ are random components (error terms) that explain the unobserved effects on injury severity of the accident observation n.

If ε_{ni} is assumed to be in a type I extreme-value distribution, a standard multinomial logit model can be expressed as (McFadden, 1981):

$$P_n(i) = \frac{e^{\beta_i X_n}}{\sum_{\forall i' \in I} e^{\beta_{i'} X_n}} \tag{2}$$

where the parameter β_i is typically estimated by the maximum likelihood method.

The mixed logit model will be generated from this multinomial logit model if the parameter β_i is allowed to vary across individuals (observations). Then a mixing distribution is introduced to the model formulation (Train, 2003):

$$P_n(i) = \frac{e^{\beta_i X_n}}{\sum_{\forall i' \in I} e^{\beta_{i'} X_n}} f(\beta \mid \varphi) \mathrm{d}\beta \tag{3}$$

where $f(\beta \mid \varphi)$ is a density function of β with φ which is a vector of parameters of the density function (mean and variance), and all other terms are previously defined (Milton et al., 2008).

We examined four potential distributions for our model parameters: normal, uniform, lognormal and triangle distributions. Simulation-based maximum likelihood methods with Halton draws are adopted, which have been confirmed to be more efficient than purely random draws (Bhat, 2003). In the present study, the final results are based on 200 Halton draws, which have been found capable of producing accurate parameter estimates (Bhat, 2003; Milton et al., 2008; Gkritza and Mannering, 2008).

In addition to the estimated parameters, elasticity is often used to describe the magnitude of the impact of the explanatory variables on the outcome probabilities (Ulfarsson and Mannering, 2004). Because the exogenous variables we explored later are discrete instead of continuous (coded as 0 and 1 indicator values), a direct pseudo-elasticity of the probability $E_{x_{nk}}^{P_n(i)}$ has been introduced to measure the effect in percentage that a 1% change in x_{nk} (the indicator varies from 0 to 1 or from 1 to 0) has on the severity probability $P(i)$. This method has been used in previous studies by several researchers such as Ulfarsson and Mannering (2004) and Khorashadi et al. (2005):

$$E_{x_{nk}}^{P_n(i)} = e^{\beta_{ik}} \frac{\sum_{\forall i' \in I} [e^{\beta_{i'} x_n}]_{x_{nk=0}}}{\sum_{\forall i' \in I} [e^{\beta_{i'} x_n}]_{x_{nk=1}}} - 1 \tag{4}$$

where $E_{x_{nk}}^{P_n(i)}$ is the direct pseudo-elasticity of the k^{th} variable from the vector x_n for observation n. x_{nk} is the value of the variable k for the outcome n . β_{ik} is the k^{th} component of the vector β_i of severity category i. $[e^{\beta_{i'} x_n}]_{x_{nk=0}}$ is the value of $e^{\beta_{i'} x_n}$ with the x_{nk} in x_n being set to zero and $[e^{\beta_{i'} x_n}]_{x_{nk=1}}$ is the value of $e^{\beta_{i'} x_n}$ with the x_{nk} in x_n being set to one.

RESULT

Table 3 and 4 show the estimated driver-injury severity models of SV and MV accidents, which include the estimated parameters and t-statistic identified for each severity category of mixed logit models. No-injury category is chosen as the base case, so the estimated parameters in the tables show the difference between the results of the target category and the base case (no-injury category). Following each variable name in Table 3 and 4, the abbreviation of the corresponding severity category to which each parameter belongs is listed in a bracket. They are defined as: [NI] no injury, [PI/NII] possible injury/non-incapacitating injury, [II/F] incapacitating injury/fatal. The tables suggest that a wide variety of variables are statistically significant on driver injury severity. The ρ^2 of the SV and MV models equal to 0.548 and 0.732 respectively, which indicate that the models fit the data satisfactorily.

Table 3 Mixed logit model of driver-injury severity conditioned on SV accident for truck-involved accidents

