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METHODOLOGICAL APPROACHES TO INCORPORATE HETEROGENEITY IN TRAFFIC ACCIDENT SEVERITY MODELS

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Abstract

Methodological Approaches to Incorporate Heterogeneity in Traffic Accident Severity Models

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Scope of the Problem

Fatal accidents exact a significant toll in terms of economic cost, in excess of 150 billion dollars yearly. Over 40,000 drivers, passengers, pedestrians and bicyclists are killed each year on United States highways. Traffic accidents cause what is termed in the medical literature as unintentional harm and injury. Only heart attacks, cancer, stroke and respiratory related illnesses cause more deaths in the United States than unintentional injuries. While traffic accident deaths may comprise less than 2 percent of all registered deaths annually, their impact on future income earners can be telling. As an example, over 40 percent of childhood deaths are due to unintentional injuries, with over 30 percent contributed by motor vehicle accidents. Among teenagers, the three leading causes of death are unintentional injuries, homicide and suicide. Nearly 52 percent of the 15-24 age group dies from unintentional injuries, with a significant number perishing in motor vehicle accidents. From an infrastructure standpoint, fatalities contribute to increase in lifecycle costs including transportation, social and emergency infrastructure. Given this backdrop, my goal in this dissertation is to parse out the contribution of

infrastructure to motor vehicle related deaths. A 1993 study by the Carter Center estimated approximately 25,000 deaths annually to be behaviorally related. In a traffic accident context, common cited reasons that constitute behavior include speeding, driving under the influence of alcohol, driving without seat belt fastened, driving under fatigue, aggressive driving such as tailgating, and failure to yield. What are of interest in this dissertation are the impact of infrastructure in these deaths, as well as infrastructure impact in single and multi-vehicle collisions leading to death. For example, fixed object related collisions contribute to nearly 27 percent of all motor vehicle deaths, while multi-vehicle collisions contribute to almost 45 percent of motor vehicle deaths.

I formulated the hypothesis that a variety of factors relating to human, roadway and vehicle effects are associated with motor vehicle accident injuries. I attempted to identify those that are strongly associated with injury severities. A focused study on single- and two-vehicle driver occupant only accidents using empirical data from the Washington State Patrol's accident database was conducted. I compiled over a 79-month period in Washington State from 1990 to 1996, detailed accident reports on over 127,000 cases.

<u>Objectives</u>

A multi-variate analytical framework that is robust and helps identify the marginal impact of important policy variables related to seat belt use, drunk driving enforcement and driving age related issues, while controlling for vehicle and roadway influences, was developed. It is also our objective to develop a framework with commonly available data without placing undue demands on data collection. Such a method will enhance the portability of our approach to be applicable to a variety of locales.

Method

Statistical methods relating to the analysis of ordinal and discrete outcomes were employed. The developed models also incorporated heterogeneity. Heterogeneity refers to effects that are not measured for various reasons. In our context, not measured implies not measurable, could be measured but was not measured for economic reasons, as well as unknown and hence not measurable. The impact of heterogeneity and correlation that exists in severity contexts is at the very least, loss in statistical efficiency of parameters in the model. As a result, strong associations can be imprecisely identified.

Using a variety of techniques within this broad category of analysis, common denominator variables that were found to be strongly associated with driver only occupant severities were identified. These methods have been embraced by WSDOT as potential frameworks for implementing their safety project prioritization plan. Three model types known as extensions of the generalized extreme value model were examined. The multinomial logit is the simplest and most popular form. However, its structure impedes incorporation of heterogeneity. By definition, the multinomial logit assumes all outcomes are identically and independently influenced by random effects that are unobserved. As alternatives, in order to address the heterogeneity problem, the nested logit, the heteroskedastic logit and the covariance heterogeneity logit structures were examined. These structures are uniquely flexible in accommodating heterogeneity. The idea behind examining these structures is the need for robustly identifying a set of strong associations in terms of infrastructure variables.

Results

Factors relating to driver sobriety, seat belt use, human error in driving, vehicle type, type of collision and type of object struck appeared to strongly associate with injury. The findings reinforce in a single multi-variate framework insights from case-controlled studies on seat belt use and driver sobriety. Over 300,000 individual accidents were initially examined, and culled to include 127,000 accidents for final model development. Separate models of injury outcomes were developed for single-vehicle and two-vehicle accidents. Several hundred model specifications were tested prior to the finalization of model structures. Due to the variety of structures that are possible within the nested logit class of models, the modeling requirement extended to over a thousand specifications in order to identify the preferred structure. The nested logit analysis showed that after substantial testing heterogeneity and correlation effects are not clearly accommodated using a nested logit structure, thereby creating an argument for more sophisticated and flexible structures such the heteroskedastic and covariance heterogeneity models.

Due to data constraints, multi-vehicle accidents involving three or more vehicles were not addressed. Furthermore, in two-vehicle accidents, vehicle mass difference effects are distinct, if they in fact exist as strong associations.

Conclusion

The benefits of this research are numerous – it presents a multi-variate analytical framework that is robust by incorporating the heterogeneity issue in modeling and helps identify the marginal impact of important policy variables related to seat belt use, drunk driving enforcement and driving age related issues, while addressing critical infrastructure issues as well. For example, addressing the sensitivity of injury probabilities to the removal of fixed objects is a critical infrastructure issue. A decision maker can use the results of this model to estimate benefits in terms of societal cost reductions and compute the benefit cost of fixed object removals or collision protection. In addition, this research also highlights the importance of data types that need to be collected for robust policy development on traffic accident injury prevention. The nested logit model was suggested as the common denominator model to incorporate unobserved heterogeneity between PDO and PINJ. This important modeling capability has the potential to significantly enhance statewide consistency in infrastructure related decision making.

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Glossary

CHM	Covariance Heterogeneity Model
DIS	Disabling Injury
FARS	Fatality Analysis Reporting System
FIML	Full-Information Maximum Likelihood
FIML-NL	Full-Information Maximum Likelihood Nested Logit
GEV	Generalized Extreme Value
HEV	Heteroskedastic Extreme Value
IIA	Independence of Irrelevant Alternatives
i.i.d.	Independently and Identically Distributed
LIML	Limited-Information Maximum Likelihood
MNL	Multinomial Logit
NHTSA	National Highway Traffic Safety Administration
NL	Nested Logit
NONDIS	Non-Disabling Injury
PINJ	Possible Injury
PDO	Property Damage Only
VMT	per 100 million vehicle miles traveled
WSDOT	Washington State Department of Transportation

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Most importantly, I am deeply grateful to all my family members for their endless love and unlimited support and encouragement. Without them, I would not have been able to accomplish this degree.

Lastly, I would like to thank all the supervisory committee members for revising and providing comments and inputs. I also would like to appreciate all the love and care from TIMG (Transportation Infrastructure Modeling Group supervised by Professor Venky Shankar) and friends and relatives all over the world. Thank you all very much.

Dedication

To my grandfather, grandmother, parents, my wife, I-Min, and lovely daughter, Jenny.

Chapter 1: Introduction

1.1 Research Motivation and Objective

The hypothesis is a variety of factors relating to human, roadway and vehicle effects are associated with motor vehicle accident injuries. I attempt to identify those that are strongly associated with injury severities. A focused research on single- and two-vehicle accidents using empirical data from police accident reports was conducted. Data over a 79-month period in Washington State from 1990 to 1996 were compiled, detailed accident reports on over 127,000 cases.

The objective is to develop a robust multi-variate analytical framework that helps identify the marginal impact of important policy variables related to seat belt use, drunk driving enforcement and driving age related issues, while controlling for vehicle and roadway influences. It is also the objective in this research to develop a framework with commonly available data without placing undue demands on data collection. Such a method will enhance the portability of the approach to a variety of locales.

1.2 Research Approach and Description

In order to analyze the severity of accident, I begin with the development of a severity model conditioned on the event that an accident has occurred. The severity of the accident consists of five separate categories: (1) property damage only (PDO), (2) possible injury (PINJ), (3) non-disabling injury (or evident injury) (NONDIS), (4) disabling injury (DIS), and (5) fatality, which are to be modeled. Statistical methods relating to the analysis of ordinal and discrete outcomes are employed. Using a variety of techniques within this broad category of analysis, common denominator variables that were found to be strongly associated with occupant severity were identified. The model developments start from the multinomial logit model (MNL) and then nested logit model (NL). The MNL model is a good starting point since it has well-understood properties in terms of parameter behavior. Furthermore, the specification in the MNL allows for unordered severity analysis. In order to derive the robust model and multi-variate analytical framework to provide the insights of the development of the robust policy and the importance of data types that need to be collected, the covariance heterogeneity model (CHM) and the heteroskedastic extreme-value model (HEV) are proposed in the research.

The basic approach to the accident severity modeling problem embodied in this research is "frequentist," that is, under the notion of repeated sampling, how parameters behave under a variety of model assumptions. The important assumptions focused on in this dissertation relate to the independence and distribution of error terms. Given these basic modeling premises, this dissertation is organized as follows:

Chapter 2 presents the relevance of the problem to transportation infrastructure programming and policy.

Chapter 3 presents the empirical settings of this research and serves as a descriptive backdrop of the database used to develop the models.

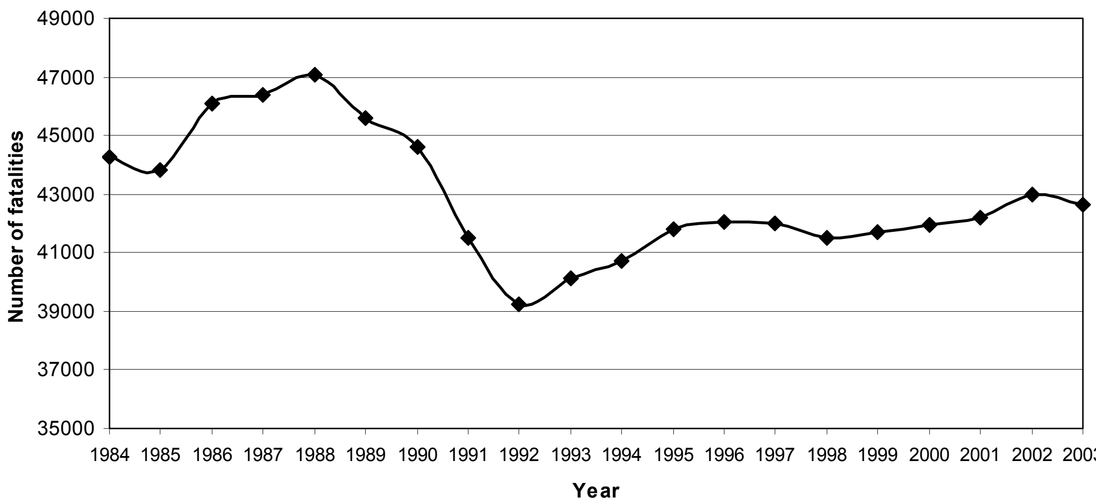
Chapter 4 presents the analytical approach of this research for single- and two- vehicle accident severities and the modeling structures including nested logit model (NL), covariance heterogeneity model (CHM) and heteroskedasticity extreme-value model (HEV).

Chapter 5 presents the results from the modeling estimations along with interpretations. Furthermore, variable elasticities are also shown in this chapter.

Finally, in Chapter 6 the dissertation conclusions and recommendations will be shown as well as policy implications and suggestions for further research.

Chapter 2: Relevance of the Problem to Transportation Infrastructure Programming and Policy

From a historical perspective, the number of fatalities on the entire roadway system in the United States ranged between 45,000 to 47,000 in the late 80s. This range included drivers, passengers, pedestrians and bicyclists. In the 1990s, fatal accident cases dropped down to the 41,000 to 43,000 range. However, more than 40,000 people are killed per year on the roadway system in the nation. Figure 1 shows the number of fatalities in the United States in 1984 to 2003.

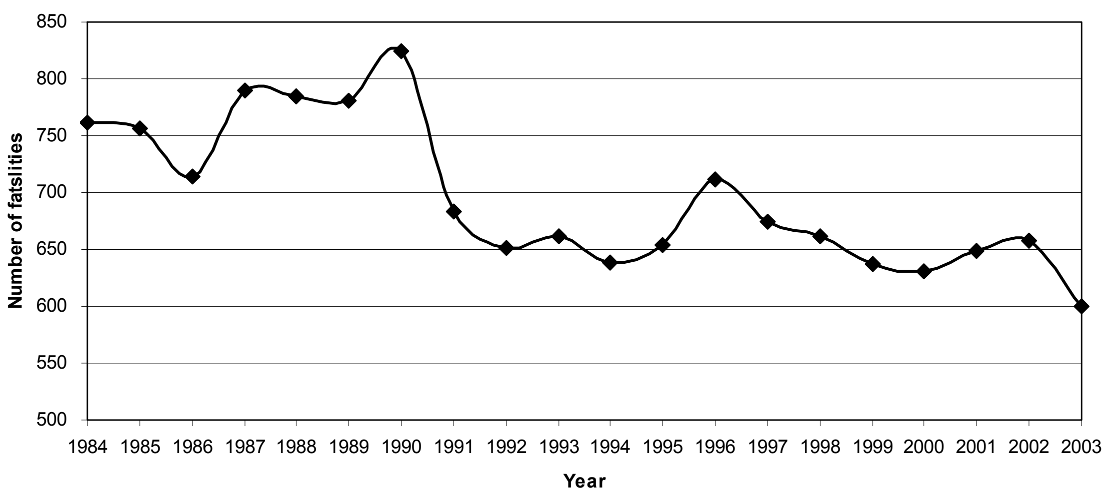


Source: Washington State Department of Transportation (WSDOT)

Figure 1 Number of fatalities on the roadway system in the United States from 1984 to 2003

According to the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) Web Based Encyclopedia, "more than 6.3 million police-reported motor vehicle crashes occurred in the United States in 2003. Almost one-third of these crashes resulted in an injury." "Forty percent of fatal crashes involved alcohol. For fatal crashes occurring from midnight to 3 a.m., 77 percent involved alcohol." "More than half of fatal crashes occurred on roads with posted speed limits of 55 mph or more, while only 25 percent of property-damage-only crashes occurred on these roads. (NHTSA FARS 2003)." It is obvious that several main factors caused accidents as well as fatalities.

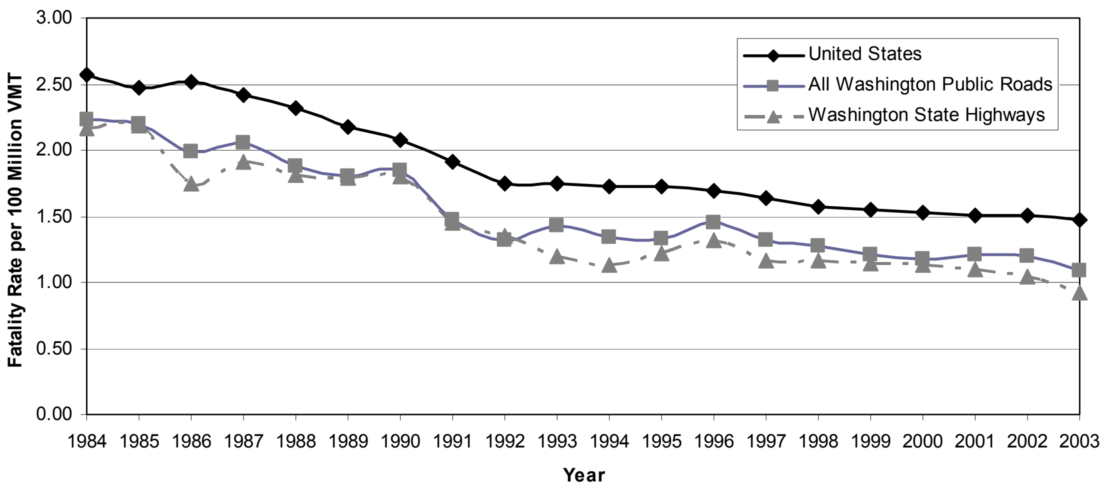
The historical trend over decades showed motor vehicle fatalities in Washington State steadily increasing to more than 1,000 persons per year in 1979. But since then the fatality toll has declined to the mid 600 range in the years 1998 to 2002. In 2003, there were 658 fatal accidents in Washington State. Figure 2 presents the number of fatalities in Washington State.



Source: Washington State Department of Transportation (WSDOT)

Figure 2 Number of fatalities on the roadway system in Washington State from 1984 to 2003

When the fatality rate is considered, since VMT has grown almost twice as fast as population, the decline in annual fatality rate in relation to VMT is more pronounced than the decline in fatality rate per capita. Fatality rates are commonly expressed as deaths (the numerator) per 100 million vehicle miles traveled (the denominator). Because the denominator – the amount of driving – has grown so fast and far, the fatality rate per 100 million vehicle miles traveled (VMT) has tended to steadily decline from 1915 forward. It is to develop a multi-variate analytical framework that is robust and helps identify the marginal impact of important policy variables affect this trend. By investigating the local context of Washington State as shown in figure 3 below, it is also our objective to develop a framework with commonly available data without placing undue demands on data collection.



Source: Washington State Department of Transportation (WSDOT)

Figure 3 Motor vehicle fatality rates in Washington and in the United States

Chapter 3: Empirical Setting

In this chapter, data assembly and severity distributions of key variables are described.

3.1 Data Assembly

This research focuses on single- and two-vehicle driver only severities using empirical data from the Washington State Patrol's accident database. Data in the 79-month period from January 1990 to July 1996 is used. These data provide over 280,000 observations of unique, reported vehicle collisions and severity throughout the Washington state highway system. Accidents involving more than two vehicles were not considered in this research. The accidents did not contain full information; for example, many variables described as "unstated" or "unknown," were eliminated from the data. Over 127,000 detailed single- and two-vehicle accidents which were reported fully without any non-stated or unknown information were compiled. Again, the universal severity set consists of five discrete accident severity types, including no injury (or property damage only (PDO)), possible injury (PINJ), non-disabling injury (NONDIS) (or evident injury), disabling injury (DIS) and fatality. Table 1 below shows the distributions of severities of drivers for single- and two-vehicle accidents.

There were a total number of 31,360 and 96,600 accident samples of single- and two-vehicle accidents respectively from 1990 to 1996 after the data assembly for this research. The particular severity having the greatest number of accidents for single- and two-vehicle accident settings was PDO with 57.08% in single-vehicle accidents and 78.89% in two-vehicle accidents. These indicate that the majority of accidents fall in low severities. Combing DIS and Fatality, they had proportions of 6.11% and 1.46% in single- and two-vehicle accidents respectively.

Table 1 Distributions of driver's severity for single- and two-vehicle accidents

Driver's Severity	Percentage		No of Accidents	
	Single-Vehicle	Two-Vehicle	Single-Vehicle	Two-Vehicle
PDO	57.08	78.89	17900	76209
PINJ	15.25	13.92	4781	13446
NONDIS	21.56	5.73	6762	5538
DIS	5.04	1.26	1582	1214
Fatality	1.07	0.20	335	193
Sub-Total	100.00	100.00	31360	96600
Total	100.00		127960	

The data include information that is quite appealing for the modeling of driver accident severity. The accident specific information contains driver, vehicle, roadway, junction and accident characteristics. Furthermore, driver characteristics include not only drivers' general information, such as driver's sex, age and so on, but also the usage of restraints, ejection, sobriety and drivers' contributing circumstances, such as exceeding the speed limits or reasonably safe speed, falling asleep, following too close and so on. Vehicle characteristics include vehicle types (car, pickup, truck, bus, etc.), year, posted speed, contributing vehicle defects (e.g. defective brakes, defective lights, tire blown, etc.) and so on. Roadway and junction characteristics include site geometrics (e.g. presence of horizontal curve, or hillcrest or sag vertical curves), locations and junction relations, surface conditions (e.g. dry, wet snowy or icy), time (e.g. dawn, day, dust or night), weather condition (e.g. clear/cloudy, raining, snowing or foggy) and street lighting conditions (e.g. presence of street lights and they are on or off) at the time of accidents occurred. Accident characteristics include collision types, defined by the Washington State Patrol, accident locations, and object struck for fixed objects collisions. From the master accident record system, the single vehicle accident object struck roadside accidents are also parsed. The types of object struck include wood or metal sign posts, guide posts, guardrail face or concrete barrier, guardrail or bridge rail leading end, trees or stumps, light poles, utility poles, railway poles, traffic sign poles, overhead sign support poles, sign boxes, bridge columns or pillasr and so on.

Based on the Washington State Patrol collision type records, the information of collision types can be aggregated into eight main categories. They are entering at angle, same direction, opposite direction, over turn, fixed object, rear end, other objects and "other" collision types. The "other" collision types include pedestrian accidents, collision with trains, with pedalcyclists and with animals. Table 2 shows the distribution of collision types for single- and two-vehicle accidents. From Table 2, fixed object collisions were of the greatest percentage in single-vehicle accidents with 72.95%, compared to 25.6% for the collision type overturn. It would be a critical issue in terms of safety improvement of roadway systems. In two-vehicle accidents, the collision type rear end has the greatest proportion with 41.37%. In addition, the collision type same direction experienced a significant number of accidents with 32.41%. Another major collision type in two-vehicle accidents is opposite direction at 10.53%.

Table 2 Distributions of collision types for single- and two-vehicle accidents

Collision Types	Percentage		No of Accidents	
	Single-Vehicle	Two-Vehicle	Single-Vehicle	Two-Vehicle
Entering Angle	0.00	14.33	0	13844
Same Direction	0.00	32.41	0	31306
Opposite Direction	0.00	10.53	0	10174
Over Turn	25.60	0.06	8028	56
Fixed Object	72.95	1.19	22878	1150
Rear End	0.00	41.37	0	39964
Other Objects	0.00	0.07	0	64
Other Collision Types	1.45	0.04	454	42
Sub-Total	100.00	100.00	31360	96600
Total	100.00		127960	

3.2 Severity Distributions By Key Variables

Table 3 and 4 show the driver severity distribution for single-vehicle driver only occupant and two-vehicle driver only occupant accidents by key variables respectively. The driver, vehicle, roadway and accident characteristics are discussed in the following sections.

3.2.1 Single-Vehicle Accidents

3.2.1.1 Driver Characteristics

Driver's gender, age and their contribution, such as whether or not they had been drinking, whether or not they used any restraints and whether or not they had been totally ejected, are key driver characteristics. In the dataset, male driver accidents were 21672 cases out of 31360 (69.11%). There were 1049 DIS cases (4.84%) and 281 fatalities (1.30%) in male driver accidents, compared to 533 DIS cases (5.50%) and 54 fatalities (0.56%) in female driver accidents. There were 7527 accidents which were the cases of driver had been drinking. There were 743 DIS cases (9.87%) and 221 fatalities (2.94%). There were 4874 accidents in which drivers did not use any restraints and 790 of them (16.21%) were DIS and 249 of them (5.11%) were fatalities. 524 accidents involved a driver who had totally been ejected. There were 225 (42.94%) DIS and 141 (26.91%) fatalities.

3.2.1.2 Vehicle Characteristics

Passenger cars and pick-ups were the two main types of vehicles in single-vehicle accidents. 18046 (57.54%) accidents were passenger car accidents and 11075 (35.32%) were pick-up accidents.

3.2.1.3 Roadway Characteristics

As can be seen in Table 3, 16248 accidents (51.81%) occurred on dry surfaces in single-vehicle accidents, compared to 7767 (24.77%) on wet surfaces, 1942 (6.19%) on snowy surfaces and 5403 (17.23%) on icy surfaces. Furthermore, dry surfaces involved higher DIS and fatality percentages (1060 DIS and 251 fatalities out of 16248 accidents, 6.52% and 1.54% respectively) compared to other surface conditions (show numbers). These imply that drivers may drive faster and pay less attention while the roadway surface was dry.