Variable[a]	Estimated parameter	t-statistic
Constant [II/F]	4.740	4.31
Constant [PI/NII]	2.910	2.22
Std. dev. of distribution of this parameter **(normal distribution)**	0.953	1.81
Driver characteristics		
Young driver (age<=25) [II/F]	-0.313	2.31
Old driver (age>=50) [PI/NII]	-0.116	1.90
Female driver [II/F]	0.320	2.18
Driver trapped/extract [II/F]	2.670	8.64
Driver trapped/extract [PI/NII]	2.230	6.51
Driver safety belt not used [II/F]	1.350	11.85
Driver safety belt not used [PI/NII]	1.100	6.72
Driver was asleep/fainted [II/F]	0.402	3.13
Driver was asleep/fainted [PI/NII]	0.547	3.85
Driver was fatigued [PI/NII]	0.384	2.24
Vehicle characteristics		
Single unit truck [PI/NII]	0.357	4.25
Truck brakes defect [PI/NII]	0.310	1.68
Truck tires defect [II/F]	0.394	2.35
Truck cargo defect [PI/NII]	0.561	1.90
Carrying hazardous material [II/F]	0.638	4.18
Temporal characteristics		
Rush hour (6:00am-9:59am) [PI/NII]	0.132	2.05
Roadway characteristics		
Light traffic (AADT/number of lanes<=2k) [PI/NII]	0.178	2.30
Class I designated truck route [PI/NII]	0.160	2.15

Stop sign/flasher [II/F] [PI/NII]	-0.723	3.11
Traffic signal [PI/NII]	-0.889	2.08
Sharp curve (degree of curve>=5) [II/F]	0.407	2.11
Sharp curve (degree of curve>=5) [PI/NII]	0.552	2.97
Steep grade (vertical curve grade>=2.2) [II/F]	0.904	4.39
Environmental characteristics		
Wet road surface [II/F]	-0.265	2.78
Snow/slush road surface [II/F]	-0.633	3.33
Snow/slush road surface [PI/NII] **(Random Parameter)**	-0.518	4.38
Std. dev. of distribution of this parameter **(normal distribution)**	1.410	2.55
Ice road surface [II/F] [PI/NII]	0.497	3.76
Fog/smoke/haze [PI/NII]	0.312	1.95
Severe cross wind [PI/NII]	0.689	4.83
Accident characteristics		
Truck ran off the roadway [II/F]	0.431	5.93
Truck ran off the roadway [PI/NII]	0.548	6.19
Truck overturn [II/F]	0.640	5.58
Truck overturn [PI/NII]	0.864	5.89
Truck jackknife [II/F]	-1.090	2.14
Exceeding speed limit [II/F] [PI/NII]	0.567	2.56
Improper lane usage [II/F]	0.263	2.87
Improper lane usage [PI/NII]	0.400	4.09
Hitting animal [II/F] [PI/NII]	-0.758	5.33
Exceeding safe speed for conditions [PI/NII]	0.359	3.00
Failing to reduce speed to avoid crash [II/F]	0.462	3.34
Failing to reduce speed to avoid crash [PI/NII]	0.318	2.20
Truck was passing/overtaking [II/F]	0.460	1.95
Truck was turning left [II/F]	-0.501	1.93
Truck was skidding/control loss [II/F] [PI/NII]	0.313	4.32
Truck was merging [PI/NII]	0.695	1.76
Number of observations		
Log likelihood at zero		-7570.5
Log likelihood at convergence		-3418.6
Number of observation used		6891
ρ^2		0.548

[a] Characters in the parentheses indicate variables defined for: [NI] no injury, [PI/NII] possible injury/non-incapacitating injury, [II/F] incapacitating injury/fatal.

Table 4 Mixed logit model of driver-injury severity conditioned on MV accident for truck-involved accidents

Variable[a]	Estimated parameter	t-statistic
Constant [II/F]	5.380	3.82
Constant [PI/NII]	5.320	5.06

Driver characteristics		
Old driver (age>=50) [PI/NII]	0.103	1.77
Female driver [II/F]	0.404	2.92
Female driver [PI/NII]	0.238	1.81
Driver trapped/extract [II/F]	2.740	9.61
Driver trapped/extract [PI/NII]	2.180	5.14
Driver safety belt not used [II/F]	1.170	9.19
Driver safety belt not used [PI/NII]	1.070	4.42
Driver was asleep/fainted [II/F] [PI/NII]	1.387	4.76
Driver was fatigued [II/F]	1.040	4.00
Vehicle characteristics		
Single unit truck [II/F]	0.499	1.76
Tractor with semi-trailer [PI/NII]	-0.339	2.23
Truck brakes defect [II/F]	0.425	2.56
Truck brakes defect [PI/NII]	0.594	3.23
Truck tires defect [PI/NII]	-1.010	1.74
Carrying hazardous material [II/F]	0.737	4.26
Roadway characteristics		
Light traffic (AADT/number of lanes<=2k) [PI/NII] **(Random Parameter)**	0.150	2.21
Std. dev. of distribution of this parameter **(normal distribution)**	1.770	2.33
Low truck percentage (percentage[b] <=0.1) [PI/NII]	-0.120	1.79
Class I designated truck route [II/F]	-0.932	4.64
Class II designated truck route [II/F]	-0.243	2.32
Wide lane(lane width>=13ft) [PI/NII]	-0.202	2.40
Wide median (median width>=60ft) [PI/NII]	-0.202	2.00
Unprotected median [II/F]	0.395	2.58
Painted median [PI/NII]	0.300	2.10
Stop sign/flasher [PI/NII]	0.144	1.91
No passing zone sign [PI/NII]	0.470	2.91
Environmental characteristics		
Darkness light condition [II/F] [PI/NII]	0.232	2.85
Snow/slush road surface [II/F]	-0.488	2.78
Snow/slush road surface [PI/NII]	-0.198	1.89
Ice road surface [PI/NII]	-0.262	1.84
Accident characteristics		
Number of vehicles in accident >=3 [II/F]	0.216	2.13
Number of vehicles in accident >=3 [PI/NII]	0.433	3.78
Truck ran off the roadway [II/F] [PI/NII]	0.477	2.80
Truck overturn [II/F]	1.690	4.70
Truck overturn [PI/NII]	2.140	3.78
Exceeding speed limit [PI/NII]	0.287	1.71
Failing to yield right-of-way [PI/NII]	0.264	2.59

Driving on wrong side/wrong way [II/F]	0.418	1.90
Driving on wrong side/wrong way [PI/NII]	0.830	3.49
Driver influenced by alcohol/drugs [PI/NII]	0.439	2.19
Truck was turning left [II/F]	-0.336	1.89
Truck was turning right [II/F]	-0.631	2.05
Truck was turning right [PI/NII]	-0.510	2.47
Truck slowed/stopped in traffic [II/F]	-0.529	2.30
Truck was avoiding vehicle/objects [PI/NII]	0.379	3.08
Truck was skidding/control loss [II/F]	0.637	5.62
Truck was skidding/control loss [PI/NII]	0.453	3.31
Number of observations		
Log likelihood at zero		-14117.2
Log likelihood at convergence		-3786.8
Number of observation used		12850
ρ^2		0.732

[a] Characters in the parentheses indicate variables defined for: [NI] no injury, [PI/NII] possible injury/non-incapacitating injury, [II/F] incapacitating injury/fatal.

We follow the work by Moore et al. (2010): first select all the parameters as random parameters, and then reduce one random parameter at a time until no further reduction of the random variables can be made. It is found that there are two random parameters in the SV model and one random parameter in the MV model. As shown in Table 3, the parameter of the snow/slush road surface indicator of possible injury/non-incapacitating injury in the SV model is normally distributed with mean -0.518 and standard deviation 1.41. With snow/slush road surface, 64.3% of the distribution is less than 0 and 35.7% of the distribution is greater than 0. This indicates that 64.3% of the SV accidents that occurred on snow-covered roads result in a decrease in possible injury/non-incapacitating injury accidents, while 35.7% of the accidents result in an increase in possible injury/non-incapacitating injury accidents. Such phenomena can be in part due to the fact that people often drive slower and more carefully on snowy roads than normal road conditions but on the other hand, it becomes truly harder to control the truck on snowy days despite carefulness of driving. The constant term of possible injury/non-incapacitating injury in the SV model is also found to be randomly distributed.

From Table 4, the parameter of the light traffic indicator of possible injury/non-incapacitating injury in the MV model is normally distributed with mean 0.15 and standard deviation 1.77. It is then found that 46.6% of the distribution is less than 0 and 53.4% of the distribution is greater than 0. This implies that nearly half of the MV accidents occurred with the light traffic condition result in a decrease in possible injury/non-incapacitating injury accidents while the other half of the accidents result in an increase in possible injury/non-incapacitating injury accidents. This result, which is similar to the finding of Milton et al. (2008) about the influence from average daily traffic (ADT) per lane, reveals the complex interaction among traffic volume, driver behavior and accident-injury severity. Obviously, without adopting the mixed logit models, the complex interaction and random nature of the parameters (e.g. the snow/slush road surface indicator and light traffic indicator) as described above would have been extremely hard, if not impossible at all, to be discovered.

The average direct pseudo-elasticity for the SV and MV models are studied and the results are presented in Table 5 and 6, respectively. Some of results in Table 5 and 6 will be discussed by category in the following section.