Comparing roadway (accidents) locations, accidents that occurred in rural areas were more severe than those in urban areas. Based on the sample, 1043 (5.87%) DIS accidents and 242 (1.36%) fatalities occurred in rural areas while 539 (3.96%) DIS and 93 (0.68%) fatalities occurred in urban areas. These could imply that in rural areas, speeds traveled were higher, or emergency response was not timely. Infrastructure improvements related to roadway conditions, emergency services and hospital networks would be critical in rural areas in order to improve the safety on the roadway systems.

3.2.1.4 Accidents Characteristics

As mentioned previously, fixed object collisions were the predominant type of collision in single-vehicle accidents. The other main type of collision, over turn, resulted in a greater proportion of severe accidents with 499 DIS cases (6.22%) and 117 fatal cases (1.46%) compared to 1074 (4.69%) DIS and 216 (0.94%) fatalities in fixed object collisions.

Among the types of object struck, guardrail or bridge rail leading end resulted in the highest fatality proportion (3.35%) compared to 1.68% for tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box , bridge column or pillar. Roughly 0.61% of accidents involving wood or metal sign post or guide post or guardrail face or concrete barrier were fatal.

Table 3 Accident severity distribution by key variables for single-vehicle driver only occupant accidents (total of 31360 accidents)

	Severity Frequency					
Variable	Property Damage Only	**Possible Injury**	**Non-Disabling Injury**	**Disabling Injury**	**Fatality**	**Total**
Driver Characteristics						
Male driver	13028	2672	4642	1049	281	21672
Female driver	4872	2109	2120	533	54	9688
Driver's age greater than 55 years old	1766	427	704	190	56	3143
Driver had been drinking	3164	974	2425	743	221	7527
Driver did not use any restraints	1349	671	1815	790	249	4874
Driver had been totally ejected	11	27	120	225	141	524
Vehicle Characteristics						
Passenger car	9956	3037	3898	962	193	18046
Pick-up	6386	1518	2489	558	124	11075
Roadway Characteristics						
Dry surface	8243	2468	4226	1060	251	16248
Wet surface	4606	1269	1478	347	67	7767
Snowy surface	1439	249	219	30	5	1942
Icy surface	3612	795	839	145	12	5403

Table 3 Accident severity distribution by key variables for single-vehicle driver only occupant accidents (total of 31360 accidents) (Continued)

Severity Frequency						
Variable	Property Damage Only	**Possible Injury**	**Non-Disabling Injury**	**Disabling Injury**	**Fatality**	**Total**
Urban area	8032	2345	2589	539	93	13598
Rural area	9868	2436	4173	1043	242	17762
Accident Characteristics						
Overturn	3961	1355	2096	499	117	8028
Fixed object	13564	3391	4633	1074	216	22878
Object struck - driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box , bridge column or pillar	1769	506	797	265	57	3394
Object struck - driver struck guardrail or bridge rail leading end	159	68	125	23	13	388
Object struck - driver struck wood or metal sign post or guide post or guardrail face or concrete barrier	5443	1309	1457	268	52	8529

3.2.2 Two-Vehicle Accidents

3.2.2.1 Driver Characteristics

Driver's gender, age and their contribution, such as whether or not they had been drinking, whether or not they used any restraints, whether or not they had been totally ejected, whether or not they exceeded the reasonably safe speed and whether or nor they followed the front vehicles too closely, are key variables in driver characteristics in two-vehicle accidents. In the dataset, male driver involved accidents were 61156 cases out of 96600 (63.31%). Considering DIS and fatal are high severities, male driver involved accidents showed approximately 1.2% in high severities comparing to 1.9% for female driver involved accidents. There were 7527 accidents which were the cases of driver had been drinking. 79 accidents involved that accident-considered driver had totally been ejected. There were 22 (27.85%) DIS and 21 (26.58%) fatalities. It indicates that the accidents would become more severe if the driver was ejected totally. Therefore, restraints usage would be one of the critical effects in accidents.

3.2.2.2 Vehicle Characteristics

For two-vehicle accidents, vehicle interactions are also important characteristics in terms of the severity-considered vehicle and the other vehicle. The severity-considered vehicle is the vehicle for which driver severity is being analyzed. By this definition, a two-vehicle accident will result in two rows of data. As can be seen in Table 4, the bigger the mass of the vehicle, the higher the fatalities proportion. Fatality proportion rises from

0.09% (54 out of 57983 accidents) for passenger car to 0.22% (67 out of 31108 accidents) for pick-up and to 1.14% (56 out of 4916 accidents) for truck.

3.2.2.3 Roadway Characteristics

The severity distributions in two-vehicle accidents, combining both DIS and fatality as high severity, show that fatality proportion for icy surface was the highest, 2.47% (72 out of 2910 accidents), compared to 1.48% (29 out of 1956 accidents) for snowy surface, 1.33% (364 out of 27376 accidents) for wet surface and 1.46% (942 out of 64358 accidents) for dry surface.

In terms of roadway locations, two-vehicle accidents in rural areas were more severe in terms of driver severity than those in urban areas. 465 (2.57%) DIS accidents and 143 (0.79%) fatalities occurred in rural areas while 749 (0.95%) DIS and 50 (0.06%) fatalities occurred in urban areas.

3.2.2.4 Junction Characteristics

Whether or not the accident happened at an intersection or related was considered in junction characteristics. As can be seen, (DIS rates and fatality rates combined) comprised 1.57% (901 out of 57258 accidents) of accidents at intersections or related areas.

3.2.2.5 Accident Characteristics

As mentioned before, opposite direction, same direction and rear end were three main types of collisions in two-vehicle accidents. Opposite direction experienced the highest DIS and fatality proportions with 413 (4.06%) DIS and 138 (1.36%) fatalities compared to 245 (0.78%) DIS and 14 (0.04%) fatalities for same direction collisions and 287 (0.72%) DIS and 11 (0.03%) fatalities for rear end collisions. Opposite direction could potentially be prevented by installing barriers or guardrails. This could be a critical infrastructure factor for roadway safety programming.

Given this broad perspective in terms of the relative distributions of key variables associated with driver injuries in single and two-vehicle accidents, a suite of methods suitable for addressing this multi-variate context is presented in the following chapter

Table 4 Accident severity distribution by key variables for two-vehicle driver only occupant accidents (total of 96600 accidents)

Severity Frequency						
Variable	Property Damage Only	**Possible Injury**	**Non-Disabling Injury**	**Disabling Injury**	**Fatality**	**Total**
Driver Characteristics						
The severity-considered driver is male	50832	6474	3115	622	113	61156
The other driver is male	47501	8766	3865	871	153	61156
The severity-considered driver is female	25377	6972	2423	592	80	35444
The other driver is female	28708	4680	1673	343	40	35444
The severity-considered driver's age greater than 55 years old	10673	1653	848	201	51	13426
The other driver's age greater than 55 years old	10522	1847	840	188	29	13426
The severity-considered driver had been drinking	2587	376	528	145	46	3682
The other driver had been drinking	2367	791	388	112	24	3682
The severity-considered driver did not use and restraints	2961	835	885	300	99	5080
The other driver did not use and restraints	3388	906	559	178	49	5080

Table 4 Accident severity distribution by key variables for two-vehicle driver only occupant accidents (total of 96600 accidents) (Continued)

	Severity Frequency					
Variable	Property Damage Only	**Possible Injury**	**Non-Disabling Injury**	**Disabling Injury**	**Fatality**	**Total**
The severity-considered driver had been totally ejected	14	4	18	22	21	79
The other driver had been totally ejected	51	7	13	4	4	79
The severity-considered driver exceeded reasonably safe speed	9394	1054	613	129	11	11201
The other driver exceeded reasonably safe speed	7818	2651	610	116	6	11201
The other driver followed too closely	7402	2679	475	70	0	10626
Vehicle Characteristics						
The severity-considered vehicle is passenger car	43569	9561	3821	889	143	57983
The other vehicle is passenger car	46604	7839	2889	597	54	57983
The severity-considered vehicle is pick-up	25524	3649	1582	308	45	31108
The other vehicle is pick-up	24193	4488	1944	416	67	31108
The other vehicle is truck	3486	734	485	155	56	4916

Table 4 Accident severity distribution by key variables for two-vehicle driver only occupant accidents (total of 96600 accidents) (Continued)

	Severity Frequency					
Variable	Property Damage Only	**Possible Injury**	**Non-Disabling Injury**	**Disabling Injury**	**Fatality**	**Total**
Roadway Characteristics						
Dry surface	50778	8919	3719	802	140	64358
Wet surface	21468	4011	1533	324	40	27376
Snowy surface	1638	185	104	25	4	1956
Icy surface	2325	331	182	63	9	2910
Urban area	62728	11160	3843	749	50	78530
Rural area	13481	2286	1695	465	143	18070
Junction Characteristics						
At intersection and related	45357	7825	3175	745	156	57258
At intersection but not related	73882	13076	5412	1178	188	93736
Intersection related but not at intersection	74550	13061	5426	1192	191	94420
Non-intersection and not related	43743	7796	3249	670	48	55506
Accident Characteristics						
Opposite direction	7011	1444	1168	413	138	10174

Table 4 Accident severity distribution by key variables for two-vehicle driver only occupant accidents (total of 96600 accidents) (Continued)

Severity Frequency						
Variable	Property Damage Only	**Possible Injury**	**Non-Disabling Injury**	**Disabling Injury**	**Fatality**	**Total**
Same direction	26690	3001	1356	245	14	31306
Rear end	30838	6974	1854	287	11	39964

Chapter 4: Analytical Approach and Modeling Structures

In order to analyze the severity of accidents, I began with the development of a severity model conditioned on the event that an accident has occurred.[1] Furthermore, the probability of a specific type of severity when an accident occurs is the main outcome of the models.

As mentioned in the empirical setting chapter, based on the universal severity set, the severity of the accident consists of five separate categories: (1) property damage only (PDO), (2) possible injury (PINJ), (3) non-disabling injury (or evident injury) (NONDIS), (4) disabling injury (DIS), and (5) fatality. Statistical methods relating to the analysis of ordinal and discrete outcomes were employed. Using a variety of techniques within this broad category of analysis, common denominator variables that were found to be strongly associated with occupant severity were identified. These methods have been embraced by the Washington State Department of Transportation as potential frameworks for implementing their safety project prioritization plan.

The methodology for this research focuses specifically on the driver only occupant severity.[2] The analysis of severities of pedestrian and of other passengers was not conducted in this research. The analysis was separated into single vehicle driver only

[1] For a statistical model of the likelihood of an accident occurring, the reader is referred to earlier work on accident frequencies (Milton and Mannering, 1996; Shankar, Milton and Mannering 1997).

[2] For the remainder of the document severity refers to the driver only occupant severity.

occupant severity analysis and two vehicles driver only occupant severity analysis. A priori justification for this separation of models involves the significance of parameters in single vehicle and two vehicle models. Model specifications could be different between the two cases, arguing against a single model that captures both single and two vehicle accident patterns. An accident was excluded if there were more than two vehicles involved. Econometric methodologies were used in this research to provide insight of the causation of specific driver severity in single- and two- vehicle accidents. The following figure shows the analytical framework of this research.

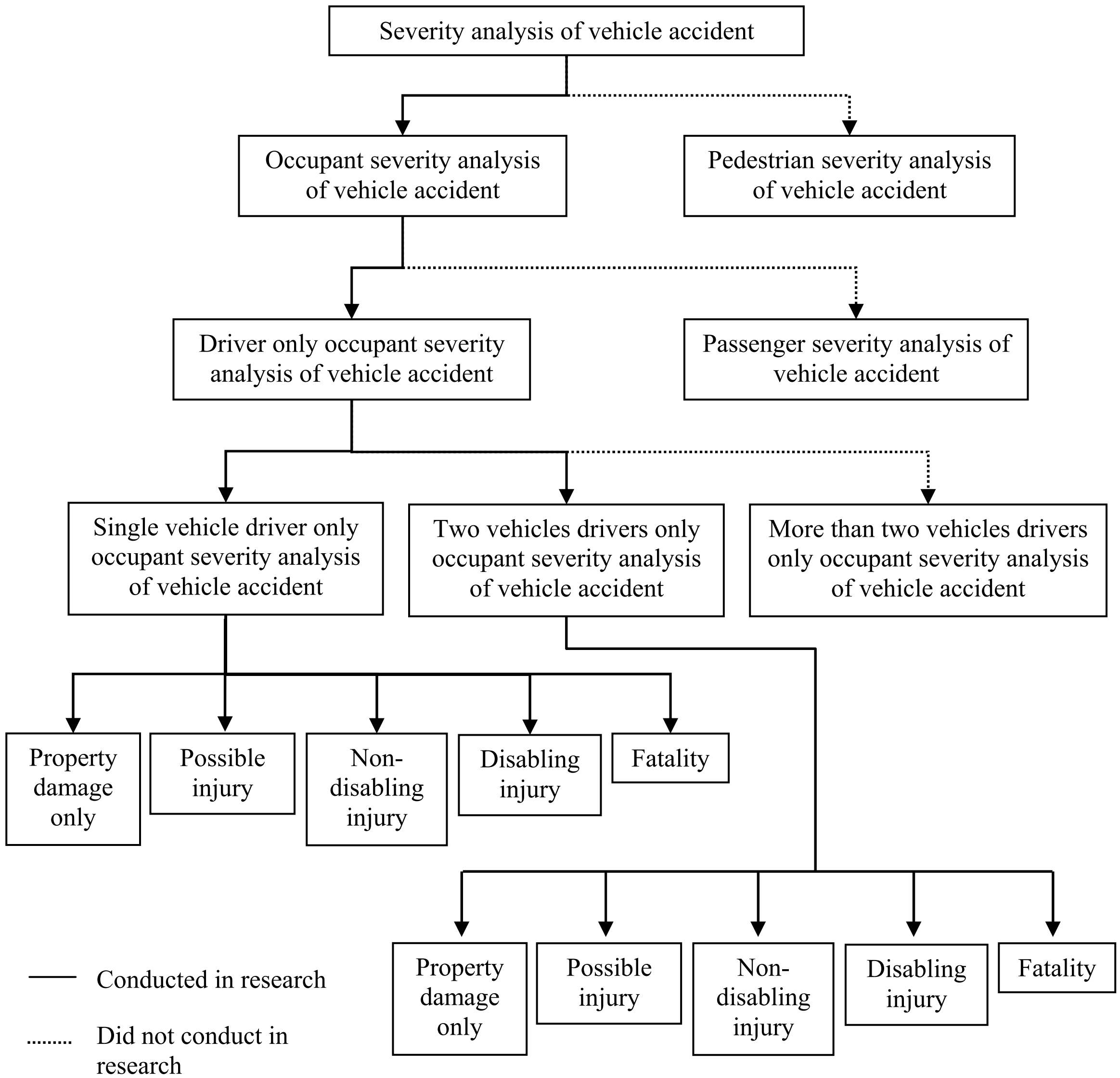


Figure 4 Analytical framework of research

Several variants of the Generalized Extreme Value (GEV) family of models are formulated in this research. Furthermore, the analysis of this research also tries to accommodate heterogeneity across individuals due to both observed and unobserved individual effects.

First, the multinomial logit model (MNL) with standard likelihood estimation techniques was estimated. Then nested logit models (NL) of ten different nested logit structures with the full information maximum likelihood (FIML) estimation technique were estimated. Each of these techniques is used for driver severity in both single- and two-vehicle accidents. Since the sequential estimator is found to be less efficient and the second stage standard errors estimates are found to be downward biased, the FIML is the preferred estimation technique (Brownstone and Small 1989) over sequential estimation and the sequential estimation was not conducted in the estimation of nested logit structure. In addition to MNL and NL models, covariance heterogeneity models (CHM) and heteroskedastic extreme-value models (HEV) were also formulated to address the heterogeneity issues and accommodate them. These two types of models were estimated for all 10 nested structures of nested logit models. The following subsections show the methodology of each model.

4.1 Multinomial Logit Model (MNL)

To set up the model that applies when the data are individual accident specific, the multinomial logit model (MNL) will help especially when there are more than two choices. Shankar, Mannering and Barfield (1996) adapted the GEV approach (McFadden 1981) to the severity context by employing the following formulation:

$$P_n(i) = P(S_{in} \geq S_{In}) \quad \forall\, I \neq i \qquad (4.1.1)$$

where the probability of an accident n and associated severity i is given by $P_n(i)$, where P implies the probability and S_{in} is a function of a set of exogenous variables that determine the likelihood of a specific severity type i of accident n (I is the set of possible severities). This function can be expressed in a linear form such that,

$$S_{in} = \beta_i \mathbf{X}_n + \varepsilon_{in} \qquad (4.1.2)$$

where β_i is a vector of statistically estimable coefficients and X_n is a vector of measurable characteristics (e.g. drivers characteristics, roadway characteristics, weather, accident characteristics, etc.) and ε_{in} is the disturbance term influencing accident severity and is independently and identically distributed (IID) with a GEV distribution.[3] The $\beta_i X_n$ term in this equation is the deterministic component of severity, which describes the measurable characteristics. Given Equations 4.1.1 and 4.1.2, the following can be written,

$$P_n(i) = P(\beta_i X_n + \varepsilon_{In} \geq \beta_I X_n + \varepsilon_{In}) \forall I \neq i \qquad (4.1.3)$$

---

[3] The GEV distribution offers a flexible structure by providing opportunities for the MNL and the nested logit as special cases of a general class of models.

or,

$$P_n(i) = P(\beta_i - \beta_I X_n \geq \varepsilon_{In} - \varepsilon_{in}) \forall I \neq i \qquad (4.1.4)$$

With Equation 4.1.4, an estimable severity model can be derived by assuming a GEV distributional form for the disturbance term. The IID assumption for the unobservable component of severity produces a MNL model

$$P_n(i) = \exp[\beta_i \mathbf{X}_n] \Big/ \sum_I \exp[\beta_I \mathbf{X}_n] \qquad (4.1.5)$$

where all variables are previously defined and β_i is estimable by standard maximum likelihood techniques. Due to the IID assumption, limitations regarding the use of the MNL structure arise. The MNL model by virtue of its IID (also known as the independence from irrelevant alternatives, IIA) assumption cannot accommodate shared unobservables. In other words, the MNL is the simplest and most popular form, but its structure impedes incorporation of heterogeneity. By definition, the multinomial logit assumes all outcomes are identically and independently influenced by random effects that are unobserved. As alternatives, in order to address the heterogeneity problem, the nested logit, the heteroskedastic logit and the covariance heterogeneity logit structures were developed as shown in the following sections.

4.2 Nested Logit Model (NL)

To remedy the potential erroneous predictions caused by shared unobserved effects between severity categories, McFadden (1981) proposed a generalized extreme value model to accommodate these effects. This is referred to as the nested logit model, which groups alternatives with correlation disturbance terms into a nest, allowing the IID constraints on the unobservables to be relaxed.[4]

---

[4] Shankar, Mannering and Barfield's (1996) adapt this to their severity model in a sequential estimation framework by the following formulation: $P_n(i) = \exp[\beta_i \mathbf{X}_n + \Theta_i L_{in}] \Big/ \sum_I \exp[\beta_i \mathbf{X}_n + \Theta_i L_{In}]$,

$$P_n(j\,|\,i) = \exp[\beta_{j|i} \mathbf{X}_n] \Big/ \sum_J \exp[\beta_{J|i} \mathbf{X}_n], \quad L_{in} = \ln\left[\sum_J \exp(\beta_{J|i} \mathbf{X}_n)\right]$$

where the unconditional probability $P_n(i)$ of an accident n having severity i (e.g., the probability of having a fatality accident), $P_n(j|i)$ is the conditional probability of accident n having severity j being in the severity category i (e.g., the probability of having a fatal or disabling injury given that there was no evident injury), J is the conditional set of severity categories (conditioned on i) and I is the unconditional set of severity categories, L_{in} is the inclusive value and is the natural log of the denominator of a conditional choice and can be interpreted as the expected maximum value of the attributes that determine severity probabilities in the lower levels of a partitioned nest of severity category i, Θ_i is an estimable coefficient which must have a value between zero and one to be consistent with the model derivation (see McFadden, 1981). A parameter value of one suggests the MNL model structure. Values between one and zero suggest varying degrees of similarity and if significantly different than one suggest the nest is justified.

I present a formulation adapted from McFadden (1981) for the FIML framework. Ten different two level nested logit structures along with the MNL model were evaluated using this formulation. The probability of severity type (j) attached to injury category (i) given by the common notation where:

$$P(j|i) = \frac{\exp\left(S_{jn|i}/\rho_i\right)}{\sum_i \exp\left(S_{jn|i}/\rho_i\right)} \qquad (4.2.1)$$

$$P(i) = \frac{\exp(\rho_i I_i)}{\sum_i \rho_i I_i} \qquad (4.2.2)$$

$$I_i = \log \sum_j \exp \frac{\left(S_{jn}\right)}{\rho_i} \qquad (4.2.3)$$

I_i is the inclusive value, ρ_i is the dissimilarity parameter unique to a given nest. Furthermore, ρ_i must be greater than 0 and less than 1 in magnitude and significantly different from 0 and 1 to be consistent with the nested logit derivation (McFdden 1981). If ρ_i equals 1, the assumed shared unobserved effects in the nest are not significant and the NL model reduces to a simple MNL model. If ρ_i equals 0, changes in the nest outcome probabilities will not affect the probability of nest selection and the correct model will be recursive. If ρ_i is less than 0, factors increasing the likelihood of an outcome being chosen in the lower nest will decrease the likelihood of the nest being chosen.

The following figure shows an example of a two-level nested structure where i = a,b,c and j = 1,....,5. Note that i = b is a degenerate node.

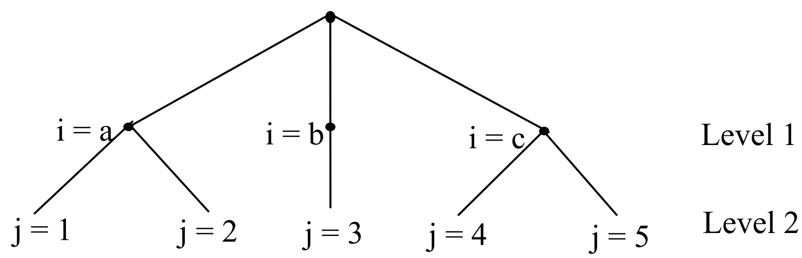


Figure 5 A two level nested logit structure of five discrete severities

The log-likelihood function for FIML estimation consists of the likelihoods at level 1 and level 2 and is given by the following set of equations:

$$L = \sum_n \log P_j \qquad (4.2.4)$$

$$= \sum_n \log P(j|i) + \sum_n \log P(i) \qquad (4.2.5)$$

$$\equiv L_1 + L_2 \qquad (4.2.6)$$

The coefficient vector β appears in both log-likelihoods L_1 and L_2, L_1 also contains the scalar ρ in β/ρ. The sequential estimator relies on this fact by maximizing L_1 in the first stage estimates and using this value to compute I_i: then estimates ρ in the second stage by maximizing L_2. This procedure produces the MNL likelihood form in parameters ρ and β/ρ, for both L_2 and L_1 respectively. The second stage estimate of the MNL estimator produces uncorrected standard-error estimate of $\hat{\rho}$, using the Hessian of L_2. In producing the L_2 estimate the assumption that β/ρ is non-stochastic results in downward biased standard errors.

Full information maximum likelihood simultaneous estimation maximizes L with respect to both β and ρ, using a nonlinear maximization algorithm.[5] The gradient and Hessian are shown below. In so doing, the second-level elements of the variance-covariance matrix are estimated correctly.[6]

$$g = \sum_{n} \frac{\partial \log P(i)}{\partial \theta_i} \quad \text{where} \quad \theta = [\beta_i, \rho_i] \qquad (4.2.7)$$

$$H = \sum_{n} \sum_{i} P(i) \left(\frac{\partial \log P(i)}{\partial \theta_i} \right) \left(\frac{\partial \log P(i)}{\partial \theta_i'} \right) \qquad (4.2.8)$$

---

[5] The full information log likelihood function can present convergence problems for inclusive values near zero (McFadden 1981).

[6] For a two-level nested structure as shown in Figure 1, the variance-covariance matrix is given by

$$\upsilon = \begin{bmatrix} M_{11}^{-1} & -M_{11}^{-1} M_{21}' M_{22}^{-1} \\ -M_{22}^{-1} M_{22} M_{11}^{-1} & M_{22}^{-1} + M_{22}^{-1} M_{21} M_{11}^{-1} M_{21}' M_{22}^{-1} \end{bmatrix}$$

where M_{ii} is the information matrix for the i^{th} level of the nest and is given by

$$M_{ii} = E\left[\frac{\partial \ln L(\theta_i)}{\partial \theta_i} \right] \left[\frac{\partial \ln L(\theta)}{\partial \theta_i'} \right]^{-1}$$

In FIML, the elements involving M_{22} are estimated consistently without downward bias.

Ten model structures examined for the nested logit model (NL) specification were examined and are shown in Figures 6 to 15.

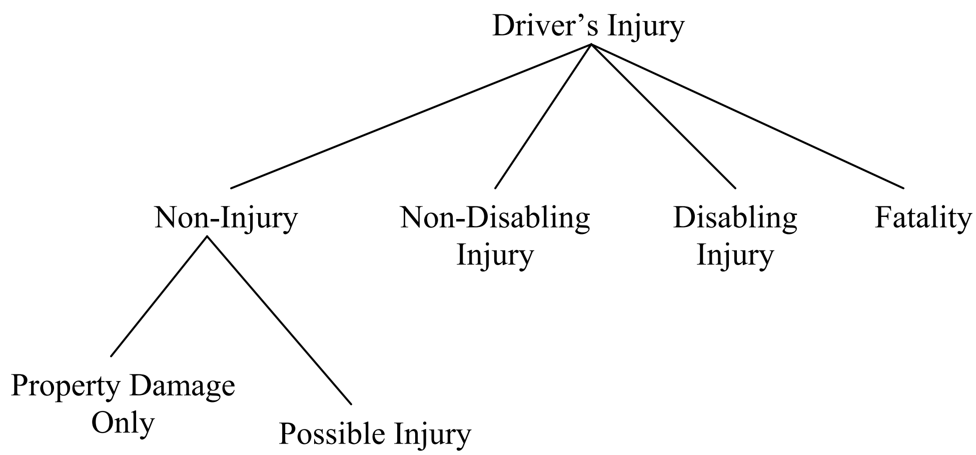


Figure 6 Nested logit structure (Structure 1) with shared unobservables between Property Damage Only and Possible Injury (Statistically Preferred Structure)

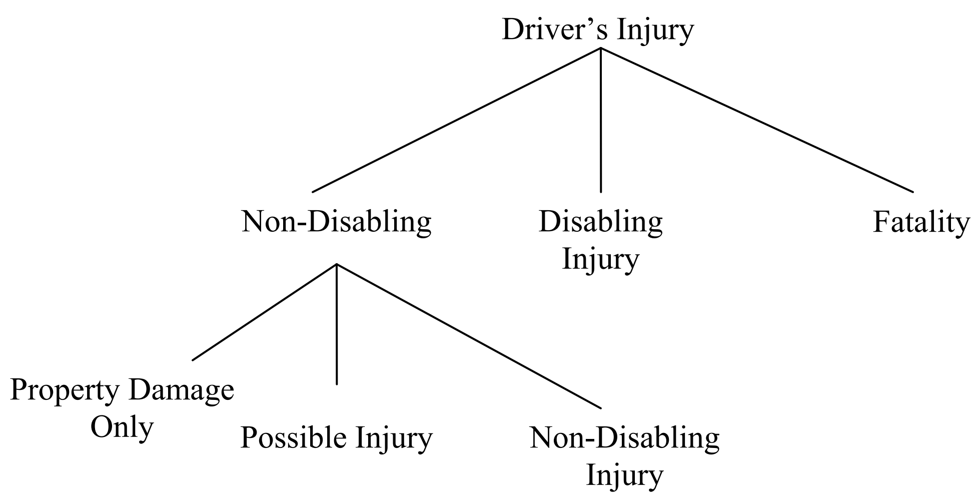


Figure 7 Nested logit structure (Structure 2) with shared unobservables among Property Damage Only, Possible Injury and Non-Disabling Injury

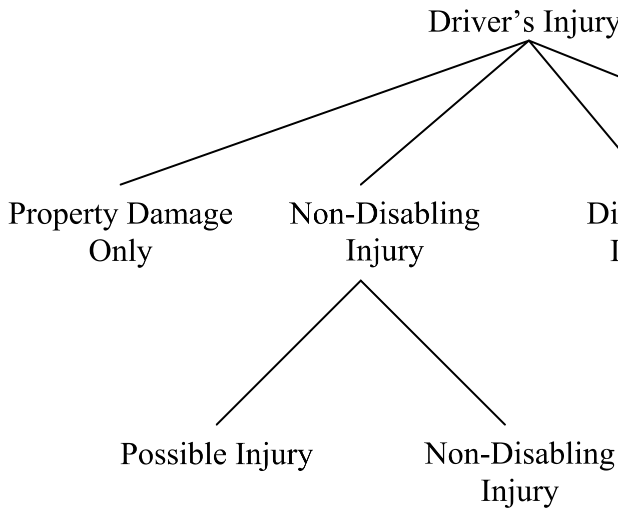


Figure 8 Nested logit structure (Structure 3) with shared unobservables between Possible Injury and Non-Disabling Injury

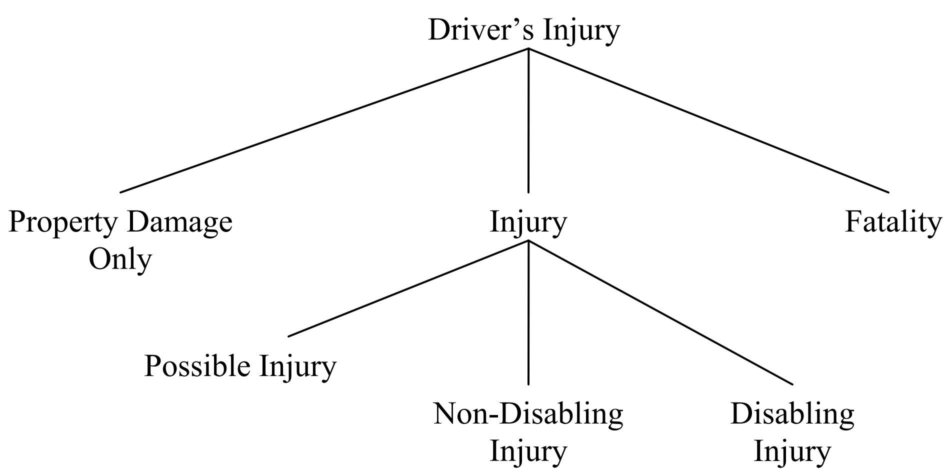


Figure 9 Nested logit structure (Structure 4) with shared unobservables among Possible Injury, Non-Disabling Injury and Disabling Injury

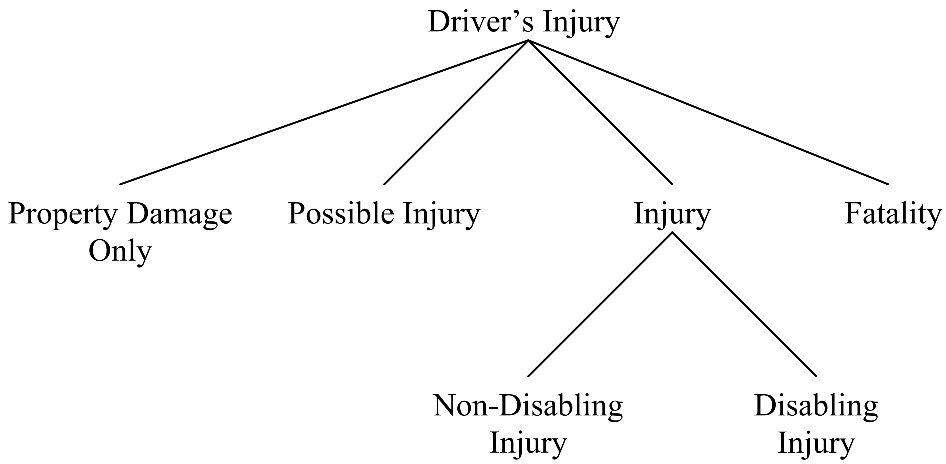


Figure 10 Nested logit structure (Structure 5) with shared unobservables between Non-Disabling Injury and Disabling Injury

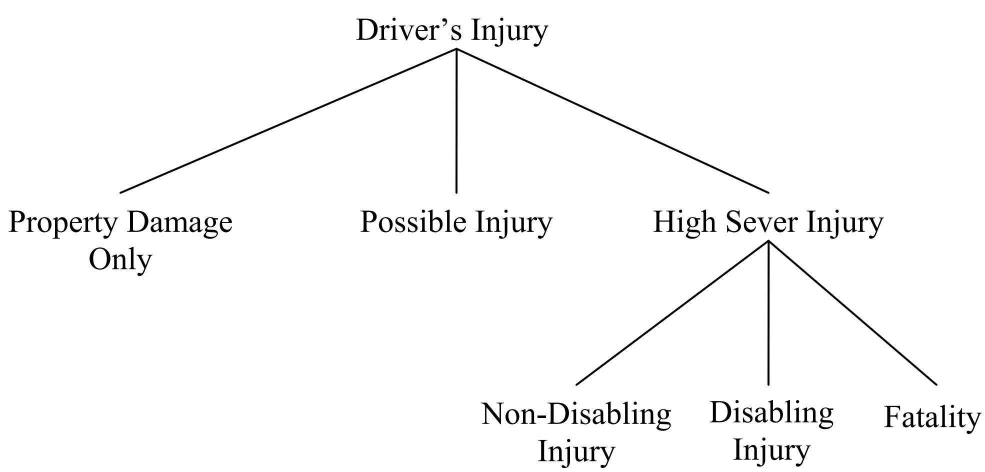


Figure 11 Nested logit structure (Structure 6) with shared unobservables among Non-Disabling Injury, Disabling Injury and Fatality

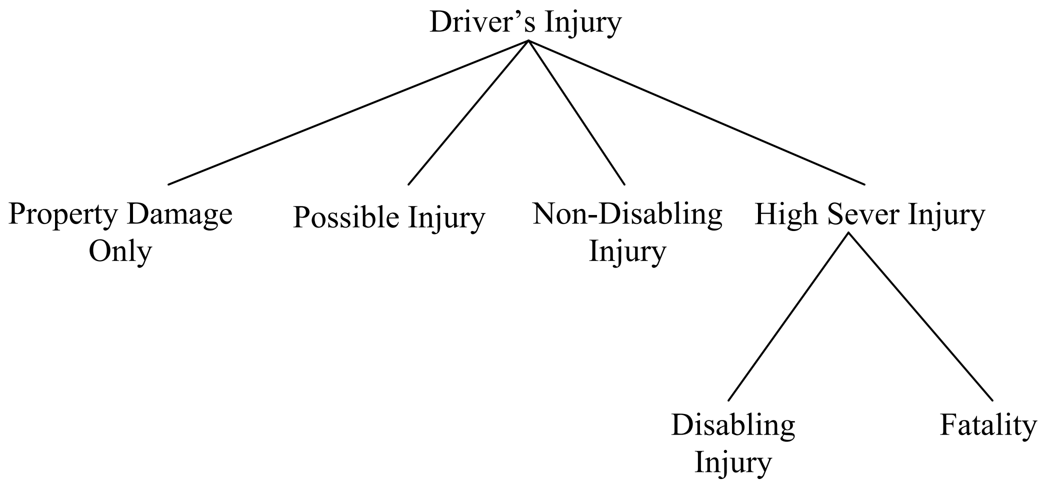


Figure 12 Nested logit structure (Structure 7) with shared unobservables between Disabling Injury and Fatality

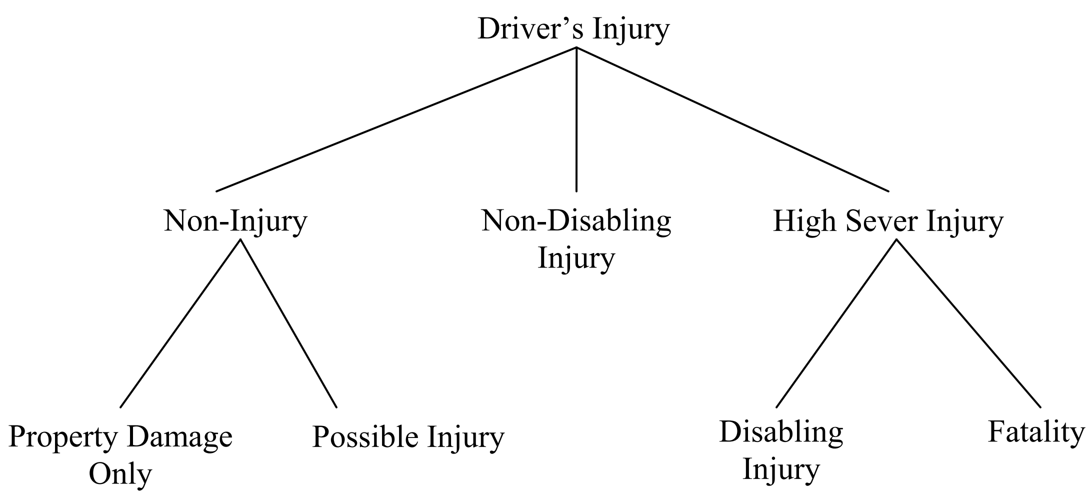


Figure 13 Nested logit structure (Structure 8) with shared unobservables between Property Damage Only and Possible Injury and unobservables between Disabling Injury and Fatality

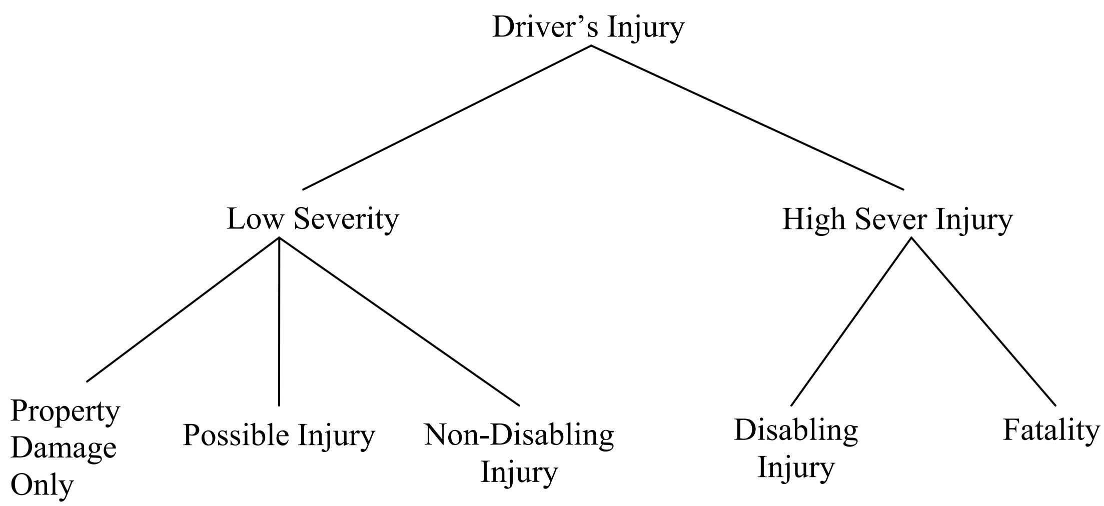


Figure 14 Nested logit structure (Structure 9) with shared unobservables among Property Damage Only, Possible Injury and Non-Disabling and unobservables between Disabling Injury and Fatality; no degenerate severity

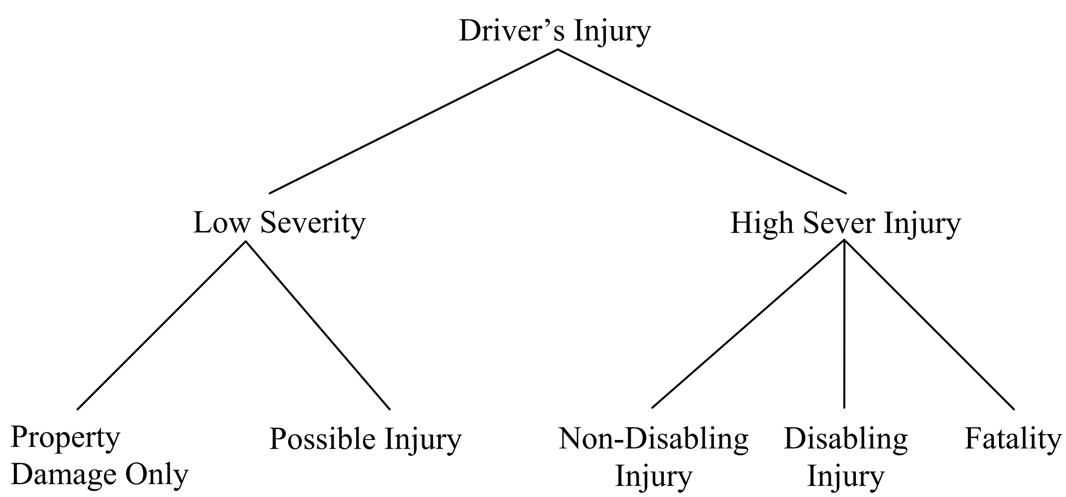
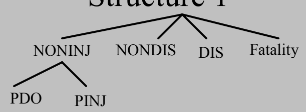
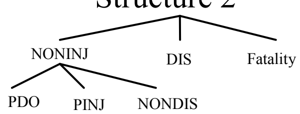
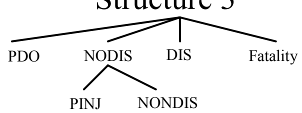
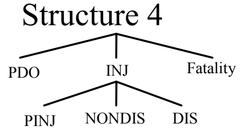


Figure 15 Nested logit structure (Structure 10) with shared unobservables among Property Damage Only and Possible Injury and unobservables among Non-Disabling, Disabling Injury and Fatality; no degenerate severity

Table 5 shows the inclusive value parameters, standard errors and t-statistics in both single- and two-vehicle driver occupant only accident severity models. Figure 6 (Structure 1), Property Damage Only (PDO) and possible injury nested as non-injury (NONINJ), is the statistically preferred structure since its inclusive value for the nest is between 0 and 1 and significantly different from 0 and 1 in both single- and two-vehicle driver occupant only accident severity models. It also shows that Structure 1 has the correct specification with regards to unobserved correlation between the severity outcomes. It accounts for shared unobserved effects that cause a correlation between property damage only and possible injury.

The estimation results for other nested are shown structures (Figure 7 to 15) for single- and two-vehicle driver only occupant accident severity model are shown in appendices A and B respectively. As can be seen, the models' inclusive value parameters exceeded one in these specifications. This violation is a generally accepted indication that the nesting structures are not consistent with the theory on shared unobservables (McFadden, 1979; Daly & Zachary, 1979).

Table 5 Estimates of Inclusive Value Parameters for all Nest Structures (Figure 6 – Figure 15) for both Single- and two-vehicle driver occupant only accident severity models

Structure	Nested Severities	Single-vehicle driver occupant only accident severity models			Two-vehicle driver occupant only accident severity models		
		Coefficient	Standard Error	t-statistic	Coefficient	Standard Error	t-statistic
Structure 1 	Property Damage Only and Possible Injury	0.4574	0.0555	8.2350* -9.7766**	0.2118	0.0520	4.0720* -15.1577**
Structure 2 	Property Damage Only, Possible Injury and Non-Disabling Injury	1.1179	0.1917	5.8320	0.5422	0.1479	3.6670
Structure 3 	Possible Injury and Non-Disabling Injury	1.2699	0.1021	12.4390	1.5761	0.1038	15.1790
Structure 4 	Possible Injury, Non-Disabling Injury and Disabling Injury	1.4039	0.1064	13.1980	1.4076	0.0763	18.4480

* t-statistic is calculated against 0.
** t-statistic is calculated against 1.

Table 5 Estimates of Inclusive Value Parameters for all Nest Structures (Figure 6 – Figure 15) for both Single- and two-vehicle driver occupant only accident severity models (Continued)

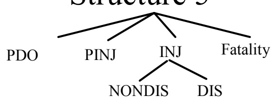
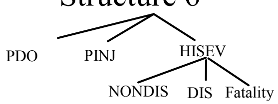
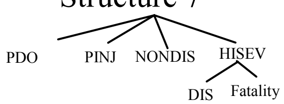
Structure	Nested Severities	Single-vehicle driver occupant only accident severity models			Two-vehicle driver occupant only accident severity models		
		Coefficient	Standard Error	t-statistic	Coefficient	Standard Error	t-statistic
Structure 5 	Non-Disabling Injury and Disabling Injury	1.6031	0.2067	7.7570	13.4435	3.0243	4.4450
Structure 6 	Non-Disabling Injury, Disabling Injury and Fatality	2.0733	0.2045	10.1380	4.2409	0.5630	7.5330
Structure 7 	Disabling Injury and Fatality	1.6839	0.6004	2.8040	5.2821	1.0612	4.9780

Table 5 Estimates of Inclusive Value Parameters for all Nest Structures (Figure 6 – Figure 15) for both Single- and two-vehicle driver occupant only accident severity models (Continued)

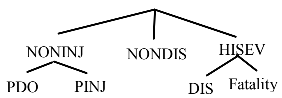
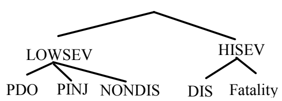
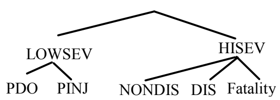
Structure	Nested Severities	Single-vehicle driver occupant only accident severity models			Two-vehicle driver occupant only accident severity models		
		Coefficient	Standard Error	t-statistic	Coefficient	Standard Error	t-statistic
Structure 8 	Property Damage Only and Possible Injury	0.4583	0.0556	8.2480	0.2137	0.0520	4.1080
	Disabling Injury and Fatality	1.7639	0.5191	3.3980	7.2214	1.5463	4.6700
Structure 9 	Property Damage Only, Possible Injury and Non-Disabling Injury	1.2013	0.1982	6.0600	0.5900	0.1499	3.9360
	Disabling Injury and Fatality	1.8917	0.6124	3.0890	5.1523	0.9511	5.4170

Table 5 Estimates of Inclusive Value Parameters for all Nest Structures (Figure 6 – Figure 15) for both Single- and two-vehicle driver occupant only accident severity models (Continued)

<table>
<tr><th rowspan="2">Structure</th><th rowspan="2">Nested Severities</th><th colspan="3">Single-vehicle driver occupant only accident severity models</th><th colspan="3">Two-vehicle driver occupant only accident severity models</th></tr>
<tr><th>Coefficient</th><th>Standard Error</th><th>t-statistic</th><th>Coefficient</th><th>Standard Error</th><th>t-statistic</th></tr>
<tr><td rowspan="2">Structure 10
</td><td>Property Damage Only and Possible Injury</td><td>0.4610</td><td>0.0557</td><td>8.2780</td><td>0.2234</td><td>0.0522</td><td>4.2780</td></tr>
<tr><td>Non-Disabling Injury, Disabling Injury and Fatality</td><td>2.0563</td><td>0.2023</td><td>10.1650</td><td>4.0832</td><td>0.5520</td><td>7.3980</td></tr>
</table>

4.3 Covariance Heterogeneity Model (CHM)

As mentioned in the previous section, the nested logit model appropriately allows the IID constraints on the unobservables to be relaxed. In particular, the nested logit model allows for different variances for groups of alternatives in the lower level and for equal correlation across the alternatives within the lower level. The covariance heterogeneity model extends this model a bit further by allowing the variances to depend on variables in the model.