Table 5 Average direct pseudo-elasticities of driver-injury severity of SV accidents

Variable	Elasticity (%) [a]		
	NI	PI/NII	II/F
Driver characteristics			
Young driver (age<=25)	7.3	10.9	-21.5
Old driver (age>=50)	4.5	-6.9	5.4
Female driver	-14.6	-1.9	17.6
Driver trapped/extract	-87.7	14.6	78.0
Driver safety belt not used	-61.9	14.6	47.1
Driver was asleep/fainted	-30.4	20.2	4.0
Driver was fatigued	-21.0	16.0	-0.5
Vehicle characteristics			
Single unit truck	-15.8	20.4	-10.8
Truck brakes defect	-13.1	18.5	-12.1
Truck tires defect	-16.7	-4.7	23.6
Truck cargo defect	-32.0	19.2	6.7
Carrying hazardous material	-21.7	-18.3	48.1
Temporal characteristics			
Rush hour (6:00am-9:59am)	-7.5	5.5	0.1
Roadway characteristics			
Light traffic (AADT/number of lanes<=2k)	-7.5	10.5	-6.2
Class I designated truck route	-7.6	8.4	-3.1
Stop sign/flasher	59.2	-22.9	-22.9
Traffic signal	58.6	-34.8	-5.4
Sharp curve (degree of curve>=5)	-30.7	20.3	4.0
Steep grade (vertical curve grade>=2.2)	-38.4	-8.4	52.1
Environmental characteristics			
Wet road surface	9.0	5.9	-16.4
Snow/slush road surface	42.6	-15.1	-26.0
Ice road surface	39.6	-16.9	-16.9
Fog/smoke/haze	-16.6	13.9	-2.1
Severe cross wind	-31.9	35.6	-14.6
Accident characteristics			
Truck ran off the roadway	-30.1	20.8	7.5
Truck overturn	-44.5	31.6	5.2
Truck jackknife	14.2	37.5	-61.6
Exceeding speed limit	-34.1	16.5	16.5

Improper lane usage	-22.2	16.0	1.2
Hitting animal	67.2	-21.3	-21.3
Exceeding safe speed for conditions	-18.3	17.0	-4.6
Failing to reduce speed to avoid crash	-24.5	3.8	19.9
Truck was passing/overtaking	-4.3	-33.5	51.6
Truck was turning left	15.4	11.3	-30.1
Truck was skidding/control loss	-20.7	9.8	9.8
Truck was merging	-29.5	41.4	-25.7

[a] Characters in the parentheses indicate variables defined for: [NI] no injury, [PI/NII] possible injury/non-incapacitating injury, [II/F] incapacitating injury/fatal.

Table 6 Average direct pseudo-elasticities of driver-injury severity of MV accidents

Variable	Elasticity (%) [a]		
	NI	PI/NII	II/F
Driver characteristics			
Old driver (age>=50)	-1.1	9.7	-7.5
Female driver	-20.2	1.3	19.5
Driver trapped/extract	-88.0	6.5	86.4
Driver safety belt not used	-57.4	24.1	37.1
Driver was asleep/fainted	-66.0	33.6	33.6
Driver was fatigued	-35.0	-49.9	83.8
Vehicle characteristics			
Single unit truck	-16.3	-18.5	37.9
Tractor with semi-trailer	1.6	-27.6	39.8
Truck brakes defect	-30.3	26.3	6.6
Truck tires defect	16.1	-57.7	38.8
Carrying hazardous material	-28.6	-20.7	49.1
Roadway characteristics			
Light traffic (AADT/number of lanes<=2k)	-3.9	11.7	-6.4
Low truck percentage (percentage[b] <=0.1)	8.8	-3.5	-5.2
Class I designated truck route	29.4	49.4	-49.1
Class II designated truck route	5.0	17.6	-17.7
Wide lane(lane width>=13ft)	8.0	-11.7	3.2
Wide median (median width>=60ft)	3.5	-15.5	11.5
Unprotected median	-7.7	-24.1	37.0
Painted median	-4.1	29.4	-22.6
Stop sign/flasher	-6.6	7.9	-0.6
No passing zone sign	-15.7	34.9	-16.0
Environmental characteristics			
Darkness light condition	-14.3	9.2	9.2
Snow/slush road surface	23.8	1.5	-24.0
Ice road surface	16.9	-10.1	-7.2
Accident characteristics			

Number of vehicles in accident >=3	-20.0	23.4	-0.7
Truck ran off the roadway	-28.8	17.3	17.3
Truck overturn	-79.3	76.0	12.2
Exceeding speed limit	-7.0	23.9	-14.9
Failing to yield right-of-way	-8.2	19.5	-9.4
Driving on wrong side/wrong way	-36.7	45.1	-3.9
Driver influenced by alcohol/drugs	-22.1	20.8	3.2
Truck was turning left	16.1	1.4	-17.0
Truck was turning right	40.8	-15.4	-25.1
Truck slowed/stopped in traffic	19.5	12.1	-29.6
Truck was avoiding vehicle/objects	-18.2	19.5	0.5
Truck was skidding/control loss	-32.4	6.3	27.8

[a] Characters in the parentheses indicate variables defined for: [NI] no injury, [PI/NII] possible injury/non-incapacitating injury, [II/F] incapacitating injury/fatal.