Formally, a CHM is a probability model similar to the nested logit (McFadden, 1981), which has been shown in Section 4.2, except for the parameterization of the coefficients on the inclusive values, presented as ρ_i in Equation 4.2.2. An inclusive parameter ρ_i in an NL model is constrained to be equal across individuals. It is relaxed to be different as an individual accident-specific parameter in a CHM.

Bhat (1997) and Greene (2003) differ in their definitions of this parameterization. Bhat (1997) defines that inclusive parameters due to the fact that they are to be in the [0-1] interval, can be appropriately modeled as a logistic cumulative distribution function. Greene (2003) uses the parameterization:

$$\rho_{ni} = \rho_i e^{\gamma x_n} \qquad (4.3.1)$$

Where ρ_i is an estimable alternative-specific coefficient, and $\boldsymbol{\gamma}$ are the estimable coefficients on the individual-specific observed factors, $\mathbf{x}_n$, where the exponentiation ensures that the alternative specific value is scaled to the individual accident level using a positive valued function. Greene's (2003) method was employed using the econometrics software, NLOGIT version 3.0.

4.4 Heteroskedastic Extreme-Value Model (HEV)

In an MNL, the assumption of equal variances produces greatly simplifies the mathematical structure and provides easily interpretable results (Greene 2002). However, if the assumption of equal variances is inappropriate, then different scaling that is present in the variances will be forced on the coefficients in the alternative functions, instead, in ways that might distort the predictions of a model. Hence, the heteroskedastic extreme-value model is introduced. It can relax the assumption of equal variances by allowing the disturbances in each alternative function to have their own variances.

Steckel and Vanhonacker (1988), Bhat (1995) and Recker (1995) developed a type of GEV model, called heteroskedastic extreme-value model, to allow have different variances for different alternatives. In Equation 4.1.2, the alternative function is $S_{in} = \beta_i X_n + \varepsilon_{in}$ for alternative i. In an MNL model, the variance of ε_{in} is same across alternatives and is distributed extreme value with variance $\pi^2/6$. In an HEV, ε_{in} is distributed independently extreme value with variance $\pi^2/(6\theta_i^2)$ (Greene, 2003), where the θ_i is a precision parameter equals to 1 over scale parameter. A correlation in unobserved factors over alternatives does not appear. However, the variance of the unobserved factors would be different for different alternatives (Train, 2003). For identification purposes, one of the θ_is needs to be set to 1. In the Nlogit (2003) estimator, this is the last one (Greene, 2003). In our empirical case, this would usually be the fatality case. Other variances for the other alternatives are then estimated relative to the normalized variance.

The probability for this HEV logit that the alternative i is made is (Greene, 2003)

$$P_i = \Pr ob[S_i > S_k] \text{ for all k not equal to i}$$

$$= \int_{-\infty}^{\infty} \prod_{k \neq i} F[\theta_k (S_i - S_k + \varepsilon_i)] \theta_i f(\theta_i \varepsilon_i) d\varepsilon_i \qquad (4.4.1)$$

where $f(t)$ is the density, $f(t) = \exp(-t)\exp(\exp(-t)) = -F(t)\log(F(t))$. Greene (2003) mentioned that the probabilities and derivatives must be evaluated numerically, since there is no closed form for the integral. As Bhat (1997) notes, it can be approximated using Gauss-Laguerre quadrature. In the Nlogit (2003) estimator, the following approximation was used.

$$\int_{-\infty}^{\infty} \prod_{k \neq i} F[t(k \mid i)] \exp(-u_i) du_i \approx \sum_{l=1}^{L} \omega_l F[\theta_k (S_i - S_k - (\log h_l)/\theta_l)] \qquad (4.4.2)$$

where $u_i = \exp(-\theta_i \varepsilon_i)$, $F(t) = \exp(-\exp(-t))$, $t(k \mid i) = \theta_k (S_i - S_k - (\log u_l)/\theta_l)]$, ω_l is the weight and h_l is the abscissa of the Gauss-Laguerre Polynomial. The Nlogit (2003) estimator has used a 40 point approximation. Bhat (1997) also proved that the quadrature method is accurate enough to approximate the probabilities by comparing the HEV model with restricted HEV (set all scale parameters to be 1).

Simulation is another way of approximation mentioned by Train (2003). The probabilities can be simulated using the following formula.

$$P_{ni} \approx \prod_{k \neq i} \exp(-\exp((S_k - S_i - \theta_i \omega)/\theta_k)) \qquad (4.4.3)$$

where $\omega = \frac{\varepsilon_{ni}}{\theta_i}$, the extreme value density is $f(\omega) = \exp(-\exp(-\omega))\exp(-\omega)$, and the cumulative distribution is $F(\omega) = \exp(-\exp(-\omega)) = \mu$.

It takes a draw from the extreme value distribution. A draw μ from the standard uniform provides a number between 0 and 1. For this draw, P_{ni} can be calculated. It should repeat taking draws and calculate formula 4.4.3 many times and average the results. In our analysis, 1000 draws were taken per P_{ni}.

Chapter 5: Empirical Results

This chapter presents the empirical analysis of both the single- and two- vehicle driver occupant only accident severity models. Three model types, namely nested logit models with 10 different nesting structures, covariance heterogeneity models and heteroskedastic extreme-value models, were estimated to analyze the effects of observed driver, vehicle, roadway and environmental factors and types accident on injury severity probabilities in single-vehicle and two-vehicle accidents on the roadway. The detailed results for both vehicle accidents are discussed in the following subsections.

As mentioned before, Figure 6 (Structure 1) shows the statistically preferred nested structure, which accounts for shared unobserved effects between property damage only and possible injury. This nested structure was appropriate for both single- and two-vehicle accidents severities. The model results of other nesting structures (Figure 7 to 15) for single- and two-vehicle driver only occupant accident severity model are shown in Appendix A and B respectively.

For the overall model goodness of fit, the ρ^2 statistic is a common measure and shown below.

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \qquad (5.1)$$

Where the LL(β) is the log-likelihood at convergence with coefficient vector β and LL(0) is initial log-likelihood with all coeffieients set to 0. Another version of ρ^2 involves LL(C) instead of LL(0) in the denominator. LL(C) is the log-likelihood at convergence with constants only. The above-mentioned versions of ρ^2 will always improve as additional coefficients are estimated even though those coefficients are insignificant. Therefore, adjusted ρ^2 that takes into account the number of parameters, k, can be employed in the model and is shown below.

$$\text{Adjusted } \rho^2 = 1 - \frac{LL(\beta) - k}{LL(0)} \tag{5.2}$$

for initial log-likelihood with all coeffieients set to 0; and

$$\text{Adjusted } \rho^2 = 1 - \frac{LL(\beta) - k}{LL(C)} \tag{5.3}$$

for initial log-likelihood with constants only.

The ρ^2 is between 0 and 1. A perfect model would have a likelihood function equal to 1 and the log-likelihoood would be 0 given a ρ^2 of 1. Therefore, the closer the ρ^2 it is to 1, the more the estimated model is explaining. The adjusted ρ^2 at convergence with all coefficients set to 0 was measured for models shown in the tables of model results, which are discussed in the following sections.

5.1 Single-Vehicle Driver Only Occupant Severity Model

5.1.1 Nested Logit Model (NL)

The results of the single-vehicle driver only occupant severity nested logit model are presented in tables 6 and 7. Table 7 shows that the parameter of the inclusive value is significant with a coefficient of 0.45739 and a t-statistic of 8.235. It proves that the inclusive value parameter is both significantly different from both 0 and 1, which is required statistically for the nest to not be rejected. This also proves that shared unobservables exist between property damage only and possible injury severities. Table 7 also shows that the signs of all coefficients are plausible and that the model has a good overall fit with a log-likelihood at zero of -59159.4624 and at convergence of -32814.14 giving an adjusted ρ^2 of 0.45.

The lower nest alternatives (PDO and PINJ) estimation result for single-vehicle driver only occupant severity model is presented in Table 6. Those estimated coefficients are specific to the PDO category and relative to the PINJ category. A positive coefficient indicates an increased log odds of PDO to PINJ. Conversely the negative coefficient indicates a decreased log odds of PDO to PINJ. As can be seen in Table 6, if the driver being male increases the log odds of PDO to PINJ, while the interaction variable between driver restraint system usage and vehicle type increases the log odds of PINJ to PDO.

Table 6 Nested logit model estimation results for property-damage-only (lower nest) for single-vehicle driver only occupant severity model

Lower nest PDO		
Variable	Coefficient	t-statistic
Constant	0.88525	33.45300
Driver characteristics		
Driver's sex indicator (1 if driver is male, 0 otherwise)	0.75299	22.28500
Interaction between driver and vehicle characteristics		
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise; specific to no injury)	-0.89470	-13.52700

The upper nest, which models non-injury (NONINJ), non-disabling injury (NONDIS), disabling injury (DIS) and fatality, as well as the overall model including the effect from lower nest through the inclusive value is presented in Table 7. The following discussions will mainly focus on the impacts of the severity estimations by different categories of variables. The categories of variables can be classified into driver, roadway, accident, interactions between driver and vehicle and interaction between driver and location characteristics.

Table 7 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	5.24578	36.74400	4.09461	36.53500	2.27367	19.51200		
Driver characteristics								
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)			0.59475	17.56800	0.91271	15.74200	1.48644	11.55000
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)					2.58615	23.06200	4.06972	28.22900
Roadway characteristics								
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	-0.48517	-17.42500						

Table 7 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Accident characteristics								
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or Concrete barrier, 0 otherwise)	0.27961	8.09600						
Collision type indicator (1 if the collision type is over turn, 0 otherwise)			0.37454	11.05900	0.37593	5.94900		
Object struck indicator (1 if driver struck Tree or Stump, Light Pole, Utility Pole, Railway Pole, Traffic Signal Pole, Overheard Sign Support Pole, Sign Box , Bridge Column or Pillar, 0 otherwise)					0.50690	7.09200	0.50690	7.09200

Table 7 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)							0.92933	2.81800
Interaction between driver and vehicle characteristics								
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	-0.95784	-15.69800						
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	-1.35638	-25.87300						

Table 7 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction between driver and location characteristics								
Interaction Variables between Driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)			0.28747	5.14800	0.60917	6.27700	1.44886	8.03800
Inclusive value of non-injury (lower) nest	0.45739	8.23500*						
Number of observations	31360							
Log-likelihood at constant only	-35649.7777							
Log-likelihood at zero	-59195.4624							
Log-likelihood at convergence	-32814.14							
Adjusted ρ^2	0.45							

* t-statistic is calculated against 0.

5.1.1.1 Driver Characteristics

From the model results, driver sobriety is a significant variable contributing to accident severities. As can be seen, by setting NONINJ as a base case, the coefficients of driver sobriety indicator (such as if driver had been drinking) increase as the accidents increase in severity. The coefficients go from 0.59475 with a t-statistic of 17.568 in NONDIS to 0.91271 with a t-statistic of 15.742 in DIS and finally to 1.48644 with a t-statistic of 11.55 in fatality. In other words, if a driver had been drinking, the propensity of severity would significantly increase towards a fatality. The other variable in the category of driver characteristics is driver ejection status (such as if driver had totally ejected), which is in the functions of DIS and fatality. It also shows the same propensity as driver sobriety, that is, as the coefficients increase in magnitude the accident is more severe. The coefficients go from 2.58615 with a t-statistic of 23.062 in disabling injury (DIS) to 4.06972 with a t-statistic of 28.229.

5.1.1.2 Roadway Characteristics

In this category there is only one variable, the condition of roadway surface (such as if the surface was dry). The coefficient of roadway surface has a negative sign in the non-injury function. It states that the dry surface decreases the propensity of severity toward non-injury. A dry surface could indicate that drivers may drive faster or more aggressively compared to other surface conditions, such as wet, snowy and icy surfaces.

5.1.1.3 Accident Characteristics

In single-vehicle accidents, two main collision types can be classified. One is over turn and the other is fixed object. Of all single-vehicle accidents, 8028 accidents were over turn with a percentage of 25.99% in the dataset. The model estimation has found that the propensities of NONDIS and DIS are significantly increased when the collision type is over turn. Interestingly, fatalities are not statistically associated with over turns in single-vehicle accidents. This is not to say that overturns do not contribute to fatalities; rather, the absence of the overturn variable in the fatality category represents the high significance threshold assumed in our specifications. We established a significance threshold corresponding to t-statistics of 15 or higher due to the fact we have panel data and a large number of observations.

Regarding fixed object collisions, there were 22,878 accidents (with a percentage of 72.95 %.) It is also known that fixed object collisions can be categorized by different objects struck by the vehicle.. In the model, there are three categories of objects examine for their impacts on severities. Vehicles striking a wood or metal sign post, a guide post, a guardrail face or a concrete barrier increase the propensity toward the severity of non-injury. Striking a guardrail or a bridge rail leading end increases the propensity toward higher-end severities. However, this variable can not be assessed adequately for fatal injury due to the lack of observations. A previous study has reported that thrie-beam hardware is associated with an increase in the probabilities of non-injury, in the context of bridge-rail crashes (Shankar et al. 2000). If a vehicle crashes into a tree, a stump or a pole (including light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar), the propensity increases toward disabling and fatal injuries. It also indicates that there is a significant injury prevention benefit to protecting traffic by preventing collisions into such trees or poles. The following table shows the relative impacts of roadside objects on severities.

Table 8 Effects of Roadside objects on propensities toward injury severities

Object Struck	Non-injury	Non-disabling injury	Disabling injury	Fatality
Wood or Metal Sign Post or Guide Post or Guardrail Face or Concrete Barrier	↑	↓	↓	↓
Guardrail or Bridge Rail Leading End	↓	↓	↓	↑
Tree or Stump, Light Pole, Utility Pole, Railway Pole, Traffic Signal Pole, Overheard Sign Support Pole, Sign Box , Bridge Column or Pillar	↓	↓	↑	↑

<u>*5.1.1.4 Interaction Between Driver and Vehicle Characteristics*</u>

The model shows that if the driver did not use any restraints and the vehicle type is passenger car, the propensity of NONINJ decreases.. Likewise, the propensity NONINJ decreases if the driver did not use any restraints and the vehicle type is pick-up. In other words, the accident would be more severe if the driver did not use any restraints in both passenger car and pick-up. Furthermore, by comparing the coefficients of these two variables, the interaction variable between pick-up vehicle and driver not using restraints has a smaller coefficient (negative sign). It indicates that the accident would be more severe if a driver drivers a pick-up.

5.1.1.5 Interaction Between Driver and Location Characteristics

The impact of the interaction between driver age and accident location (urban or rural area) was modeled. The model's result shows that if the driver is more than 55 years of age and the accident happened in a rural area, propensity of higher severity significantly increases. The coefficients increase from 0.28747 with a t-statistic of 5.148 in NONDIS to 0.60917 with a t-statistic of 6.277 in DIS and finally to 1.44886 with a t-statistic of 8.038 in fatality. Emergency response could be an issue in rural areas. Improving hospital networks to provide greater trauma coverage in rural areas would be a significant injury prevention benefit.

5.1.2 Covariance Heterogeneity Model (CHM)

The results of the single-vehicle driver only occupant severity covariance heterogeneity model (CHM) are presented in Table 9 and 10. This CHM used the same specification as the nested logit model. Table 10 shows that the parameter of the inclusive value is significant with a coefficient of 1.55881 and a t-statistic of 8.97200 when compared to zero. The inclusive value parameter is greater than 1. It indicates that the model is consistent with outcome maximizing behavior for some range of the explanatory variables but not for all values (Train, 2003). The model has an overall fit with a log-likelihood of -59195.4624 at zero and -34057.91 at convergence giving an adjusted ρ^2 of 0.42. These indicate that adding covariance heterogeneity to this NL model structure did not lead to a significant improvement in the likelihood function. It could be due to the results that some variables which are significantly different from 0 in the NL model turned out to be statistically insignificant in the CHM. These variables will be discussed below.

The lower nest (PDO and PINJ) estimation result for the single-vehicle driver only occupant severity covariance heterogeneity model is presented in Table 9. The results of the severity parameters are similar to the NL model. In particular, the signs of all coefficients are consistent with those in the NL model. As can be seen in Table 9, a male driver increases the propensity significantly toward PDO. However, compared to the NL result, the CHM indicates a lower propensity of PDO for male drivers. The other variable, interaction variable between driver restraint system usage and vehicle type, shows that if a driver did not use any restraints and the vehicle type is passenger car, the log odds of PINJ to PDO increases. The CHM indicates a higher propensity of PINJ for a driver who did not use any restraints and the vehicle type is passenger car. Results show that the lower nest of the model is plausible in CHM and again consistent with the NL model.

Table 9 Covariance heterogeneity model estimation results for property-damage-only (lower nest) for single-vehicle driver only occupant severity model

Lower nest PDO Variable	Coefficient	t-statistic
Constant	1.16238	52.18800
Driver characteristics		
Driver's sex indicator (1 if driver is male, 0 otherwise)	0.32101	13.18700
Interaction between driver and vehicle characteristics		
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise; specific to no injury)	-0.93285	-14.44600

The estimates of the upper nest of CHM are presented in Table 10. The following discussions will mainly focus on not only the impacts of the severity estimations by different categories of variables but also the differences compared to the NL model. The variables which turned out to be statistically insignificant will be discussed also. The categories of variables can be classified into driver, roadway, accident, interaction between driver and vehicle and interaction between driver and location characteristics. Furthermore, the parameters representing covariance heterogeneity will be discussed.

Table 10 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	0.47157	1.94800	1.52938	10.96500	0.21725	1.95500		
Driver characteristics								
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)			0.63841	12.60700	0.59265	8.35400	-0.22582	-1.86600
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)					0.33984	3.86900	0.19915	1.71100
Roadway characteristics								
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	-0.45579	-16.08100						

Table 10 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Accident characteristics								
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	0.37598	10.85800						
Collision type indicator (1 if the collision type is over turn, 0 otherwise)			0.43039	10.67500	0.24683	3.82700		
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)					-0.06892	-0.99100	-0.06892	-0.99100

Table 10 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)							-0.01302	-0.04500
Interaction between driver and vehicle characteristics								
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	-0.49916	-3.93500						
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	-0.78874	-15.04900						

Table 10 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction between driver and location characteristics								
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)			0.17169	3.04900	0.07404	0.70100	-0.10504	-0.56800
Inclusive value of non-injury (lower) nest	1.55881	8.97200*						

Covariates in Inclusive Value Parameters	Coefficient	t-statistic
Vehicle speed	0.00325	2.96400

* t-statistic is calculated against 0.

Table 10 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Covariates in Inclusive Value Parameters	Coefficient	t-statistic
Weather indicator (1 if it was snowing, 0 otherwise)	0.28021	6.86700
Interaction variable between driver's age and accident type (1 if driver's age is greater than 55 and the accident type is over turn, 0 otherwise)	-0.13190	-1.92000
Interaction variable between light condition and roadway character (1 if it was dark and the accident happened at curve, 0 otherwise)	-0.18035	-5.19100
Vehicle type indicator (1 if the vehicle type is passenger car, 0 otherwise)	0.07211	3.82600

Table 10 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for single-vehicle driver only occupant severity model (Continued)

Number of observations	31360
Log-likelihood at constant only	-35649.7777
Log-likelihood at zero	-59195.4624
Log-likelihood at convergence	-34057.91000
Adjusted ρ^2	0.42

5.1.2.1 Driver Characteristics

From the model results, driver sobriety is a significant variable driving accident severities. To recall the NL model result, by setting NONINJ as the base case, the coefficients of the driver sobriety indicator (such as if driver had been drinking) increase accident severity. In other words, if a driver had been drinking, the propensity of severity would significantly increase towards a fatality in the NL model. However, the results in the CHM are not consistent with the NL model. The propensity of severity in CHM would increase towards NONDIS with the coefficients going from 0.6384 with a t-statistic of 12.607 in NONDIS to 0.5926 with a t-statistic of 8.352 in DIS and finally changing to negative sign -0.2258 with a t-statistic of -1.866 in fatality, if a driver had been drinking. In other words, a driver would have a less severity if he/she had been drinking. This is not consistent with expectations. Clearly, the CHM provides a result counter-intuitive and inconsistent with commonly accepted findings on driver sobriety.

The other variable in the category of driver characteristics is driver ejection status (such as if driver had totally ejected), which is in the functions of DIS and fatality. It shows the same sign effects as it did in the NL model. But, again, the results in CHM are not consistent with NL model. The coefficients vary from 0.3398 with a t-statistic of 3.869 in DIS to 0.1992 with a t-statistic of 1.711 in fatality. CHM indicates lower propensities than NL model for drivers who were totally ejected in the accident.

5.1.2.2 Roadway Characteristics

In this category there is only one variable, the condition of roadway surface (such as if the surface was dry). The coefficient of roadway surface has a negative sign in the non-injury function in CHM which is very similar and consistent with the results in the NL model. The coefficient is -0.4558 with a t-statistic of -16.081 in CHM comparing to -0.4852 with a t-statistic of -17.425 in NL model. It indicates a higher propensity of severity toward non-injury in CHM.

5.1.2.3 Accident Characteristics

The CHM estimation has also found that the propensities of NONDIS and DIS are significantly increased when the collision type is over turn which is similar to the results in the NL model. Interestingly, however, the propensities in CHM will increase significantly toward NONDIS with the coefficient going from 0.2468 with a t-statistic of 3.827 in DIS to 0.4304 with a t-statistic of 10.675 in NONDIS. For unexplainable reasons, the same level of significance was not found to be associated with overturn accidents' impact on fatality.

In the CHM, vehicles striking a wood, a metal sign post, a guide post, a guardrail face or a concrete barrier increase the propensity toward non-injury. Again, the results are similar to the NL model, but with a stronger propensity in CHM with a coefficient of 0.3760 and t-statistic of 10.858 compared to the NL model with a coefficient 0.2796 and t-statistic of 8.096. Striking a guardrail or a bridge rail leading end or crashing into a tree, a stump or a pole (including light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar) unfortunately become statistically insignificant in CHM with t-statistics of -0.045 and -0.991 respectively. These are unusual findings completely inconsistent with prior findings on utility poles (Holdridge et al 2005) as well as findings from the NL model in this research. One can suspect that either poor parameter behavior or resulting model instability from the algorithm involved in optimization might be contributing to this inconsistency.

5.1.2.4 Interaction Between Driver and Vehicle Characteristics

The CHM model shows similar and consistent results with the NL model when the variable involving driver restraint use interaction with vehicle type being passenger car is included. The propensity decreases toward NONINJ. Likewise, the propensity decreases toward NONINJ if the driver did not use any restraints and the vehicle type is a pick-up. Furthermore, by comparing the coefficients of these two variables, the accidents would be even more severe if drivers drive pick-ups. By comparing the CHM with the NL model, the coefficients of these variables indicate a stronger propensity toward PINJ (lower nest) in CHM than in the NL model but a lower propensity toward higher severities (upper nest) in the CHM than in the NL model.

5.1.2.5 Interaction Between Driver and Location Characteristics

The CHM model's result shows that if the driver is more than 55 years of age and the accident happened in the rural area, the propensity increases significantly toward NONDIS only with coefficient of 0.1717 and a t-statistic of 3.049, which indicates a lower propensity toward NONDIS in CHM than NL model. Unfortunately, this variable is not statistically significant in the functions of DIS and fatality.

5.1.2.6 Covariates in Inclusive Value Parameters

The parameters representing covariance heterogeneity indicate that there are significant differences in the correlation between PDO and PINJ among individuals. A positive parameter on a variable indicates that the variable increases the variance of the random components for PDO and PINJ conditional on a NONINJ having occurred. Therefore, the correlation is reduced between PDO and PINJ.

In CHM five variables are modeled as inclusive value parameter effects. Three variables, namely vehicle speed, snowy weather condition and passenger car in vehicle type, are positive and statistically significant different from 0. It indicates that these three variables reduce the correlation between PDO and PINJ. It can be said that unobserved effects of NONINJ severity may vary substantially more among NONINJ individuals when they drove in higher speed. In other words, PDO and PINJ are closer for lower speed drivers than for higher speed drivers. Similar explanations can be provided for the effects of snowy weather condition and passenger car in vehicle type. Unobserved effects of NONINJ severity may vary substantially more among NONINJ individuals when it was snowy weather condition or when a driver drove a passenger car. PDO and PINJ are closer accident severities when it was snowy than when it was in other weather conditions. They are also closer when a driver drove a passenger car compared to other vehicle types.

Two variables, which are driver's age greater than 55 and the over turn accident type and dark and curvature accident location, are negative and statistically significant different from 0. It indicates that these two variables increase the correlation between PDO and PINJ. It can be said that unobserved effects of NONINJ severity may vary substantially less among NONINJ individuals when they drove in a dark area or at a curve. In other words, PDO and PINJ are closer for accidents happed in dark areas or at curves.

5.1.3 Heteroskedastic Extreme-Value Model

The results of single-vehicle driver only occupant severity heteroskedastic extreme-value (HEV) model are presented in Table 11. This HEV model used the same specification as in the NL model and CHM. The differences are that the HEV model is a one level structure and the variables in the function of NONINJ (upper level in NL model and CHM) were modeled in the function of PINJ in HEV model. Table 11 shows that the scale parameters of extreme value for all four severities (Fatality was set to be fixed number, 1) are statistically significant different from 1 with a coefficient of 3.7227 and a t-statistic of 5.263 in PDO, a coefficient of -0.5681 and a t-statistic of -95.419 in PINJ, a coefficient of -0.5598 and a t-statistic of -17.817 in NONDIS, a coefficient of -0.3200 and a t-statistic of -4.492 in DIS. It indicates that the scale parameter of the random error component associated with the function of PDO is significantly greater than that associated with the function of fatality. The scale parameters of random error component associated with the functions of PINJ, NONDIS and DIS are significantly smaller than that associated with the function of fatality. It also clearly shows that the assumption of heteroskedasticity is correct and the random components are independently and non-identically distributed.

The model has an overall fit with a log-likelihood at 0 of -50471.97 and at convergence of -32212.20 giving an adjusted ρ^2 of 0.36. These indicate that adding heteroskedasticity to the model structure did not lead to a significant improvement in the likelihood function. It could be due to the results that some variables which are significantly different from 0 in the NL model and HEV turned out to be statistically insignificant in the HEV model. These variables will be discussed below.

5.1.3.1 Driver Characteristics

From the HEV model results, the male driver increases the propensity significantly toward the probability of PDO. However, the HEV model indicates a much lower propensity toward the probability of PDO for male driver than NL model and CHM. Driver sobriety is also statistically significant variable in HEV model. In NL model, it suggests that if a driver had been drinking, the propensity of severity would significantly increase towards a fatality. However, the results in the HEV model are not consistent with the NL model, which is same as CHM. The propensity of severity in HEV would increase towards NONDIS with the coefficients going from 1.8087 with a t-statistic of 14.17 in NONDIS to 0.7274 with a t-statistic of 4.444 in DIS and finally changing to 0.3191 with a t-statistic of 5.157 in fatality, if a driver had been drinking.

The other variable in the category of driver characteristics is driver ejection (such as if driver had totally ejected) shows the same sign as it is in the NL model and CHM, that is, a positive sign. The coefficients go from 4.0119 with a t-statistic of 11.305 in DIS to 3.2994 with a t-statistic of 27.197 in fatality.

Table 11 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for single-vehicle driver only occupant severity model

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	3.42324	96.57600			0.14654	0.62200	-1.02569	-2.09200		
Driver characteristics										
Driver gender indicator (1 if driver is male, 0 otherwise)	0.09072	2.80800								
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)					1.80870	14.17000	0.72742	4.44400	0.31912	5.15700
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)							4.01186	11.30500	3.29940	27.19700
Roadway characteristics										
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)			0.04467	0.81000						

Table 11 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for single-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Accident characteristics										
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)			0.04402	0.67300						
Collision type indicator (1 if the collision type is over turn, 0 otherwise)					0.13113	2.11800	0.10989	1.17600		
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)							0.15098	2.64900	0.15098	2.64900

Table 11 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for single-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)									0.06425	0.64700
Interaction between driver and vehicle characteristics										
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	-1.51862	-16.94500	-1.26168	-8.23300						
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)			0.08297	0.57900			0.19454	1.02000		

Table 11 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for single-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction between driver and location characteristics										
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)					0.01444	0.14600			0.26507	3.35200

Scale Parameters of Extreme Value Distns Minus 1.0	Coefficient	t-statistic
Property Damage Only (PDO)	3.72271	5.26300
Possible Injury (PINJ)	-0.56806	-95.41900
Non-Disabling Injury (NONDIS)	-0.55980	-17.87100
Disabling Injury (DIS)	-0.31999	-4.49200

Table 11 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for single-vehicle driver only occupant severity model (Continued)

Scale Parameters of Extreme Value Distns Minus 1.0	Coefficient	t-statistic
Fatality	0	......(Fixed Parameter).......
Std.Dev=pi/(theta*sqr(6)) for H.E.V. distribution.	Coefficient	t-statistic
Non-Injury	0.27157	6.67700
Possible Injury	2.96924	72.55600
Non-Disabling Injury	2.91356	14.05300
Disabling Injury	1.88607	9.54500
Fatality	1.28255	......(Fixed Parameter).......
Number of observations	31360	
Log-likelihood at constant only	-35649.77	
Log-likelihood at zero	-50471.97	
Log-likelihood at convergence	-32212.20	
Adjusted ρ^2	0.36	

5.1.3.2 Roadway Characteristics

The condition of roadway surface (such as if the surface was dry) is the variable in the function of PINJ. It is statistically insignificant different from 0 with a coefficient of 0.0447 and a t-statistic of 0.81.

5.1.3.3 Accident Characteristics

The HEV model estimation has found that the collision type over turn is barely statistically significant in the functions of NONDIS with a coefficient of 0.1311 and a t-statistic of 2.118 with 31360 observations. But it is not significantly different from 0 in the function of DIS with a coefficient of 0.110 and a t-statistic of 1.176.

Vehicles striking a wood, a metal sign post, a guide post, a guardrail face or a concrete barrier becomes an insignificant variable at any level for the severity of PINJ with a coefficient of 0.0440 and a t-statistic of 0.673. Striking a guardrail or a bridge rail leading end also becomes an insignificant variable at any level for the severity of fatality with a coefficient of 0.0642 and a t-statistic of 0.647. Crashing into a tree, a stump or a pole (including light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar) is a statistically significant variable in the functions of DIS and fatality in HEV model with a coefficient of 0.1510 and a t-statistic of 2.649. It also shows a lower propensity towards DIS and fatality than NL model (it is insignificant in CHM).

5.1.3.4 Interaction Between Driver and Vehicle Characteristics

As mentioned in the NL model and CHM if the driver did not use any restraints and the vehicle type is passenger car the propensity decreases toward NONINJ. The result shows the same sign of this variable and has a consistent trend in the HEV model, as that, the propensity of severities would go toward higher severities. The coefficients and t-statistics are -1.5186 and -16.945 in PDO and -1.2617 and -8.233 in PINJ. But the other interaction variable between driver and vehicle, if the driver did not use any restraints and the vehicle type is pick-up, does not significantly associate with the severity of PINJ with a coefficient of 0.083 and a t-statistic of 0.579 and with the severity of DIS with a coefficient of 0.195 and a t-statistic of 1.020.

5.1.3.5 Interaction Between Driver and Location Characteristics

The HEV model's result shows that if the driver is more than 55 years of age and the accident happened in the rural area, the propensity increases significantly toward fatality only with a coefficient of 0.2651 and a t-statistic of 3.352, which indicates a lower propensity comparing to which in the NL model. Contrarily, this variable is not statistically significant different from 0 in the functions of NONDIS and DIS.

5.2 Two-Vehicle Driver Only Occupant Severity Model

5.2.1 Nested Logit Model (NL)

The results of the two-vehicle driver only occupant severity nested logit models are presented in Table 12 and 13. Table 13 shows that the parameter of the inclusive value is significant with a coefficient of 0.21183 and a t-statistic of 4.072. It proves that the inclusive value parameter is both significantly different from both 0 and 1, which is required statistically for the nest not to be rejected. This also proves that shared unobservables exist between property damage only and possible injury severities. Table 13 also shows that the signs of all coefficients are plausible and that the model has a good overall fit with a log-likelihood at 0 of -192797.5 and at convergence of -86902.26 giving an adjusted ρ^2 of 0.55.

The lower nest, PDO and PINJ, estimation result for two-vehicle driver only occupant severity nested logit model is presented in Table 12. Similar to the single-vehicle driver only occupant accident severity model, the positive coefficient indicates an increased probability of PDO and decreased probability of PINJ and conversely the negative coefficient indicates a decreased probability of PDO and an increased probability of PINJ. As can be seen in Table 12, if both the severity-considered driver and the other driver are male, the propensity increases toward PDO. In other words, female drivers would have a higher probability of a PINJ. In the driver's contribution to an accident, it is found that both drivers exceeding the reasonably safe speed cause the propensity of severity toward

PINJ. It was also found that if the other driver was following too closely, the probability of being involved in a PINJ is higher than being in a PDO. The other variable, an interaction variable between driver restraint system usage and vehicle type, shows that if either driver did not use any restraints and either vehicle type is a passenger car, the probability of a PINJ is higher than PDO. Results show that the lower nest of the model is plausible. In the policy stand point of view, restraints could significantly reduce the severity, which is consistent with the finding in single-vehicle driver only occupant severity models.

The upper nest, which models non-injury (NONINJ), non-disabling injury (NONDIS), disabling injury (DIS) and fatality, as well as the overall model including the effect from lower nest through the inclusive value is presented in Table 13. The following discussions will mainly focus on the impacts of the severity estimations by different categories of variables. The categories of variables can be classified into driver, vehicle, roadway, accident, interaction between driver and vehicle and interaction between driver and location characteristics.

Table 12 Nested logit model estimation results for property-damage-only (lower nest) for two-vehicle driver only occupant severity model

Variable	Lower nest PDO Coefficient	t-statistic
Constant	0.82945	49.33800
Driver characteristics		
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	0.32834	20.40200
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	0.33258	20.64800
Driver contributing circumstances indicator (1 if the severity-considered vehicle had exceeded reasonably safe speed, 0 otherwise)	-0.39373	-16.53200
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	-0.39576	-16.60000
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	-0.34722	-14.10900
Interaction between driver and vehicle characteristics		
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	-0.62211	-17.28500

5.2.1.1 Driver Characteristics

One significant variable found in this category is driver ejection. If either driver had totally ejected in the two-vehicle accident, the propensity increases toward disabling DIS and fatality for the severity-considered driver. The coefficients increase from 2.62997 with a t-statistic of 12.34 in DIS to 4.20277 with a t-statistic of 16.153. It indicates that ejection of driver will make an accident more severe. This propensity is consistent with the single-vehicle accident findings.

The other significant variable driving the severities is driver sobriety. As can be seen, by setting non-injury as a base case, the coefficients of driver sobriety indicator (such as if either driver had been drinking) increase with severity. The coefficients increase from 0.76302 with a t-statistic of 21.644 in NONDIS to 0.92556 with a t-statistic of 15.065 in DIS and finally to 1.24652 with a t-statistic of 9.938 in the fatality case. In other words, if either driver had been drinking in the two-vehicle accident, the propensity of severity would significantly increase toward a fatality for the severity-considered driver. It also can be said that either driver involving the drinking condition would drive the severity to a higher level when an accident happens. This propensity is consistent with the single-vehicle accident finding. This variable indicates that drinking and driving significantly increases the severity level at both single- and two-vehicle accidents.

Table 13 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	5.54061	40.13800	4.08193	35.52300	2.63918	22.81800		
Driver characteristics								
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)					2.62997	12.34000	4.20277	16.15300
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)			0.76302	21.64400	0.92556	15.06500	1.24652	9.93800
Vehicle characteristics								
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)							1.06024	6.47900

Table 13 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Roadway characteristics								
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)			-0.38258	-13.98300	-0.62265	-12.59200	-1.64707	-12.05400
Accident characteristics								
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	0.92626	25.80200						
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	1.11302	18.48700	0.37912	6.41100				

Table 13 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)			0.19673	5.29800	0.68965	11.92200	2.46106	19.77100
Interaction between driver and vehicle characteristics								
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	-1.19215	-30.14400						
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	-0.89224	-15.40600						

Table 13 Nested logit model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction between driver and location characteristics								
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)			0.50832	9.58500	0.63559	6.69800	1.35117	8.38900
Inclusive value of non-injury (lower) nest	0.21183	4.07200*						
Number of observations	96600							
Log-likelihood at constant only	-90916.4							
Log-likelihood at zero	-192797.5							
Log-likelihood at convergence	-86902.26							
Adjusted ρ^2	0.55							

* t-statistic is calculated against 0.

5.2.1.2 Vehicle Characteristics

One variable, the type of the other vehicle involved in the accident, was modeled in the two-vehicle driver only occupant severity model. It was found that the propensity increases toward fatality significantly if the other vehicle is a truck. This captures mass difference effects.

5.2.1.3 Roadway Characteristics

In this category there is only one variable, the junction relationship indicator (such as if the accident was at intersection and related). The coefficient of junction relationship has a negative sign in NONDIS, DIS and fatality functions. They decrease from -0.38258 with a t-statistic of -13.983 in NONDIS to -0.62265 with a t-statistic of -12.592 in DIS and finally to -1.64707 with a t-statistic of -12.054 in fatality. It states that if the accident was at an intersection or related area, the propensity decreases with higher severities. In other words, the probability of low severity, such as NONINJ, is relatively higher if the accident happens at the intersections and related areas. However, the types of intersections and the controls of intersections are unknown due to lack of information.

5.2.1.4 Accident Characteristics

In the two-vehicle accident case, it can be seen in Table 2 that rear end has the highest percentage of 41.371% of the overall 127,960 two-vehicle accidents in the dataset and followed by "same direction" with the percentage of 32.408%. Entering at angle type of collisions are 14.331% and opposite direction collisions 10.532%. The model estimation showed that the same direction type of collision increases the propensity toward NONINJ. Furthermore, the rear end type of collision also has significant impacts on both NONINJ and NONDIS. But, by examining the coefficients of rear end type collision, it indicates that it increase the propensities toward NONINJ more than NONDIS since the coefficient is 1.11302 with a t-statistic of 18.487 in NONINJ comparing to 0.37912 with a t-statistic of 6.411 in NONDIS.

As mentioned above, opposite direction has a significant percentage in two-vehicle accident collisions. It was found that the opposite direction type of collision increases the propensities significantly toward higher severities. The coefficients increase from 0.19673 with a t-statistic of 5.298 in NONDIS to 0.68965 with a t-statistic of 11.922 in DIS and finally to 2.46106 with a t-statistic of 19.771. It shows that the probability increases dramatically for fatalities. This finding makes a compelling case for center-line barriers or other forms of prevention of opposite direction accidents. A previous study has reported the consideration of design policy of median barrier for the State of Washington: (a) Barrier all medians less than or equal to 50 feet in width; (b) Do not recommend barriers for medians wider than 60 feet; (c) Consider case-by-case assessments for barriering medians in the 50-foot to 60-foot range (Chayanan et al. 2004).

5.2.1.5 Interaction Between Driver and Vehicle Characteristics

The model shows that if either driver did not use any restraints and either vehicle type is passenger car the propensity decreases toward NONINJ. Likewise, the propensity decreases toward NONINJ if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up. In other words, the accident would be more severe if the driver did not use any restraints in both passenger car and pick-up. This finding is consistent with the single-vehicle accident findings. By comparing the coefficients of these two variables, the interaction variable between pick-up vehicle and driver did not use restraints has a bigger coefficient (negative sign). It indicates that a passenger car can cause a higher severity if the driver did not use any restraints than a pick-up. This finding is completely opposite to single-vehicle accident severity finding.

5.2.1.6 Interaction Between Driver and Location Characteristics

The impact of the interaction between the driver's age and the accident location (urban or rural area) was modeled. The model's result shows that if the severity-considered driver is more than 55 years of age and the accident happened in the rural area, the propensity increases significantly toward high severities. The coefficients go from 0.50832 with a t-statistic of 9.585 in NONDIS to 0.63559 with a t-statistic of 6.698 in DIS and finally to 1.35117 with a t-statistic of 8.389 in fatality. It indicates that the severity will increase if that accident happened in the rural area and the driver is older than 55. This finding is consistent with the single-vehicle accident severity case.

5.2.2 Covariance Heterogeneity Model (CHM)

The results of two-vehicle driver only occupant severity covariance heterogeneity model (CHM) are presented in Table 14 and 15. This CHM used the same specification as the nested logit model. Table 15 shows that the parameter of the inclusive value is significant with a coefficient of 1.12191 and a t-statistic of 43.047 against 0. The inclusive value parameter is greater than 1. It indicates that the model is consistent with outcome maximizing behavior for some range of the explanatory variables but not for all values (Train, 2003). The model has an overall fit with a log-likelihood at 0 of -192797.5 and at convergence of -89518.24 giving an adjusted ρ^2 of 0.54. These indicate that adding covariance heterogeneity to this NL model structure did not lead to a further significant improvement in the likelihood function from NL model. It could be due to the results that some variables which are significantly different from 0 in the NL model turned out to be statistically insignificant in the CHM. These variables will be discussed below.

The lower nest, PDO and PINJ, estimation result for single-vehicle driver only occupant severity covariance heterogeneity model is presented in Table 14. The results of the severity parameters are similar to the NL model. In particular, the signs of all coefficients are consistent with the NL model. As can be seen in Table 14, if both the severity-considered driver and the other driver are male, the propensity increases toward PDO. However, the CHM indicates a higher propensity toward the probability of PDO for male drivers. In the driver's contribution to an accident, it is found that both drivers exceeding the reasonably safe speed cause the propensity of severity to shift toward PINJ. The CHM indicates that the severity-considered driver causes a higher propensity toward PINJ and the other driver causes a lower propensity toward PINJ than those in NL model. It was also found that if the other driver was following too closely, the probability of being involved in a PINJ is higher than being in a PDO. In other words, following too closely would cause higher severity. This CHM finding is consistent with the NL model. The other variable, an interaction variable between driver restraint system usage and vehicle type, shows that if either driver did not use any restraints and either vehicle type is a passenger car, the probability of a PINJ is higher than PDO, which is also consistent with the NL model.

The estimates of upper nest of CHM are presented in Table 15. The following discussions will mainly focus on not only the impacts of the severity estimations by different categories of variables but also the differences compared with the NL model. The variables which turned out to be statistically insignificant will be discussed also. The categories of variables can be classified into driver, vehicle, roadway, accident, interaction between driver and vehicle and interaction between driver and location characteristics. Furthermore, the parameters representing covariance heterogeneity will be discussed.

Table 14 Covariance heterogeneity model estimation results for property-damage-only (lower nest) for two-vehicle driver only occupant severity model

Lower nest		
PDO		
Variable	Coefficient	t-statistic
Constant	1.01207	64.363
Driver characteristics		
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	0.3769	25.633
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	0.38097	25.928
Driver contributing circumstances indicator (1 if the severity-considered vehicle had exceeded reasonably safe speed, 0 otherwise)	-0.38356	-17.535
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	-0.38562	-17.613
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	-0.3108	-13.577
Interaction between driver and vehicle characteristics		
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	-0.93692	-26.786

Table 15 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	2.39319	17.26500	1.88127	13.74600	0.12718	0.92100		
Driver characteristics								
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)					0.09715	0.58800	0.10087	0.59200
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)			0.92537	26.58900	0.55932	9.30900	-0.06125	-0.52800
Vehicle characteristics								
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)							-0.09673	-0.65800

Table 15 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Roadway characteristics								
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)			-0.52878	-19.61700	-0.31388	-6.44100	-1.63997	-10.66700
Accident characteristics								
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	1.23331	34.83400						
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	1.49477	25.59700	0.67216	11.39300				

Table 15 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)			0.25431	6.99500	0.60570	10.57000	0.02471	0.18500
Interaction between driver and vehicle characteristics								
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	-0.69798	-18.94700						

Table 15 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	-0.53352	-9.76900						
Interaction between driver and location characteristics								
Interaction Variable between driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)			0.15803	2.87600	0.09882	1.02900	-0.04661	-0.29900

Table 15 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Inclusive value of non-injury (lower) nest	1.12193	43.04700*						
Covariates in Inclusive Value Parameters	Coefficient				t-statistic			
Driver contributing circumstances indicator (1 if either vehicle had exceeded speed limit, 0 otherwise)	-0.28492				-4.82100			
Driver age indicator (1 if either driver's age is greater than 55, 0 otherwise)	-1.31533				-70.65900			
Vehicle age indicator (1 if either vehicle's age is greater than 15 years, 0 otherwise)	-0.92576				-55.25500			

* t-statistic is calculated against 0.

Table 15 Covariance heterogeneity model estimation results for non-injury, non-disabling injury, disabling injury, and fatality (upper nest) for two-vehicle driver only occupant severity model (Continued)

Variable	Upper nest							
	Non-Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Covariates in Inclusive Value Parameters	Coefficient				t-statistic			
Interaction variable between roadway condition and character (1 if the roadway was icy and the accident happened at the curve, 0 otherwise)	-0.19107				-2.41400			
Number of observations	96600							
Log-likelihood at constant only	-90916.4							
Log-likelihood at zero	-192797.5							
Log-likelihood at convergence	-89518.24							
Adjusted ρ^2	0.54							

* t-statistic is calculated against 0.

5.2.2.1 Driver Characteristics

The variable, driver ejection (such as if either driver had totally ejected), significantly drives the severities of DIS and fatality in the NL model. But it becomes an insignificant variable which is not statistically significantly different from 0 at any level in the CHM. The coefficients are 0.0971 with a t-statistic of 0.588 in DIS and 0.1009 with a t-statistic of 0.592 in fatality.

The other significant variable, driver sobriety, indicates that if either driver had been drinking in the two-vehicle accident, the propensity of severity would significantly increase towards a fatality for the severity-considered driver in NL model. However, the results in the CHM are not consistent with the NL model. The propensity of severity in CHM would increase towards NONDIS with the coefficients going from 0.9254 with a t-statistic of 26.589 in NONDIS to 0.5593 with a t-statistic of 9.309 in DIS and finally changing to negative sign (-0.0612(with a t-statistic of -0.528 in fatality, if a driver had been drinking. In other words, a driver would have a less severity if he/she had been drinking. This is not consistent with expectations. Furthermore, it can be seen that the driver sobriety is insignificantly different from 0 in the function of fatality. The CHM by far has inconsistent results relating to important policy variables such as drunk driving.