[b] truck percentage is equal to commercial volume/AADT

Driver Characteristics

The different influence of old drivers in SV and MV accidents is worthy of investigation. When the driver is old (≥ 50 years), depending on getting involved in a SV or MV accident, it has a 5.4% increase or 7.5% decrease in incapacitating injury/fatal probability, respectively. This phenomenon is perhaps because of the combined effects from cautious driving behavior, likely more driving experience, and yet longer reaction time of older drivers. The opposite effects of old drivers on driver-injury severity of the SV and MV accidents show the statistical difference of the two models, and are possibly also the reason why this indicator had not been found to be significant in the past when SV and MV accidents involving trucks were typically analyzed altogether. For older drivers, it is found that the chances of suffering severe injury and fatality increase while involving a SV accident. Accordingly, specific mitigation strategies of severe injury for old drivers may need to be developed in the future by considering the unique characteristics of SV accidents.

In addition to old drivers, young drivers (≤ 25 years) are also specifically studied. It is found that there are respectively 21.5% decreases and 10.9% increases in the probability of incapacitating injury/fatal probability and possible injury/non-incapacitating injury probability, if the driver is young and involves SV accidents. However the young driver indicator is not significant in the MV model at all. Similar to old drivers, the results suggest that more attention probably should be given to the traffic safety of young drivers in SV accidents in the future. Other than old and young drivers, female truck drivers are also found vulnerable to severe injury. Perhaps a combination of physiological and behavioral factors significantly affects the injury severity of truck driver and causes the observed differences between male and female drivers. It is found that the incapacitating injury/fatal probability increases in both the SV and MV models if the driver is female. Being consistent with the observations from other studies (e.g. Chang and Mannering, 1999), this finding suggests that a higher probability of experiencing severe injury exists for female truck drivers regardless of the type of the accidents involved.

For truck drivers, it is not uncommon to become fatigued or sometimes even fall into sleep when driving (NIOSH, 2007). The probabilities of incapacitating injury/fatal in the SV and MV models both increase if the truck driver was asleep/fainted, but the probability in MV accidents is around 8 times higher than that of the SV accidents (33.6% vs 4%). The SV and MV models give similar findings about incapacitating injury/fatal probability if the driver did not use safety belt (47.1% vs 37.1%). These findings confirm again that using safety belts by truck drivers can notably reduce incapacitating injury/fatal probability in both SV and MV accidents. Similar observations have been made by for example, Chang and Mannering (1999) among other researchers.

Vehicle Characteristics

Opposite effects on driver-injury severity were found between SV and MV accidents if the truck is single-unit. For example, if a truck is single-unit, the probability of incapacitating injury/fatal increases by 37.9% in a MV accident while decreases by 10.8% in a SV accident as compared to trucks which are not single-unit. Also the tractor with semi-trailer indicator is significant in the MV model by increasing the probability of incapacitating injury/fatal by 39.8%, but not significant in the SV model. So from the perspective of lowering injury severity of the driver, a single-unit truck is better than other non-single-unit trucks in a SV accident, but usually becomes worse than other non-single-unit trucks in a MV accident.

If a truck has a brake or tire defect, there is considerable difference of incapacitating injury/fatal probability between the SV and MV models (-12.1% vs 6.6% for brake defect, 23.6% vs 38.8% for tire defect). Comparatively, tire defect is found to be more critical than brake defect in terms of causing severe injury of truck drivers. This finding may help trucking industry on developing safer maintenance process and highway patrol on conducting improved law enforcement. The probabilities of incapacitating injury/fatal in both SV and MV accidents will increase significantly if the truck is carrying hazardous material (48.1% and 49.1% for the SV and MV accidents respectively). This result highlights the significantly elevated life threats to the drivers of HazMat trucks no matter what kind of accident is involved.