5.2.2.2 Vehicle Characteristics

One variable, the type of the other vehicle involved in the accident, was also modeled in CHM. It was found that the variable, if the other vehicle is a truck, is not significantly different from 0 in the function of fatality when the covariance heterogeneity was incorporated in the CHM.

5.2.2.3 Roadway Characteristics

In this category there is only one variable, the junction relationship indicator (such as if the accident was at intersection and related). In the CHM, the coefficient of junction relationship is also significant and has a negative sign in NONDIS, DIS and fatality functions which are consistent with the ones in NL model. However, it has a lower propensity towards NONDIS in the CHM with a coefficient of -0.5288 and a t-statistic of -19.617 than in the NL model with a coefficient of -0.38258 and a t-statistic of -13.983. It has a higher propensity towards DIS in the CHM with a coefficient of -0.3139 and t-statistic of -6.441 than in the NL model with a coefficient of -0.62265 with a t-statistic of -12.592. It has a similar propensity towards fatality in the CHM with it in the NL model. It states that if the accident was at an intersection or related area, the propensity of NONDIS would decrease and DIS would increase more in the CHM.

5.2.2.4 Accident Characteristics

The CHM estimation shows that the same direction type of collision increases the propensity toward NONINJ which is consistent with the NL model. Furthermore, it has a higher propensity towards NONINJ in the CHM with a coefficient of 1.2333 and a t-statistic of 34.834 than it in the NL model with a coefficient of 0.9263 and a t-statistic of 25.802. The rear end type of collision also has significant impacts on both NONINJ and

NONDIS in the CHM and suggests a higher propensity towards low severities than it in the NL model. The coefficients and t-statistics are 1.4948 and 25.597 in the function of NONINJ and 0.6722 and 11.393 in the function of NONDIS. The CHM found that the opposite direction type of collision increases the propensities significantly towards higher severities. The coefficients increase from 0.2543 with a t-statistic of 6.995 (0.19673 with a t-statistic of 5.298 in the NL model) in NONDIS to 0.6057 with a t-statistic of 10.57 (0.68965 with a t-statistic of 11.922 in the NL model) in DIS. But it is not a significant impact for fatality with a t-statistic of 0.182.

5.2.2.5 Interaction Between Driver and Vehicle Characteristics

The CHM model shows that if either driver did not use any restraints and either vehicle type is passenger car the propensity decreases towards NONINJ which is consistent with the NL model. It shows a higher propensity towards NONINJ in the CHM with a coefficient of -0.6980 and a t-statistic of -18.947 than it in the NL model with a coefficient of -1.1922 and a t-statistic of -30.144 since it has negative impacts. Likewise, the propensity decreases toward NONINJ if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up which is also consistent with the results in the NL model. The coefficient and t-statistic are -0.5335 and -9.769. It suggests a higher propensity towards NONINJ than it in the NL model (a coefficient of -0.8922 and a t-statistic of -15.406 in the NL model). By comparing the coefficients of these two variables in both NL model and CHM, the interaction variable between pick-up vehicle and driver did not use restraints has a smaller coefficient which is also consistent for both models.

5.2.2.6 Interaction Between Driver and Location Characteristics

The CHM model's result shows that if the driver is more than 55 years of age and the accident happened in the rural area, the propensity increases significantly toward NONDIS only with coefficient of 0.1580 and a t-statistic of 2.876, which indicates a lower propensity toward NONDIS in CHM than NL model. Unfortunately, this variable is not statistically significant in the functions of DIS and fatality.

5.2.2.7 Covariates in Inclusive Value Parameters

The parameters representing covariance heterogeneity indicate that there are significant differences in the correlation between PDO and PINJ among individuals in the two-vehicle driver only occupant severity model. As mentioned in 5.2.1.6, a positive parameter on a variable indicates that the variable increases the variance of the random components for PDO and PINJ conditional on a NONINJ has occurred. Therefore, the correlation is reduced between PDO and PINJ.

In the two-vehicle CHM four variables are modeled as inclusive value parameters. All four variables, which are if either vehicle had exceeded speed limit, if either driver's age is greater than 55, if either vehicle's age is greater than 15 years and if the roadway was icy and the accident happened at the curve, are negative and statistically significant different from 0. It indicates that these variables increase the correlation between PDO and PINJ. It can be said that unobserved effects of NONINJ severity may vary substantially less among NONINJ individuals when either driver exceeded the speed limits, either driver is older than 55 years old, either vehicle's age is greater 15 years or roadway was dry and accident occurred at the curve. In other words, PDO and PINJ are closer for accidents happed in these four conditions.

5.2.3 Heteroskedastic Extreme-Value Model

The results of two-vehicle driver only occupant severity heteroskedastic extreme-value (HEV) model are presented in Table 16. This HEV model used the similar specification with NL model and CHM. The differences are that the HEV model is one level structure and the variables in the function of NONINJ (upper level in NL model and CHM) were modeled in the function of PINJ in HEV model. Furthermore, the variable, if the severity-considered vehicle had exceeded reasonably safe speed, was not modeled in the function of PDO. Table 16 shows that the scale parameters of extreme value for all four severities (Fatality was set to be fixed number, 1) are statistically significant different from 1 with a coefficient of 1.5004 and a t-statistic of 6.341 in PDO, a coefficient of -0.6869 and a t-statistic of -59.503 in PINJ, a coefficient of -0.6618 and a t-statistic of -10.896 in NONDIS, a coefficient of -0.6394 and a t-statistic of -4.088 in DIS. It indicates that the scale parameter of random error component associated with the function of PDO is significantly greater than that associated with the function of fatality. The scale parameters of random error component associated with the functions of PINJ, NONDIS and DIS are significantly smaller than that associated with the function of fatality. These are consistent with the single-vehicle HEV model. It also clearly shows that the assumption of heteroskedasticity is correct and the random components are independently non-identical distributed.

The model has an overall fit with a log-likelihood at 0 of -155471.7 and at convergence of -85150.42 giving an adjusted ρ^2 of 0.45. These indicate that adding heteroskedasticity to the model structure led to a further significant improvement in the likelihood function. Variables significant in the NL model and HEV turning out to be statistically insignificant in the HEV model will be discussed below.

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	4.31574	45.83700			-4.02482	-2.69800	-4.34835	-1.14300		
Driver characteristics										
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)							6.04906	2.28800	3.36004	14.61800
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)					3.90799	5.71100	0.58501	2.91400	0.74038	9.80500
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	0.08089	5.64300								
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	0.11600	7.55000								

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	-0.01068	-0.43100								
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	0.09456	2.22700								
Vehicle characteristics										
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)									0.66574	8.74700

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Roadway characteristics										
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)					0.00564	0.08700	-0.01455	-0.22800	0.23147	9.31500
Accident characteristics										
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)			-0.28103	-3.68500						
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)			2.36014	34.62000	0.15328	1.64600				

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)					3.94042	5.80100	0.68606	3.61300	1.09572	10.94800
Interaction between driver and vehicle characteristics										
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	-0.79271	-10.19700	-0.64084	-5.51900						

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model (Continued)

Variable	Property Damage Only		Possible Injury		Non-Disabling Injury		Disabling Injury		Fatality	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)			0.05406	0.36100						
Interaction between driver and location characteristics										
Interaction Variable between driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)					3.75769	5.60100	0.41348	1.62400	0.74238	7.78800

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model (Continued)

Scale Parameters of Extreme Value Distns Minus 1.0	Coefficient	t-statistic
Non-Injury	1.50043	6.34100
Possible Injury	-0.68687	-59.50300
Non-Disabling Injury	-0.66181	-10.89600
Disabling Injury	-0.63938	-4.08800
Fatality	0.00000	......(Fixed Parameter).......
Std.Dev=pi/(theta*sqr(6)) for H.E.V. distribution.	Coefficient	t-statistic
Non-Injury	0.51293	10.56800
Possible Injury	4.09592	27.12600
Non-Disabling Injury	3.79238	5.56800
Disabling Injury	3.55651	2.30600

Table 16 Heteroskedastic extreme-value model estimation results for non-injury, possible injury, non-disabling injury, disabling injury, and fatality for two-vehicle driver only occupant severity model (Continued)

Std.Dev=pi/(theta*sqr(6)) for H.E.V. distribution.	Coefficient	t-statistic
Fatality	1.28255	......(Fixed Parameter).......
Number of observations	96600	
Log-likelihood at constant only	-90916.4	
Log-likelihood at zero	-155471.7	
Log-likelihood at convergence	-85150.42	
Adjusted ρ^2	0.45	

5.2.3.1 Driver Characteristics

In HEV model, if both the severity-considered driver and the other driver are male, the propensity increases toward PDO. However, the HEV model indicates a much lower propensity toward the probability of PDO for male driver. In the category of driver's contribution to an accident, the other driver exceeding the reasonably safe speed is not a significant variable in the function of PINJ at any level with a t-statistic of -0.431. It was found that if the other driver was following too closely, the probability of being involved in a PDO is higher than being in a PINJ. This finding of the HEV model is inconsistent with the findings of the NL model and the CHM.

The variable, driver ejection (such as if either driver had totally ejected), significantly drives the severities of DIS and fatality in the HEV model, which is similar to the NL model. But it suggests a much higher propensity towards DIS, not fatality. This is not consistent with the NL model. The coefficients are 6.0491 with a t-statistic of 2.288 in DIS and 3.3600 with a t-statistic of 14.618 in fatality.

The other significant variable in the functions of NONDIS, DIS and fatality, driver sobriety, indicates that if either driver had been drinking in the two-vehicle accident, the propensity of severity would significantly increase towards a fatality for the severity-considered driver in NL model. However, the results in the HEV model are not consistent with the NL model. The propensity of severity in CHM would increase towards NONDIS with the coefficients going from 3.9080 with a t-statistic of 5.711 in NONDIS to 0.585 with a t-statistic of 2.914 in DIS and finally to 0.7404 with a t-statistic of 9.805 in fatality, if a driver had been drinking. In other words, a driver would have a less severity if he/she had been drinking. This is not consistent with expectations.

5.2.3.2 Vehicle Characteristics

One variable, the type of the other vehicle involved in the accident, was also modeled in HEV model. It was found that the variable, if the other vehicle is a truck, significantly driver the propensity towards fatality with a coefficient of 0.6657 and a t-statistic of 8.747. This is consistent with the NL model.

5.2.3.3 Roadway Characteristics

In this category there is only one variable, the junction relationship indicator (such as if the accident was at intersection and related). In the HEV model, this variable is not statistically significant different from 0 in NONDIS, DIS. It only significantly let the propensity goes towards fatality with a coefficient of 0.2315 and a t-statistic of 9.315. However, it is not consistent with results in the NL model and CHM since the junction relationship indicator (such as if the accident was at intersection and related) has a negative impact in the function fatality.

5.2.3.4 Accident Characteristics

The HEV model estimation shows that the same direction type of collision decreases the propensity toward PINJ with a coefficient of -0.2810 and a t-statistic of -3.685. The rear end type of collision also has significant impacts in PINJ but not in NONDIS in the HEV model. It suggests the propensity goes towards PINJ with a coefficient of 2.3601 and a t-statistic of 34.620. The HEV model found that the opposite direction type of collision has significant impacts in NONDIS, DIS and fatality. It suggests a much higher propensity towards NONDIS than NL model and CHM. The coefficient is 3.9404 with a t-statistic of 5.801 (0.19673 with a t-statistic of 5.298 in the NL model and 0.2543 with a t-statistic of 6.995 in the CHM) in NONDIS. It has a similar result with NL model and CHM with a coefficient of 0.6861 and a t-statistic of 3.613 in DIS. But it has a lower propensity towards fatality than NL model with a coefficient of 1.0957 and t-statistic of 10.948.

5.2.3.5 Interaction Between Driver and Vehicle Characteristics

The variable, an interaction variable between driver restraint system usage and vehicle type, shows that if either driver did not use any restraints and either vehicle type is a passenger car, the propensity would go towards higher severities, which is also consistent with the NL model and CHM. The coefficients and t-statistics are -0.7927 and -10.197 in PDO and -0.6408 and -5.519 in PINJ. The variable, if the severity-considered driver did not use any restraints and he or she drove a pick-up, does not have significant impacts in the function of PINJ with a t-statistic of 0.361.

5.2.3.6 Interaction Between Driver and Location Characteristics

The HEV model's result shows that if the severity-considered driver is more than 55 years of age and the accident happened in the rural area, the propensity increases significantly toward NONDIS and fatality. The coefficients and t-statistics are 3.7577 and 5.601 in NOONDIS and 0.7424 and 7.788 in fatality. It indicates that the propensity would go towards NONDIS instead of fatality in HEV model, which is not consistent with the NL model. This variable is not statistically significant in the function of DIS.

5.3 Elasticity

Elasticity may be defined as a unitless measure that describes the relationship between the percentage change for variables and the percentage change in the quantity demanded (Hensher et al., 2005). There are two types of elasticities defined by economists. They are direct-elasticities and cross-elasticities. Louviere, Hensher and Swait (2000) have defined direct- and Cross-elasticities as follows:

> *"A direct elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in an attribute of that same alternative."*
>
> *"A cross elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in a competing alternative."*

Since most of the variables are dummy (coded 0 or 1) or indicator variables in severity models, it would not be meaningful of the interpretation for the percentage change in such these variables, for example, 1 percent change in gender. Thus the elasticity is calculated to measure the percentage change in the probability of a particular severity given a status change (from 0 to 1, for example, from male driver to female driver, or 1 to 0) in an attribute. The following equation was employed to calculate the elasticities of dummy variables.

$$E_{kj} = \frac{\overline{P}_{\tilde{k}j} - \overline{P}_{kj}}{\overline{P}_{kj}} \qquad (5.3.1)$$

Where E_{kj} is the elasticity of variable k for severity j, $\overline{P}_{\tilde{k}j}$ is the average probability of the sub-sample for variable k when is currently changed to be 1 (or 0) for observations in the sub-sample for severity j, and $\overline{P}_{kj}$ is the average probability of the sub-sample for variable k when is currently coded to be 0 (or 1) as observed values for severity j.

The direct- and cross-elasticities of every variable in the single- and two-vehicle driver only occupant severity NL models, CHMs and HEV models were calculated, and will be discussed in this section. These elasticities were calculated for status changes from 0 to 1 as well as from 1 to 0 for every variable. Two sub-samples for each variable were created (separate 0 sample and 1 sample) and the average probability changes of severities with respect to the changes of every variable were calculated one variable at a time. In the following sections, not only the average probabilities for the sub-samples (every variable one at a time) which were 0 and 1 separately for all observations and for the sub-samples after the changes (set 0 to 1 for 0 sub-samples and 1 to 0 for 1 sub-samples) and the elasticities are reported in tables for all three models, but also ratios of average probabilities for after-status change status of a particular variable to average probability for the observed values

The ratio, similar to elasticities, can be calculated using the following equation.

$$R_{kj} = \frac{\overline{P}_{\tilde{k}j}}{\overline{P}_{kj}} \qquad (5.3.2)$$

Where R_{kj} is the ratio of the average probability, $\overline{P}_{\tilde{k}j}$, of the sub-sample for variable k after currently changed the status to be 1 (or 0) for observations in the sub-sample for severity j to the average probability, $\overline{P}_{kj}$, of the sub-sample for variable k when is currently coded to be 0 (or 1) as observed values for severity j.

5.3.1 Elasticity for Single-Vehicle Driver Only Occupant Severity Model

The following tables, Table 17 and 18 are the tables of the average probabilities when sub-sampled observed indicator is 0 and 1 respectively in elasticity computations for the nested logit single-vehicle driver only occupant severity model. Table 19 and 20 are the tables of the average probabilities when sub-sampled observed indicator is 0 and 1 respectively in elasticity computations for the covariance heterogeneity single-vehicle driver only occupant severity model. Table 21 and 22 are the tables of the average probabilities when sub-sampled observed indicator is 0 and 1 respectively in elasticity computations for the heteroskedastic extreme-value single-vehicle driver only occupant severity model. In the tables, bold numbers represent direct-elasticities while un-bolded numbers represent cross-elasticities. The highlighted values represent the variables that are elastic.

As can be seen in tables 17, 19 and 21, all variables are not elastic in low severities, such as PDO, PINJ (lower nest) and NONINJ (upper nest), when the indicator changes from 0 to 1. But for the high severities, several observations can be made from these tables. Driver ejection indicator (1 if driver has been totally ejected) is most elastic in high severities in the NL and HEV models, especially the fatality case in the NL model with an elasticity of 24.2088. This is not elastic in the CHM across all severities. The only elastic variable in the CHM is the interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car). The elasticities go from 1.5341 for NONDIS to 1.5553 for DIS and then to 1.7015 for fatality. This variable is also elastic and increases the probability of NODIS in the NL model with an elasticity of 1.0772 while increasing the probability of DIS and fatality in the HEV model with elasticities of 1.1049 and 2.2670 respectively. Other effects which would increase the severities in the NL model are the driver drinking status variable for the fatality case, driver's age being greater than 55, and the accident occurring in a rural area for fatality. In addition, guardrail or bridge rail leading end are elastic in fatality and the interaction between driver restraint use and vehicle type being pick-up is elastic in NONDIS and DIS.

In tables 18, 20 and 22, tables of average probabilities and elasticities in nested logit, covariance heterogeneity and heteroskedastic extreme-value models for the indicators changing from 1 to 0, all variables are not elastic in high severities. There are only two elastic variables across all three models. They are the interaction between driver restraint use and vehicle type being passenger car for PDO in the NL model and for PDO and NONINJ in the CHM, and driver ejection status for PDO, PINJ, NONINJ and NONDIS in the NL model and for PDO in the HEV model.

In summary, NL has slightly overestimated the effects increasing the probabilities of high severities when variables change from 0 to 1 and effects increasing the probabilities of low severities when variables change from 1 to 0.

Table 17 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in nested logit single-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver gender indicator (1 if driver is male, 0 otherwise)	currently ZERO for all observations	**0.5029**	**0.2177**	**0.7206**	0.2227	0.0481	0.0086
	currently set to ONE for all observations	**0.6344**	**0.1305**	**0.7649**	0.1864	0.0410	0.0077
	Ratio	**1.2615**	**0.5996**	**1.0615**	0.8367	0.8538	0.8890
	Elasticities	**0.2615**	**-0.4004**	**0.0615**	-0.1633	-0.1462	-0.1110
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.5996**	**0.1522**	**0.7518**	0.1975	0.0429	0.0078
	currently set to ONE for all observations	**0.3065**	**0.1859**	**0.4925**	0.4103	0.0840	0.0133
	Ratio	**0.5113**	**1.2213**	**0.6551**	2.0772	1.9571	1.7073
	Elasticities	**-0.4887**	**0.2213**	**-0.3449**	1.0772	0.9571	0.7073
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.6136	0.1645	0.7780	**0.1820**	**0.0352**	**0.0048**
	currently set to ONE for all observations	0.5154	0.1367	0.6521	**0.2653**	**0.0677**	**0.0149**
	Ratio	0.8400	0.8314	0.8382	**1.4577**	**1.9241**	**3.1094**
	Elasticities	-0.1600	-0.1686	-0.1618	**0.4577**	**0.9241**	**2.1094**
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	currently ZERO for all observations	0.5850	0.1585	0.7434	**0.2000**	**0.0464**	0.0102
	currently set to ONE for all observations	0.5342	0.1437	0.6779	**0.2552**	**0.0584**	0.0086
	Ratio	0.9132	0.9069	0.9119	**1.2759**	**1.2575**	0.8408
	Elasticities	-0.0868	-0.0931	-0.0881	**0.2759**	**0.2575**	-0.1592
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.5737	0.1533	0.7270	**0.2137**	**0.0494**	**0.0099**
	currently set to ONE for all observations	0.5182	0.1375	0.6557	**0.2447**	**0.0719**	**0.0277**
	Ratio	0.9033	0.8969	0.9019	**1.1449**	**1.4578**	**2.7886**
	Elasticities	-0.0967	-0.1031	-0.0981	**0.1449**	**0.4578**	**1.7886**

Table 17 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in nested logit single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.5786	0.1544	0.7330	0.2167	**0.0440**	**0.0063**
	currently set to ONE for all observations	0.3549	0.0927	0.4476	0.1116	**0.2823**	**0.1586**
	Ratio	0.6133	0.6003	0.6106	0.5150	**6.4142**	**25.2088**
	Elasticities	-0.3867	-0.3997	-0.3894	-0.4850	**5.4142**	**24.2088**
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)	currently ZERO for all observations	0.5750	0.1536	0.7286	0.2143	**0.0470**	**0.0100**
	currently set to ONE for all observations	0.5600	0.1493	0.7093	0.2054	**0.0715**	**0.0138**
	Ratio	0.9739	0.9720	0.9735	0.9581	**1.5211**	**1.3763**
	Elasticities	-0.0261	-0.0280	-0.0265	-0.0419	**0.5211**	**0.3763**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	currently ZERO for all observations	0.5713	0.1526	0.7239	0.2153	0.0504	**0.0104**
	currently set to ONE for all observations	0.5666	0.1512	0.7178	0.2119	0.0477	**0.0226**
	Ratio	0.9918	0.9909	0.9916	0.9840	0.9465	**2.1759**
	Elasticities	-0.0082	-0.0091	-0.0084	-0.0160	-0.0535	**1.1759**
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	currently ZERO for all observations	**0.6246**	**0.1675**	**0.7921**	0.1659	0.0356	0.0065
	currently set to ONE for all observations	**0.5608**	**0.1493**	**0.7101**	0.2331	0.0486	0.0083
	Ratio	**0.8978**	**0.8915**	**0.8965**	1.4054	1.3650	1.2718
	Elasticities	**-0.1022**	**-0.1085**	**-0.1035**	0.4054	0.3650	0.2718
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	**0.5874**	**0.1579**	**0.7453**	0.2020	0.0444	0.0083
	currently set to ONE for all observations	**0.3659**	**0.0958**	**0.4617**	0.4347	0.0893	0.0143
	Ratio	**0.6228**	**0.6070**	**0.6195**	2.1519	2.0119	1.7280
	Elasticities	**-0.3772**	**-0.3930**	**-0.3805**	1.1519	1.0119	0.7280

Table 17 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in nested logit single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	currently ZERO for all observations	**0.5516**	**0.1461**	**0.6977**	0.2337	0.0565	0.0121
	currently set to ONE for all observations	**0.5894**	**0.1569**	**0.7463**	0.1946	0.0483	0.0109
	Ratio	**1.0684**	**1.0740**	**1.0696**	0.8326	0.8549	0.8972
	Elasticities	**0.0684**	**0.0740**	**0.0696**	-0.1674	-0.1451	-0.1028

Table 18 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in nested logit single-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver gender indicator (1 if driver is male, 0 otherwise)	currently ZERO for all observations	**0.6012**	**0.1233**	**0.7244**	0.2124	0.0515	0.0116
	currently set to ONE for all observations	**0.4733**	**0.2043**	**0.6776**	0.2503	0.0593	0.0128
	Ratio	**0.7873**	**1.6571**	**0.9354**	1.1784	1.1506	1.1010
	Elasticities	**-0.2127**	**0.6571**	**-0.0646**	0.1784	0.1506	0.1010
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.2546**	**0.1548**	**0.4094**	0.4144	0.1334	0.0428
	currently set to ONE for all observations	**0.5434**	**0.1378**	**0.6812**	0.2097	0.0793	0.0298
	Ratio	**2.1345**	**0.8901**	**1.6640**	0.5059	0.5943	0.6972
	Elasticities	**1.1345**	**-0.1099**	**0.6640**	-0.4941	-0.4057	-0.3028
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.4353	0.1145	0.5498	**0.3222**	**0.0987**	**0.0294**
	currently set to ONE for all observations	0.5405	0.1456	0.6862	**0.2399**	**0.0614**	**0.0125**
	Ratio	1.2418	1.2723	1.2481	**0.7447**	**0.6224**	**0.4247**
	Elasticities	0.2418	0.2723	0.2481	**-0.2553**	**-0.3776**	**-0.5753**
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	currently ZERO for all observations	0.5296	0.1350	0.6646	**0.2611**	**0.0622**	0.0121
	currently set to ONE for all observations	0.5822	0.1493	0.7314	**0.2041**	**0.0498**	0.0147
	Ratio	1.0992	1.1056	1.1005	**0.7816**	**0.8016**	1.2117
	Elasticities	0.0992	0.1056	0.1005	**-0.2184**	**-0.1984**	0.2117
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.5311	0.1406	0.6717	**0.2416**	**0.0655**	**0.0212**
	currently set to ONE for all observations	0.5859	0.1561	0.7420	**0.2075**	**0.0433**	**0.0071**
	Ratio	1.1032	1.1104	1.1047	**0.8588**	**0.6615**	**0.3358**
	Elasticities	0.1032	0.1104	0.1047	**-0.1412**	**-0.3385**	**-0.6642**

Table 18 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in nested logit single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.1085	0.0389	0.1474	0.1540	**0.4294**	**0.2691**
	currently set to ONE for all observations	0.2894	0.1075	0.3969	0.4806	**0.1060**	**0.0164**
	Ratio	2.6669	2.7631	2.6923	3.1199	**0.2469**	**0.0611**
	Elasticities	1.6669	1.7631	1.6923	2.1199	**-0.7531**	**-0.9389**
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)	currently ZERO for all observations	0.5362	0.1427	0.6789	0.2262	**0.0787**	**0.0162**
	currently set to ONE for all observations	0.5524	0.1474	0.6998	0.2373	**0.0513**	**0.0115**
	Ratio	1.0302	1.0333	1.0308	1.0492	**0.6524**	**0.7101**
	Elasticities	0.0302	0.0333	0.0308	0.0492	**-0.3476**	**-0.2899**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	currently ZERO for all observations	0.5298	0.1422	0.6720	0.2411	0.0535	**0.0335**
	currently set to ONE for all observations	0.5355	0.1439	0.6794	0.2463	0.0579	**0.0164**
	Ratio	1.0108	1.0120	1.0110	1.0217	1.0834	**0.4888**
	Elasticities	0.0108	0.0120	0.0110	0.0217	0.0834	**-0.5112**
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	currently ZERO for all observations	**0.5207**	**0.1385**	**0.6592**	0.2619	0.0643	0.0146
	currently set to ONE for all observations	**0.5884**	**0.1581**	**0.7466**	0.1918	0.0494	0.0122
	Ratio	**1.1300**	**1.1418**	**1.1325**	0.7324	0.7691	0.8347
	Elasticities	**0.1300**	**0.1418**	**0.1325**	-0.2676	-0.2309	-0.1653
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	**0.3175**	**0.0698**	**0.3873**	0.4227	0.1426	0.0473
	currently set to ONE for all observations	**0.5581**	**0.1231**	**0.6812**	0.2045	0.0823	0.0321
	Ratio	**1.7581**	**1.7628**	**1.7590**	0.4836	0.5767	0.6777
	Elasticities	**0.7581**	**0.7628**	**0.7590**	-0.5164	-0.4233	-0.3223

Table 18 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in nested logit single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	currently ZERO for all observations	**0.6221**	**0.1696**	**0.7917**	0.1673	0.0342	0.0068
	currently set to ONE for all observations	**0.5879**	**0.1595**	**0.7474**	0.2038	0.0410	0.0079
	Ratio	**0.9450**	**0.9408**	**0.9441**	1.2180	1.1977	1.1490
	Elasticities	**-0.0550**	**-0.0592**	**-0.0559**	0.2180	0.1977	0.1490

Table 19 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in covariance heterogeneity single-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver gender indicator (1 if driver is male, 0 otherwise)	currently ZERO for all observations	**0.5252**	**0.1711**	**0.6964**	0.2152	0.0541	0.0343
	currently set to ONE for all observations	**0.6271**	**0.1494**	**0.7765**	0.1588	0.0399	0.0248
	Ratio	**1.1940**	**0.8732**	**1.1151**	0.7376	0.7372	0.7233
	Elasticities	**0.1940**	**-0.1268**	**0.1151**	-0.2624	-0.2628	-0.2767
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.6060**	**0.1523**	**0.7583**	0.1731	0.0429	0.0257
	currently set to ONE for all observations	**0.2341**	**0.1483**	**0.3824**	0.4386	0.1095	0.0696
	Ratio	**0.3862**	**0.9737**	**0.5042**	2.5341	2.5553	2.7015
	Elasticities	**-0.6138**	**-0.0263**	**-0.4958**	1.5341	1.5553	1.7015
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.6136	0.1600	0.7736	**0.1578**	**0.0395**	**0.0291**
	currently set to ONE for all observations	0.5354	0.1385	0.6739	**0.2474**	**0.0593**	**0.0193**
	Ratio	0.8726	0.8658	0.8712	**1.5679**	**1.5006**	**0.6645**
	Elasticities	-0.1274	-0.1342	-0.1288	**0.5679**	**0.5006**	**-0.3355**
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	currently ZERO for all observations	0.5883	0.1558	0.7441	**0.1801**	**0.0471**	0.0286
	currently set to ONE for all observations	0.5400	0.1419	0.6819	**0.2404**	**0.0524**	0.0253
	Ratio	0.9178	0.9108	0.9164	**1.3349**	**1.1115**	0.8835
	Elasticities	-0.0822	-0.0892	-0.0836	**0.3349**	**0.1115**	-0.1165
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.5738	0.1507	0.7245	**0.1973**	**0.0496**	**0.0286**
	currently set to ONE for all observations	0.5564	0.1458	0.7022	**0.2225**	**0.0507**	**0.0246**
	Ratio	0.9697	0.9672	0.9692	**1.1274**	**1.0228**	**0.8614**
	Elasticities	-0.0303	-0.0328	-0.0308	**0.1274**	**0.0228**	**-0.1386**

Table 19Average probabilities when sub-sampled observed indicator is 0 and elasticity results in covariance heterogeneity single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.5774	0.1512	0.7286	0.1951	**0.0481**	**0.0282**
	currently set to ONE for all observations	0.5649	0.1477	0.7126	0.1887	**0.0654**	**0.0333**
	Ratio	0.9784	0.9767	0.9780	0.9672	**1.3588**	**1.1836**
	Elasticities	-0.0216	-0.0233	-0.0220	-0.0328	**0.3588**	**0.1836**
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)	currently ZERO for all observations	0.5758	0.1510	0.7268	0.1961	**0.0490**	**0.0282**
	currently set to ONE for all observations	0.5783	0.1517	0.7301	0.1974	**0.0460**	**0.0265**
	Ratio	1.0045	1.0048	1.0045	1.0069	**0.9399**	**0.9394**
	Elasticities	0.0045	0.0048	0.0045	0.0069	**-0.0601**	**-0.0606**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	currently ZERO for all observations	0.5728	0.1504	0.7232	0.1988	0.0495	**0.0285**
	currently set to ONE for all observations	0.5685	0.1496	0.7181	0.2030	0.0506	**0.0284**
	Ratio	0.9924	0.9949	0.9929	1.0213	1.0207	**0.9953**
	Elasticities	-0.0076	-0.0051	-0.0071	0.0213	0.0207	**-0.0047**
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	currently ZERO for all observations	**0.6270**	**0.1641**	**0.7911**	0.1485	0.0372	0.0232
	currently set to ONE for all observations	**0.5684**	**0.1477**	**0.7161**	0.2014	0.0505	0.0320
	Ratio	**0.9066**	**0.9000**	**0.9052**	1.3564	1.3578	1.3779
	Elasticities	**-0.0934**	**-0.1000**	**-0.0948**	0.3564	0.3578	0.3779
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	**0.5822**	**0.1536**	**0.7358**	0.1893	0.0471	0.0278
	currently set to ONE for all observations	**0.4638**	**0.1204**	**0.5841**	0.2968	0.0740	0.0451
	Ratio	**0.7965**	**0.7839**	**0.7939**	1.5680	1.5707	1.6213
	Elasticities	**-0.2035**	**-0.2161**	**-0.2061**	0.5680	0.5707	0.6213

Table 19Average probabilities when sub-sampled observed indicator is 0 and elasticity results in covariance heterogeneity single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	currently ZERO for all observations	**0.5498**	**0.1438**	**0.6936**	0.2214	0.0544	0.0306
	currently set to ONE for all observations	**0.6001**	**0.1582**	**0.7583**	0.1750	0.0430	0.0238
	Ratio	**1.0914**	**1.1001**	**1.0932**	0.7902	0.7904	0.7776
	Elasticities	**0.0914**	**0.1001**	**0.0932**	-0.2098	-0.2096	-0.2224

Table 20 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in covariance heterogeneity single-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver gender indicator (1 if driver is male, 0 otherwise)	currently ZERO for all observations	**0.5935**	**0.1410**	**0.7345**	0.1918	0.0477	0.0260
	currently set to ONE for all observations	**0.4905**	**0.1594**	**0.6500**	0.2522	0.0627	0.0351
	Ratio	**0.8265**	**1.1307**	**0.8849**	1.3149	1.3156	1.3503
	Elasticities	**-0.1735**	**0.1307**	**-0.1151**	0.3149	0.3156	0.3503
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.2031**	**0.1286**	**0.3316**	0.4846	0.1244	0.0594
	currently set to ONE for all observations	**0.5810**	**0.1457**	**0.7267**	0.1992	0.0510	0.0230
	Ratio	**2.8614**	**1.1333**	**2.1915**	0.4112	0.4098	0.3882
	Elasticities	**1.8614**	**0.1333**	**1.1915**	-0.5888	-0.5902	-0.6118
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.4420	0.1197	0.5616	**0.3297**	**0.0818**	**0.0269**
	currently set to ONE for all observations	0.5264	0.1457	0.6721	**0.2257**	**0.0586**	**0.0436**
	Ratio	1.1909	1.2178	1.1966	**0.6845**	**0.7170**	**1.6193**
	Elasticities	0.1909	0.2178	0.1966	**-0.3155**	**-0.2830**	**0.6193**
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	currently ZERO for all observations	0.5262	0.1344	0.6606	**0.2541**	**0.0570**	0.0283
	currently set to ONE for all observations	0.5779	0.1485	0.7264	**0.1902**	**0.0513**	0.0321
	Ratio	1.0983	1.1048	1.0996	**0.7485**	**0.9004**	1.1340
	Elasticities	0.0983	0.1048	0.0996	**-0.2515**	**-0.0996**	0.1340
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.5536	0.1447	0.6983	**0.2228**	**0.0507**	**0.0281**
	currently set to ONE for all observations	0.5713	0.1496	0.7209	**0.1970**	**0.0494**	**0.0326**
	Ratio	1.0319	1.0341	1.0324	**0.8842**	**0.9743**	**1.1600**
	Elasticities	0.0319	0.0341	0.0324	**-0.1158**	**-0.0257**	**0.1600**

Table 20 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in covariance heterogeneity single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.2804	0.0975	0.3778	0.4302	**0.1413**	**0.0506**
	currently set to ONE for all observations	0.2931	0.1024	0.3955	0.4545	**0.1063**	**0.0437**
	Ratio	1.0453	1.0507	1.0467	1.0563	**0.7520**	**0.8647**
	Elasticities	0.0453	0.0507	0.0467	0.0563	**-0.2480**	**-0.1353**
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)	currently ZERO for all observations	0.5449	0.1445	0.6895	0.2237	**0.0552**	**0.0316**
	currently set to ONE for all observations	0.5421	0.1437	0.6858	0.2219	**0.0587**	**0.0336**
	Ratio	0.9948	0.9942	0.9947	0.9920	**1.0628**	**1.0633**
	Elasticities	-0.0052	-0.0058	-0.0053	-0.0080	**0.0628**	**0.0633**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	currently ZERO for all observations	0.5413	0.1447	0.6860	0.2222	0.0591	**0.0327**
	currently set to ONE for all observations	0.5411	0.1446	0.6858	0.2220	0.0591	**0.0331**
	Ratio	0.9996	0.9996	0.9996	0.9995	0.9995	**1.0126**
	Elasticities	-0.0004	-0.0004	-0.0004	-0.0005	-0.0005	**0.0126**
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	currently ZERO for all observations	**0.5216**	**0.1375**	**0.6591**	0.2461	0.0613	0.0335
	currently set to ONE for all observations	**0.5857**	**0.1561**	**0.7418**	0.1868	0.0465	0.0249
	Ratio	**1.1228**	**1.1356**	**1.1254**	0.7590	0.7590	0.7435
	Elasticities	**0.1228**	**0.1356**	**0.1254**	-0.2410	-0.2410	-0.2565
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	**0.4233**	**0.1004**	**0.5237**	0.3478	0.0885	0.0400
	currently set to ONE for all observations	**0.5630**	**0.1338**	**0.6967**	0.2221	0.0564	0.0248
	Ratio	**1.3299**	**1.3322**	**1.3303**	0.6384	0.6373	0.6212
	Elasticities	**0.3299**	**0.3322**	**0.3303**	-0.3616	-0.3627	-0.3788

Table 20 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in covariance heterogeneity single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	currently ZERO for all observations	**0.6329**	**0.1677**	**0.8006**	0.1393	0.0370	0.0231
	currently set to ONE for all observations	**0.5877**	**0.1546**	**0.7423**	0.1797	0.0477	0.0303
	Ratio	**0.9286**	**0.9221**	**0.9272**	1.2899	1.2901	1.3090
	Elasticities	**-0.0714**	**-0.0779**	**-0.0728**	0.2899	0.2901	0.3090

Table 21 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in heteroskedastic extreme-value single-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver gender indicator (1 if driver is male, 0 otherwise)	currently ZERO for all observations	**0.5459**	**0.1895**	0.2341	0.0501	0.0323
	currently set to ONE for all observations	**0.5602**	**0.1844**	0.2283	0.0478	0.0295
	Ratio	**1.0262**	**0.9730**	0.9752	0.9559	0.9130
	Elasticities	**0.0262**	**-0.0270**	-0.0248	-0.0441	-0.0870
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.5646**	**0.1864**	0.2294	0.0445	0.0253
	currently set to ONE for all observations	**0.3563**	**0.1740**	0.3508	0.0937	0.0826
	Ratio	**0.6311**	**0.9332**	1.5292	2.1049	3.2670
	Elasticities	**-0.3689**	**-0.0668**	0.5292	1.1049	2.2670
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.5885	0.1908	**0.2023**	**0.0429**	**0.0273**
	currently set to ONE for all observations	0.4295	0.1666	**0.3609**	**0.0589**	**0.0294**
	Ratio	0.7297	0.8729	**1.7838**	**1.3748**	**1.0796**
	Elasticities	-0.2703	-0.1271	**0.7838**	**0.3748**	**0.0796**
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	currently ZERO for all observations	0.5406	0.1843	**0.2443**	**0.0496**	0.0313
	currently set to ONE for all observations	0.5301	0.1827	**0.2550**	**0.0528**	0.0298
	Ratio	0.9804	0.9910	**1.0436**	**1.0652**	0.9537
	Elasticities	-0.0196	-0.0090	**0.0436**	**0.0652**	-0.0463
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.5382	0.1834	**0.2456**	**0.0513**	**0.0315**
	currently set to ONE for all observations	0.5279	0.1822	**0.2451**	**0.0577**	**0.0396**
	Ratio	0.9809	0.9934	**0.9980**	**1.1244**	**1.2593**
	Elasticities	-0.0191	-0.0066	**-0.0020**	**0.1244**	**0.2593**
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.5476	0.1850	0.2445	**0.0458**	**0.0273**
	currently set to ONE for all observations	0.1305	0.1265	0.1630	**0.3412**	**0.2931**
	Ratio	0.2382	0.6839	0.6667	**7.4504**	**10.7352**
	Elasticities	-0.7618	-0.3161	-0.3333	**6.4504**	**9.7352**

Table 21 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in heteroskedastic extreme-value single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)	currently ZERO for all observations	0.5422	0.1840	0.2420	**0.0507**	**0.0312**
	currently set to ONE for all observations	0.5391	0.1836	0.2414	**0.0561**	**0.0308**
	Ratio	0.9942	0.9978	0.9974	**1.1066**	**0.9884**
	Elasticities	-0.0058	-0.0022	-0.0026	**0.1066**	**-0.0116**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	currently ZERO for all observations	0.5397	0.1836	0.2437	0.0514	**0.0318**
	currently set to ONE for all observations	0.5387	0.1835	0.2436	0.0512	**0.0334**
	Ratio	0.9983	0.9995	0.9994	0.9978	**1.0497**
	Elasticities	-0.0017	-0.0005	-0.0006	-0.0022	**0.0497**
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	currently ZERO for all observations	**0.5617**	**0.1851**	0.2291	0.0463	0.0283
	currently set to ONE for all observations	**0.5597**	**0.1883**	0.2288	0.0462	0.0277
	Ratio	**0.9964**	**1.0175**	0.9984	0.9982	0.9787
	Elasticities	**-0.0036**	**0.0175**	-0.0016	-0.0018	-0.0213
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	**0.5445**	**0.1841**	0.2419	0.0493	0.0305
	currently set to ONE for all observations	**0.5405**	**0.1900**	0.2412	0.0491	0.0298
	Ratio	**0.9928**	**1.0320**	0.9968	0.9962	0.9768
	Elasticities	**-0.0072**	**0.0320**	-0.0032	-0.0038	-0.0232
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	currently ZERO for all observations	**0.5353**	**0.1820**	0.2464	0.0533	0.0332
	currently set to ONE for all observations	**0.5336**	**0.1852**	0.2461	0.0532	0.0323
	Ratio	**0.9968**	**1.0172**	0.9985	0.9987	0.9732
	Elasticities	**-0.0032**	**0.0172**	-0.0015	-0.0013	-0.0268

Table 22 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in heteroskedastic extreme-value single-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver gender indicator (1 if driver is male, 0 otherwise)	currently ONE for all observations	**0.5364**	**0.1809**	0.2484	0.0520	0.0317
	currently set to ZERO for all observations	**0.5225**	**0.1859**	0.2545	0.0543	0.0335
	Ratio	**0.9742**	**1.0274**	1.0246	1.0439	1.0547
	Elasticities	**-0.0258**	**0.0274**	0.0246	0.0439	0.0547
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	currently ONE for all observations	**0.2621**	**0.1522**	0.4037	0.1272	0.1047
	currently set to ZERO for all observations	**0.4700**	**0.1725**	0.2786	0.0787	0.0488
	Ratio	**1.7931**	**1.1327**	0.6901	0.6192	0.4662
	Elasticities	**0.7931**	**0.1327**	-0.3099	-0.3808	-0.5338
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	currently ONE for all observations	0.3835	0.1607	**0.3758**	**0.0786**	**0.0466**
	currently set to ZERO for all observations	0.5421	0.1869	**0.2145**	**0.0618**	**0.0476**
	Ratio	1.4136	1.1636	**0.5709**	**0.7866**	**1.0206**
	Elasticities	0.4136	0.1636	**-0.4291**	**-0.2134**	**0.0206**
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	currently ONE for all observations	0.5355	0.1814	**0.2429**	**0.0568**	0.0338
	currently set to ZERO for all observations	0.5462	0.1830	**0.2326**	**0.0535**	0.0346
	Ratio	1.0199	1.0090	**0.9577**	**0.9418**	1.0255
	Elasticities	0.0199	0.0090	**-0.0423**	**-0.0582**	0.0255
Interaction variable between driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ONE for all observations	0.5546	0.1862	**0.2218**	**0.0531**	**0.0379**
	currently set to ZERO for all observations	0.5652	0.1873	**0.2221**	**0.0469**	**0.0293**
	Ratio	1.0190	1.0064	**1.0013**	**0.8832**	**0.7734**
	Elasticities	0.0190	0.0064	**0.0013**	**-0.1168**	**-0.2266**
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	currently ONE for all observations	0.0519	0.0979	0.2119	**0.3832**	**0.3032**
	currently set to ZERO for all observations	0.3806	0.1677	0.3761	**0.0733**	**0.0498**
	Ratio	7.3384	1.7128	1.7750	**0.1913**	**0.1643**
	Elasticities	6.3384	0.7128	0.7750	**-0.8087**	**-0.8357**

Table 22 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in heteroskedastic extreme-value single-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Object struck indicator (1 if driver struck tree or stump, light pole, utility pole, railway pole, traffic signal pole, overheard sign support pole, sign box, bridge column or pillar, 0 otherwise)	currently ONE for all observations	0.5154	0.1799	0.2602	**0.0575**	**0.0381**
	currently set to ZERO for all observations	0.5218	0.1806	0.2614	**0.0524**	**0.0331**
	Ratio	1.0124	1.0041	1.0050	**0.9113**	**0.8682**
	Elasticities	0.0124	0.0041	0.0050	**-0.0887**	**-0.1318**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	currently ONE for all observations	0.5100	0.1792	0.2637	0.0572	**0.0397**
	currently set to ZERO for all observations	0.5113	0.1794	0.2640	0.0574	**0.0373**
	Ratio	1.0027	1.0008	1.0010	1.0039	**0.9398**
	Elasticities	0.0027	0.0008	0.0010	0.0039	**-0.0602**
Roadway surface condition indicator (1 if the surface is dry, 0 otherwise)	currently ONE for all observations	**0.5185**	**0.1822**	0.2578	0.0562	0.0353
	currently set to ZERO for all observations	**0.5209**	**0.1791**	0.2583	0.0564	0.0349
	Ratio	**1.0047**	**0.9831**	1.0020	1.0031	0.9880
	Elasticities	**0.0047**	**-0.0169**	0.0020	0.0031	-0.0120
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is pick-up, 0 otherwise)	currently ONE for all observations	**0.4613**	**0.1759**	0.2748	0.0840	0.0531
	currently set to ZERO for all observations	**0.4648**	**0.1704**	0.2757	0.0843	0.0533
	Ratio	**1.0077**	**0.9687**	1.0033	1.0039	1.0047
	Elasticities	**0.0077**	**-0.0313**	0.0033	0.0039	0.0047
Object struck indicator (1 if driver struck wood or metal sign post or guide post or guardrail face or concrete barrier, 0 otherwise)	currently ONE for all observations	**0.5501**	**0.1877**	0.2374	0.0465	0.0285
	currently set to ZERO for all observations	**0.5523**	**0.1846**	0.2378	0.0466	0.0286
	Ratio	**1.0041**	**0.9833**	1.0018	1.0024	1.0029
	Elasticities	**0.0041**	**-0.0167**	0.0018	0.0024	0.0029

5.3.2 Elasticity for Two-Vehicle Driver Only Occupant Severity Model

The following tables, Table 23 and 24 are the tables of the average probabilities when sub-sampled observed indicator is 0 and 1 respectively in elasticity computations for the nested logit two-vehicle driver only occupant severity model. Table 25 and 26 are the tables of the average probabilities when sub-sampled observed indicator is 0 and 1 respectively in elasticity computations for the covariance heterogeneity two-vehicle driver only occupant severity model. Tables 27 and 28 are the tables of the average probabilities when sub-sampled observed indicator is 0 and 1 respectively in elasticity computations for the heteroskedastic extreme-value two-vehicle driver only occupant severity model.