Roadway Characteristics

Roadway characteristics affect the driver injury severity in the SV and MV accidents in a rather complex manner. In MV accidents both Class I and II designated truck routes increase the probability of possible injury/non-incapacitating injury (49.4% vs 17.6%), while they decrease the probability of incapacitating injury/fatal (49.1% vs 17.7%) at the same time. Because of the trade-offs, Class I and II designated truck routes may not have considerable impacts on the two injury levels as a whole, but they both significantly decrease the probability of severe injury and fatality, which are usually very critical to policy-making. Comparatively, Class I designated truck routes are more effective than Class II designated truck routes. Since this study is only based on the data in Illinois, it is advisable that transportation agencies may evaluate the effectiveness of the designated truck routes by considering the site-specific accident and injury data. It is believed that studies on optimizing the strategy of designated truck routes may need to be conducted on a case-by-case basis for different highways, especially those historically suffering severe injury of truck drivers.

There are some variables which are found to be significant only for one type of accidents. For example, wide lane, wide median, unprotected median indicators decrease the probability of possible injury/non-incapacitating injury by 11.7%, 15.5%, 24.1% while increase the probability of incapacitating injury/fatal by 3.2%, 11.5% , 37% in the MV model, respectively. All these indicators, however, are found to be not significant in the SV model. Obviously, the impacts from wide lanes, wide medians or unprotected median on the injury severity of truck drivers in MV accidents are complex in nature: these roadway design features help on reducing the probability of moderate injury, but increasing the probability of severe injury and fatality at the same time. This is probably the outcome from the trade-offs between the provided physical protection and the affected driving behavior due to either "safer" or "more dangerous" feeling by the drivers. For example, on one hand, wide lanes and wide medians do provide more physical safety margins for truck drivers. On the other hand, the "safer" feeling may also encourage unsafe driving behavior by the truck drivers. In contrast, an unprotected median may pose higher risks of injury during accidents, but it may also alert truck drivers to drive more cautiously. The results imply the need to evaluate the impacts of some roadway design features on traffic safety more comprehensively by traffic agencies and the research community, from both engineering and psychological perspectives simultaneously.

Similar to those variables as summarized above which are only significant in the MV model, there are also some variables which are only significant in the SV model. For example, if a highway has sharp curves, the probability of possible injury/non-incapacitating injury or incapacitating injury/fatal increase by 20.3% or 4% in the SV model respectively, but no significant impact was observed in the MV model. The steep grade indicator will increase the probability of incapacitating injury/fatal by more than 50% in the SV model but has no influence in the MV model. These findings underscore the substantial effects of complex terrains on injury severity in SV accidents. It is known that SV accidents are pretty common in areas with complex terrains (e.g. mountainous states). The results suggest that highways should be designed very carefully, given that optimizing the terrain may potentially save many lives and avoid injuries of many truck drivers through these highways each day.

Environmental Characteristics

If an accident happens on an icy road, the probabilities of possible injury/non-incapacitating injury and incapacitating injury/fatal in both the SV and MV models are all found to decrease. Besides, the results for both SV and MV accidents are generally similar if the accidents occur on a snow-covered road, except for one situation: the probability of possible injury/non-incapacitating injury in the MV model slightly increases by 1.5% while that in the SV model decrease by 15.1%. Trucks are well known to be vulnerable to both SV and MV accidents on icy and snow-covered roads. The results in the present study show that severe injuries of truck drivers are overall less likely to occur in both SV and MV accidents than normal road conditions. But as discussed in the first part of this Section, it is noted that snow-covered road surface condition has been identified as randomly distributed over observations of SV accidents.

The darkness indicator was found to be significant in the MV model, but no in the SV model. The finding that the probability of severe injury increases in the night condition has also been found by a study on truck-involved accidents as a whole (Chang and Mannering, 1999). But the different impacts on SV and MV accidents, as introduced above, have not been discussed previously. Contrary to the darkness indicator, the wet road surface indicator was found to be significant in the SV model, but no in the MV model. Another interesting finding is that inclement weather like fog or windy weather increases the possible injury/non-incapacitating injury probability in the SV model while these weather conditions were found to be not significant in the MV model. So depending on the specific adverse environmental condition, more effective injury mitigation technology for truck drivers can be developed accordingly with an emphasis on SV accidents based on the findings summarized above.

Accident Characteristics

Many variables of accident characteristics were also found to have totally different influence on SV and MV accidents. There are many characteristic indicators which only have significant impacts on the truck-driver injury severity in either MV or SV accidents, but not both. For example, six accident characteristic indicators (e.g. the failing to yield right-of-way indicator) were found to be significant in the MV model but no in the SV model. While other seven accident characteristics indicators (e.g. the improper lane usage indicator) were found to be significant in the SV model but not in the MV model. Details of these variables and all other characteristics are summarized in Table 7.

Even for some indicators which were found to be significant in both models, there is still considerable difference. For example, if a truck is overturned, the probability of possible injury/non-incapacitating injury in the MV model increases more significantly than in the SV model (76% vs 31.6%). When a truck loses control, there is also large difference between the increasing of the probability of incapacitating injury/fatal in the SV and MV models (9.8% vs 27.8%). Considerably higher probabilities of experiencing severe injury in MV accidents than SV accidents are possibly related to the difference of the crash nature of SV and MV accidents.

It can be found from the above results that there is substantial difference between the impacts from a variety of variables on the driver-injury severity in MV and SV accidents. For clarity purpose, Table 7 summarize all the indicators which have different influence in the SV and MV models, including those only significant to one type of accidents, with opposite trends, with the same trend but significantly different elasticity and with opposite influence to both types of accidents. By conducting the injury severity study for MV and SV accidents involving trucks separately, some new or more comprehensive observations, which have not been covered in the existing studies, can be made. As a result, the complex interactions of various indicators and the nature of truck-driver injury are able to be disclosed in a better way.

MODEL SPECIFICATION TESTS

The likelihood ratio test is also conducted to verify the statistical justification of estimating SV and MV accidents separately in the present study. The method is conducted to check the significance of the combined model for all vehicle accidents (both SV and MV accidents) and two separate models for SV and MV only. The following formula is adopted to apply the likelihood ratio test (Ulfarsson and Mannering, 2004):

$$-2\left[L_N(\beta)-L_{N_s}(\beta^s)-L_{N_m}(\beta^m)\right] \tag{5}$$

where $L_{N(\beta)}$ is the log-likelihood at convergence of the all data model, with a parameter β, $L_{N_s}(\beta^s)$ and $L_{N_m}(\beta^m)$ are the log-likelihood at convergence of the model estimated on the SV data subset, and the MV data subset, respectively. The test adopts χ^2 distribution with the degrees of freedom equal to the sum of the number of the estimated parameters in the SV and MV models minus the number of the parameters estimated in all data models.

With P<0.001, the result of the test indicates that significant difference of severity likelihood exists between SV and MV accidents, which justifies the choice of modeling SV and MV accidents separately in the present study. We also conduct the likelihood ratio tests to check whether the random parameter models (mixed logit models) are significantly better than the fixed parameter models (base multinomial models). The likelihood ratio test is (Washington et al., 2003):

$$2\left[L_{MXL}(\beta)-L_{MNL}(\beta)\right] \tag{6}$$

where $L_{MXL}(\beta)$ and $L_{MNL}(\beta)$ are the log-likelihood at convergence of mixed logit model and multinomial logit model of the same dataset (e.g. SV or MV dataset), respectively.

The statistic is in χ^2 distribution with the degrees of freedom equal to the difference of the numbers of the parameters between the two models. For the SV model, the χ^2 value of the test is 7.04 with two degrees of freedom. The corresponding *p*-value is 0.03. The χ^2 value of the test for the MV model is 9.06 with one degree of freedom. The corresponding *p*-value is 0.003. Therefore, it is obvious that there exists significant difference between the random parameter models and the fixed parameter models.

DISCUSSIONS AND CONCLUSIONS

Ten-year detailed HSIS accident data on major interstate highways, US highways and state highways in Illinois were studied. The mixed logit model was adopted to analyze the injury severity of truck drivers on rural highways. Estimation findings indicate that snow road surface will be better modeled as random-parameters in the SV model and the same with the light traffic indicators in the MV model. The result of the likelihood ratio test indicates that the injury mechanisms of SV and MV accidents involving trucks are clearly distinct. A comprehensive collection of different risk factors including driver characteristics, vehicle characteristics, temporal characteristics, roadway characteristics, environmental characteristics, and accident characteristics were included in the mixed logit models. For the first time, SV and MV accidents involving trucks were studied separately to identify those risk factors which have significant influence on the driver-injury severity. Some variables are only significant in the SV accident model or the MV accident model, but not both. According to the results in the present study, there are sixteen variables which are only significant in the SV model while not in the MV model. Also there are sixteen variables which were found to be significant in the MV model only. Even if some variables were found to be significant in both SV and MV models, there is considerable difference of marginal effects on these two models. Some of them can have opposite effects for

SV and MV accidents. There are also some variables which have noteworthy difference of magnitudes even with the same trend.

Table 7 Summary of indicators by influence types

Indicators only significant to SV model	**Indicators only significant to MV model**
(1)-Young driver (age<=25)	**(2)**-Tractor with semi-trailer
(2)-Truck cargo defect	**(4)**-Low truck percentage (percentage<=0.1)
(3)- Rush hour (6:00am-9:59am)	**(4)**-Class II designated truck route
(4)-Traffic signal	**(4)**-Wide lane(lane width>=13ft)
(4)-Sharp curve (degree of curve>=5)	**(4)**-Wide median (median width>=60ft)
(4)-Steep grade (vertical curve grade>=2.2)	**(4)**-Unprotected median
(5)-wet road surface	**(4)**-Painted median
(5)- Fog/smoke/haze	**(4)**-No passing zone sign
(5)- Severe cross wind	**(5)**- Darkness light condition
(6)-Truck jackknife	**(6)**-Number of vehicles in accident >=3
(6)-Improper lane usage	**(6)**-Failing to yield right-of-way
(6)-Hitting animal	**(6)**-Driving on wrong side/wrong way
(6)-Exceeding safe speed for conditions	**(6)**-Driver influenced by alcohol/drugs
(6)-Failing to reduce speed to avoid crash	**(6)**-Truck was turning right
(6)-Truck was passing/overtaking	**(6)**-Truck slowed/stopped in traffic
(6)-Truck was merging	**(6)**-Truck was avoiding vehicle/objects
Indicators having influence on SV and MV models with the same trend and the difference of elasticity is small (smaller than 10% for both PI/NII and II/F)	**Indicators having influence on SV and MV models with the same trend but the difference of elasticity is large (bigger than 20% for either of PI/NII and II/F)**
(1)-Driver trapped/extract	**(1)**-Driver was asleep/fainted (II/F)
(1)-Driver safety belt not used	**(2)**-Truck tires defect (PI/NII and II/F)
(2)-Carrying hazardous material	**(4)**-Class I designated truck route (PI/NII and II/F)
(4)-Light traffic (AADT/number of lanes<=2k)	(6)-Truck overturn (II/F)
(5)- Ice road surface	(6)-Truck was skidding/control loss
(6)-Truck ran off the roadway	
Indicators which have opposite influence on SV and MV models	
(1)-Old driver (age>=50)	(2)-Truck brakes defect
(1)-Female driver	(4)-Stop sign/flasher
(1)-Driver was fatigued	(5)-Snow/slush road surface
(2)-Single unit truck	(6)-Exceeding speed limit

The numbers in brackets before indicators are defined as: (1) driver characteristics (2) vehicle characteristics (3) temporal characteristics (4) roadway characteristics (5) environmental characteristics (6) accident characteristics

The ultimate goal of any injury study is to provide scientific basis to potentially reduce injury severity through advancing the state-of-the-art of modeling, manufacturing and policy-making. Therefore, among a large number of risk factors being investigated in the present study, it is felt helpful to summarize those critical risk factors which have been rarely reported before, while cause more severe injury or less severe injury in truck-involved accidents. Depending on the impacts, these risk factors should be considered strategically in any future injury mitigation strategy, transportation design and management. There are some risk factors which were found to be significant to the severity of truck-related accidents in the present study, but were rarely reported in the existing studies about truck-involved accidents. These risk factors include old driver, driver trapped/extract, driver was asleep/fainted, driver was fatigued, carrying hazardous material, light traffic, low truck percentage, class I and II designated truck route, wide lane, wide median, no passing zone sign, stop sign/flasher, traffic signal, sharp curve, fog/smoke/haze, severe cross wind, hitting animal, truck overturn, truck jackknife, improper lane usage, driving on wrong side/wrong way, failing to reduce speed to avoid crash, truck was avoiding vehicle/objects, truck was passing/overtaking and truck was skidding/control loss indicators. In fact, some of these variables which are significant to the severity of SV or MV accidents would not have been identified if only the analysis of the data from all the accidents as a whole were conducted.

The detailed findings on risk factors in MV and SV accidents will add to the existing knowledge of injury studies about truck drivers. Based on the improved understanding of the injury severity of truck drivers, it is expected that more rational and effective injury prevention strategies may be developed for truck drivers by trucking industry and related agencies, such as occupational safety and transportation agencies. In the meantime, some findings may be helpful for transportation agencies to evaluate and improve the existing designs of transportation infrastructure and traffic management system. Finally, the present study can also help on developing training and educational courses for truck drivers, state patrols, engineers and general public.

Similar to most studies, the present study also has some limitations, such as the fact that data reflect information from a single US state, were obtained from a single database, as well as the fact that the truck types investigated are limited by the available types from the database. Future studies with multiple states, data from different databases and more comprehensive truck types may be conducted, which may provide more comprehensive insights.

Acknowledgement

This study is partially supported by the fund from USDOT through Mountain Plain Consortium (MPC), which is greatly appreciated. The writers also like to thank the HSIS lab manager Yusuf Mohamedshah for providing the accident data for this study.

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