As can be seen in tables 23, 25 and 27, all variables are not elastic in low severities, such as PDO, PINJ (lower nest) and NONINJ (upper nest), when the indicators change from 0 to 1. This is consistent with the single-vehicle analysis. But for high severities, several observations can be made from these tables. Driver ejection indicator (1 if either driver has been totally ejected) is most elastic in high severities in the NL and HEV models, especially the fatality in the NL model having an elasticity of 24.8504. This is not elastic in the CHM across all severities. These results are also consistent with the single-vehicle analysis. Another elastic variable in the NL model is the opposite direction collision type with an elasticity of 9.4237 in fatality. This is also an elastic variable for NONDIS and fatality in the HEV model with elasticities of 2.1758 and 1.6917 respectively. Another elastic variable in all three models is the interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car). The elasticities go from 1.7494 for NONDIS to 1.6616 for DIS and then to 1.2309 for fatality in the NL model. The elasticities go from 1.3518 for NONDIS to 1.2836 for DIS and then to 1.4054 for fatality in the CHM. It is only elastic for the fatality outcome in HEV model with an elasticity of 1.1683. Driver drinking status is also elastic for DIS and fatality in the NL model, for NONDIS in the CHM and for NONDIS in the HEV model. Other effects which would increase the severities in the NL model are driver's age being greater than 55 and the accident occurring in a rural area for fatalities and the other vehicle being a truck for the fatality case.

In Table 24, 26 and 28, tables of average probabilities and elasticities in nested logit, covariance heterogeneity and heteroskedastic Extreme-value models for the indicators changing from 1 to 0, most of the variables are not elastic in low severities, except for the driver ejection indictor (1 if either driver had totally ejected) for PINJ in the NL model and for PDO in the HEV model. This is not consistent with the single-vehicle analysis for the changes from yes to no (or 1 to 0 as indicator coding). Three effective variables are shown in the NL model and CHM. They are consistent in both models. The change of collision type is rear end from yes to no in the NL model and CHM would effectively increase the probabilities of DIS and fatality. The change of collision type is same direction from yes to no in the NL model and CHM would effectively increase the probabilities of NONDIS, DIS and fatality. The change of accident was at intersection or related from yes to no would effectively increase the probability fatality

Table 23 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in nested logit two-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	currently ZERO for all observations	**0.6210**	0.2619	0.8829	0.0935	0.0204	0.0031
	currently set to ONE for all observations	**0.6781**	0.2076	0.8857	0.0912	0.0200	0.0031
	Ratio	**1.0919**	0.7925	1.0031	0.9753	0.9804	0.9973
	Elasticities	**0.0919**	-0.2075	0.0031	-0.0247	-0.0196	-0.0027
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	currently ZERO for all observations	**0.6205**	0.2614	0.8819	0.0945	0.0207	0.0029
	currently set to ONE for all observations	**0.6781**	0.2065	0.8845	0.0922	0.0203	0.0029
	Ratio	**1.0929**	0.7897	1.0030	0.9760	0.9819	1.0018
	Elasticities	**0.0929**	-0.2103	0.0030	-0.0240	-0.0181	0.0018
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.6688**	**0.2249**	**0.8937**	0.0847	0.0186	0.0030
	currently set to ONE for all observations	**0.4394**	**0.2715**	**0.7110**	0.2329	0.0495	0.0066
	Ratio	**0.6571**	**1.2072**	**0.7955**	2.7494	2.6616	2.2309
	Elasticities	**-0.3429**	**0.2072**	**-0.2045**	1.7494	1.6616	1.2309
Driver contributing circumstances indicator (1 if the severity-considered vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6609**	0.2196	0.8805	0.0944	0.0214	0.0037
	currently set to ONE for all observations	**0.5860**	0.2862	0.8722	0.1009	0.0230	0.0040
	Ratio	**0.8867**	1.3035	0.9906	1.0687	1.0707	1.0735
	Elasticities	**-0.1133**	0.3035	-0.0094	0.0687	0.0707	0.0735
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6609**	0.2196	0.8805	0.0943	0.0214	0.0038
	currently set to ONE for all observations	**0.5856**	0.2866	0.8722	0.1008	0.0230	0.0040
	Ratio	**0.8860**	1.3052	0.9906	1.0691	1.0708	1.0732
	Elasticities	**-0.1140**	0.3052	-0.0094	0.0691	0.0708	0.0732
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	currently ZERO for all observations	**0.6584**	0.2199	0.8783	0.0956	0.0221	0.0040
	currently set to ONE for all observations	**0.5923**	0.2783	0.8706	0.1017	0.0235	0.0043
	Ratio	**0.8995**	1.2655	0.9912	1.0629	1.0654	1.0737
	Elasticities	**-0.1005**	0.2655	-0.0088	0.0629	0.0654	0.0737

Table 23 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in nested logit two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.6628	0.2296	0.8923	**0.0864**	**0.0185**	**0.0027**
	currently set to ONE for all observations	0.5889	0.2032	0.7921	**0.1610**	**0.0399**	**0.0071**
	Ratio	0.8885	0.8853	0.8877	**1.8622**	**2.1491**	**2.6331**
	Elasticities	-0.1115	-0.1147	-0.1123	**0.8622**	**1.1491**	**1.6331**
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	currently ZERO for all observations	0.6659	0.2310	0.8969	**0.0853**	**0.0166**	**0.0012**
	currently set to ONE for all observations	0.6361	0.2203	0.8564	**0.0995**	**0.0313**	**0.0128**
	Ratio	0.9553	0.9536	0.9548	**1.1665**	**1.8896**	**10.4237**
	Elasticities	-0.0447	-0.0464	-0.0452	**0.1665**	**0.8896**	**9.4237**
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	currently ZERO for all observations	0.6551	**0.2094**	**0.8645**	**0.1029**	0.0270	0.0056
	currently set to ONE for all observations	0.7028	**0.2266**	**0.9294**	**0.0572**	0.0107	0.0027
	Ratio	1.0728	**1.0823**	**1.0751**	**0.5560**	0.3952	0.4833
	Elasticities	0.0728	**0.0823**	**0.0751**	**-0.4440**	-0.6048	-0.5167
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.6579	0.2268	0.8847	**0.0918**	**0.0204**	**0.0032**
	currently set to ONE for all observations	0.6085	0.2093	0.8178	**0.1386**	**0.0341**	**0.0096**
	Ratio	0.9249	0.9227	0.9243	**1.5103**	**1.6753**	**2.9910**
	Elasticities	-0.0751	-0.0773	-0.0757	**0.5103**	**0.6753**	**1.9910**
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	currently ZERO for all observations	0.6539	0.2296	0.8835	**0.0905**	**0.0211**	**0.0049**
	currently set to ONE for all observations	0.6735	0.2339	0.9074	**0.0762**	**0.0151**	**0.0014**
	Ratio	1.0299	1.0185	1.0270	**0.8420**	**0.7145**	**0.2831**
	Elasticities	0.0299	0.0185	0.0270	**-0.1580**	**-0.2855**	**-0.7169**
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.6565	0.2260	0.8826	0.0936	**0.0206**	**0.0032**
	currently set to ONE for all observations	0.5009	0.1721	0.6731	0.0642	**0.1793**	**0.0834**
	Ratio	0.7630	0.7616	0.7627	0.6856	**8.6924**	**25.8504**
	Elasticities	-0.2370	-0.2384	-0.2373	-0.3144	**7.6924**	**24.8504**

Table 23 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in nested logit two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	currently ZERO for all observations	0.6545	0.2272	0.8817	0.0941	0.0210	**0.0032**
	currently set to ONE for all observations	0.6498	0.2256	0.8754	0.0948	0.0210	**0.0088**
	Ratio	0.9928	0.9931	0.9929	1.0076	1.0005	**2.7194**
	Elasticities	-0.0072	-0.0069	-0.0071	0.0076	0.0005	**1.7194**
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	0.6578	**0.2267**	**0.8845**	0.0917	0.0204	0.0034
	currently set to ONE for all observations	0.5707	**0.1959**	**0.7666**	0.1868	0.0406	0.0060
	Ratio	0.8676	**0.8640**	**0.8667**	2.0384	1.9873	1.7515
	Elasticities	-0.1324	**-0.1360**	**-0.1333**	1.0384	0.9873	0.7515
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	currently ZERO for all observations	0.6398	**0.2280**	**0.8678**	0.1047	0.0230	0.0046
	currently set to ONE for all observations	0.6911	**0.2467**	**0.9378**	0.0484	0.0111	0.0027
	Ratio	1.0800	**1.0822**	**1.0806**	0.4626	0.4851	0.5876
	Elasticities	0.0800	**0.0822**	**0.0806**	-0.5374	-0.5149	-0.4124

Table 24 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in nested logit two-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	currently ZERO for all observations	**0.6767**	0.2043	0.8811	0.0936	0.0214	0.0039
	currently set to ONE for all observations	**0.6160**	0.2575	0.8735	0.0995	0.0228	0.0042
	Ratio	**0.9102**	1.2602	0.9914	1.0627	1.0660	1.0775
	Elasticities	**-0.0898**	0.2602	-0.0086	0.0627	0.0660	0.0775
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	currently ZERO for all observations	**0.6771**	0.2046	0.8817	0.0930	0.0212	0.0041
	currently set to ONE for all observations	**0.6155**	0.2587	0.8742	0.0989	0.0226	0.0044
	Ratio	**0.9090**	1.2641	0.9914	1.0629	1.0658	1.0746
	Elasticities	**-0.0910**	0.2641	-0.0086	0.0629	0.0658	0.0746
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.4039**	**0.2435**	**0.6474**	0.2677	0.0683	0.0166
	currently set to ONE for all observations	**0.6453**	**0.2099**	**0.8551**	0.1059	0.0292	0.0098
	Ratio	**1.5974**	**0.8620**	**1.3209**	0.3955	0.4281	0.5884
	Elasticities	**0.5974**	**-0.1380**	**0.3209**	-0.6045	-0.5719	-0.4116
Driver contributing circumstances indicator (1 if the severity-considered vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6177**	0.2743	0.8919	0.0874	0.0176	0.0030
	currently set to ONE for all observations	**0.6871**	0.2074	0.8945	0.0848	0.0174	0.0032
	Ratio	**1.1125**	0.7561	1.0029	0.9707	0.9884	1.0616
	Elasticities	**0.1125**	-0.2439	0.0029	-0.0293	-0.0116	0.0616
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6176**	0.2743	0.8919	0.0877	0.0177	0.0027
	currently set to ONE for all observations	**0.6875**	0.2071	0.8946	0.0850	0.0175	0.0029
	Ratio	**1.1131**	0.7551	1.0030	0.9691	0.9891	1.0739
	Elasticities	**0.1131**	-0.2449	0.0030	-0.0309	-0.0109	0.0739
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	currently ZERO for all observations	**0.6365**	0.2726	0.9090	0.0774	0.0127	0.0009
	currently set to ONE for all observations	**0.6998**	0.2124	0.9122	0.0747	0.0122	0.0009
	Ratio	**1.0995**	0.7793	1.0035	0.9653	0.9665	0.9643
	Elasticities	**0.0995**	-0.2207	0.0035	-0.0347	-0.0335	-0.0357

Table 24 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in nested logit two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.5615	0.1742	0.7357	**0.1924**	**0.0552**	**0.0167**
	currently set to ONE for all observations	0.6434	0.2029	0.8463	**0.1155**	**0.0300**	**0.0082**
	Ratio	1.1459	1.1646	1.1503	**0.6004**	**0.5432**	**0.4899**
	Elasticities	0.1459	0.1646	0.1503	**-0.3996**	**-0.4568**	**-0.5101**
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	currently ZERO for all observations	0.5720	0.1817	0.7536	**0.1636**	**0.0588**	**0.0240**
	currently set to ONE for all observations	0.6112	0.1958	0.8070	**0.1541**	**0.0356**	**0.0033**
	Ratio	1.0687	1.0777	1.0708	**0.9423**	**0.6057**	**0.1354**
	Elasticities	0.0687	0.0777	0.0708	**-0.0577**	**-0.3943**	**-0.8646**
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	currently ZERO for all observations	0.6571	**0.2486**	**0.9057**	**0.0807**	0.0127	0.0009
	currently set to ONE for all observations	0.5905	**0.2222**	**0.8127**	**0.1503**	0.0346	0.0025
	Ratio	0.8986	**0.8938**	**0.8973**	**1.8617**	2.7204	2.7306
	Elasticities	-0.1014	**-0.1062**	**-0.1027**	**0.8617**	1.7204	1.7306
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.5985	0.1959	0.7944	**0.1482**	**0.0406**	**0.0168**
	currently set to ONE for all observations	0.6488	0.2147	0.8635	**0.1043**	**0.0262**	**0.0061**
	Ratio	1.0841	1.0960	1.0870	**0.7034**	**0.6445**	**0.3618**
	Elasticities	0.0841	0.0960	0.0870	**-0.2966**	**-0.3555**	**-0.6382**
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	currently ZERO for all observations	0.6589	0.2204	0.8793	**0.0980**	**0.0209**	**0.0018**
	currently set to ONE for all observations	0.6140	0.2046	0.8185	**0.1346**	**0.0367**	**0.0102**
	Ratio	0.9319	0.9281	0.9309	**1.3743**	**1.7530**	**5.5223**
	Elasticities	-0.0681	-0.0719	-0.0691	**0.3743**	**0.7530**	**4.5223**
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.2598	0.0900	0.3498	0.0812	**0.2849**	**0.2841**
	currently set to ONE for all observations	0.4956	0.1845	0.6801	0.2229	**0.0675**	**0.0295**
	Ratio	1.9081	2.0492	1.9444	2.7459	**0.2368**	**0.1038**
	Elasticities	0.9081	1.0492	0.9444	1.7459	**-0.7632**	**-0.8962**

Table 24 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in nested logit two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	currently ZERO for all observations	0.6844	0.1999	0.8844	0.0833	0.0206	**0.0117**
	currently set to ONE for all observations	0.6861	0.2015	0.8876	0.0854	0.0218	**0.0052**
	Ratio	1.0024	1.0079	1.0036	1.0263	1.0574	**0.4402**
	Elasticities	0.0024	0.0079	0.0036	0.0263	0.0574	**-0.5598**
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	0.5403	**0.1692**	**0.7095**	0.2156	0.0585	0.0164
	currently set to ONE for all observations	0.6402	**0.2030**	**0.8432**	0.1148	0.0321	0.0100
	Ratio	1.1849	**1.1996**	**1.1884**	0.5324	0.5488	0.6072
	Elasticities	0.1849	**0.1996**	**0.1884**	-0.4676	-0.4512	-0.3928
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	currently ZERO for all observations	0.6905	**0.2212**	**0.9117**	0.0698	0.0168	0.0017
	currently set to ONE for all observations	0.6109	**0.1953**	**0.8063**	0.1538	0.0365	0.0034
	Ratio	0.8848	**0.8828**	**0.8843**	2.2041	2.1741	2.0328
	Elasticities	-0.1152	**-0.1172**	**-0.1157**	1.2041	1.1741	1.0328

Table 25 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in covariance heterogeneity two-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	currently ZERO for all observations	**0.6534**	0.2256	0.8789	0.0976	0.0165	0.0070
	currently set to ONE for all observations	**0.7207**	0.1732	0.8939	0.0854	0.0146	0.0061
	Ratio	**1.1030**	0.7678	1.0170	0.8753	0.8822	0.8793
	Elasticities	**0.1030**	-0.2322	0.0170	-0.1247	-0.1178	-0.1207
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	currently ZERO for all observations	**0.6529**	0.2253	0.8782	0.0982	0.0166	0.0070
	currently set to ONE for all observations	**0.7209**	0.1724	0.8933	0.0859	0.0147	0.0062
	Ratio	**1.1041**	0.7653	1.0172	0.8749	0.8821	0.8790
	Elasticities	**0.1041**	-0.2347	0.0172	-0.1251	-0.1179	-0.1210
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.7072**	**0.1863**	**0.8935**	0.0858	0.0143	0.0063
	currently set to ONE for all observations	**0.4533**	**0.2969**	**0.7502**	0.2019	0.0327	0.0152
	Ratio	**0.6410**	**1.5935**	**0.8396**	2.3518	2.2836	2.4054
	Elasticities	**-0.3590**	**0.5935**	**-0.1604**	1.3518	1.2836	1.4054
Driver contributing circumstances indicator (1 if the severity-considered vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6972**	0.1848	0.8821	0.0949	0.0163	0.0067
	currently set to ONE for all observations	**0.6237**	0.2404	0.8641	0.1095	0.0187	0.0078
	Ratio	**0.8945**	1.3006	0.9796	1.1536	1.1442	1.1609
	Elasticities	**-0.1055**	0.3006	-0.0204	0.1536	0.1442	0.1609
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6973**	0.1848	0.8821	0.0949	0.0163	0.0067
	currently set to ONE for all observations	**0.6233**	0.2407	0.8640	0.1096	0.0187	0.0078
	Ratio	**0.8939**	1.3023	0.9795	1.1545	1.1450	1.1618
	Elasticities	**-0.1061**	0.3023	-0.0205	0.1545	0.1450	0.1618
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	currently ZERO for all observations	**0.6942**	0.1856	0.8797	0.0965	0.0168	0.0070
	currently set to ONE for all observations	**0.6346**	0.2302	0.8648	0.1085	0.0188	0.0079
	Ratio	**0.9142**	1.2405	0.9830	1.1248	1.1167	1.1326
	Elasticities	**-0.0858**	0.2405	-0.0170	0.1248	0.1167	0.1326

Table 25 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in covariance heterogeneity two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.6993	0.1927	0.8920	**0.0861**	**0.0150**	**0.0068**
	currently set to ONE for all observations	0.6234	0.1708	0.7941	**0.1793**	**0.0213**	**0.0054**
	Ratio	0.8914	0.8859	0.8902	**2.0809**	**1.4154**	**0.7865**
	Elasticities	-0.1086	-0.1141	-0.1098	**1.0809**	**0.4154**	**-0.2135**
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	currently ZERO for all observations	0.7043	0.1945	0.8988	**0.0831**	**0.0119**	**0.0062**
	currently set to ONE for all observations	0.6824	0.1884	0.8708	**0.1023**	**0.0207**	**0.0061**
	Ratio	0.9689	0.9686	0.9689	**1.2312**	**1.7462**	**0.9869**
	Elasticities	-0.0311	-0.0314	-0.0311	**0.2312**	**0.7462**	**-0.0131**
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	currently ZERO for all observations	0.6884	**0.1765**	**0.8649**	**0.1048**	0.0221	0.0082
	currently set to ONE for all observations	0.7433	**0.1936**	**0.9369**	**0.0550**	0.0059	0.0022
	Ratio	1.0798	**1.0970**	**1.0833**	**0.5251**	0.2672	0.2632
	Elasticities	0.0798	**0.0970**	**0.0833**	**-0.4749**	-0.7328	-0.7368
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.6960	0.1912	0.8872	**0.0910**	**0.0152**	**0.0066**
	currently set to ONE for all observations	0.6848	0.1883	0.8731	**0.1043**	**0.0164**	**0.0062**
	Ratio	0.9839	0.9850	0.9841	**1.1464**	**1.0766**	**0.9411**
	Elasticities	-0.0161	-0.0150	-0.0159	**0.1464**	**0.0766**	**-0.0589**
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	currently ZERO for all observations	0.6951	0.1934	0.8886	**0.0903**	**0.0123**	**0.0089**
	currently set to ONE for all observations	0.7256	0.2031	0.9288	**0.0592**	**0.0101**	**0.0019**
	Ratio	1.0439	1.0502	1.0453	**0.6557**	**0.8248**	**0.2133**
	Elasticities	0.0439	0.0502	0.0453	**-0.3443**	**-0.1752**	**-0.7867**
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.6932	0.1902	0.8834	0.0941	**0.0158**	**0.0068**
	currently set to ONE for all observations	0.6906	0.1899	0.8806	0.0945	**0.0174**	**0.0076**
	Ratio	0.9963	0.9987	0.9968	1.0044	**1.1042**	**1.1147**
	Elasticities	-0.0037	-0.0013	-0.0032	0.0044	**0.1042**	**0.1147**

Table 25 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in covariance heterogeneity two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	currently ZERO for all observations	0.6908	0.1913	0.8821	0.0951	0.0159	**0.0068**
	currently set to ONE for all observations	0.6899	0.1916	0.8815	0.0961	0.0161	**0.0063**
	Ratio	0.9987	1.0016	0.9993	1.0104	1.0091	**0.9202**
	Elasticities	-0.0013	0.0016	-0.0007	0.0104	0.0091	**-0.0798**
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	0.6943	**0.1907**	**0.8850**	0.0927	0.0156	0.0067
	currently set to ONE for all observations	0.6485	**0.1777**	**0.8262**	0.1403	0.0233	0.0103
	Ratio	0.9340	**0.9316**	**0.9335**	1.5129	1.4955	1.5328
	Elasticities	-0.0660	**-0.0684**	**-0.0665**	0.5129	0.4955	0.5328
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	currently ZERO for all observations	0.6738	**0.1912**	**0.8650**	0.1101	0.0184	0.0065
	currently set to ONE for all observations	0.7394	**0.2119**	**0.9513**	0.0396	0.0067	0.0023
	Ratio	1.0974	**1.1078**	**1.0997**	0.3599	0.3668	0.3599
	Elasticities	0.0974	**0.1078**	**0.0997**	-0.6401	-0.6332	-0.6401

Table 26 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in covariance heterogeneity two-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	currently ZERO for all observations	**0.7165**	0.1690	0.8856	0.0923	0.0154	0.0067
	currently set to ONE for all observations	**0.6467**	0.2215	0.8682	0.1064	0.0176	0.0078
	Ratio	**0.9026**	1.3105	0.9804	1.1525	1.1424	1.1580
	Elasticities	**-0.0974**	0.3105	-0.0196	0.1525	0.1424	0.1580
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	currently ZERO for all observations	**0.7168**	0.1692	0.8860	0.0920	0.0153	0.0067
	currently set to ONE for all observations	**0.6461**	0.2224	0.8686	0.1062	0.0175	0.0077
	Ratio	**0.9014**	1.3144	0.9803	1.1541	1.1437	1.1594
	Elasticities	**-0.0986**	0.3144	-0.0197	0.1541	0.1437	0.1594
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.4136**	**0.2649**	**0.6785**	0.2603	0.0448	0.0164
	currently set to ONE for all observations	**0.6780**	**0.1730**	**0.8511**	0.1205	0.0210	0.0075
	Ratio	**1.6394**	**0.6532**	**1.2544**	0.4630	0.4676	0.4559
	Elasticities	**0.6394**	**-0.3468**	**0.2544**	-0.5370	-0.5324	-0.5441
Driver contributing circumstances indicator (1 if the severity-considered vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6598**	0.2310	0.8908	0.0895	0.0120	0.0076
	currently set to ONE for all observations	**0.7291**	0.1762	0.9053	0.0775	0.0106	0.0067
	Ratio	**1.1050**	0.7628	1.0162	0.8654	0.8807	0.8732
	Elasticities	**0.1050**	-0.2372	0.0162	-0.1346	-0.1193	-0.1268
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6597**	0.2310	0.8907	0.0896	0.0120	0.0076
	currently set to ONE for all observations	**0.7293**	0.1760	0.9053	0.0775	0.0106	0.0067
	Ratio	**1.1056**	0.7617	1.0164	0.8640	0.8799	0.8716
	Elasticities	**0.1056**	-0.2383	0.0164	-0.1360	-0.1201	-0.1284
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	currently ZERO for all observations	**0.6836**	0.2259	0.9095	0.0774	0.0079	0.0053
	currently set to ONE for all observations	**0.7399**	0.1803	0.9202	0.0682	0.0069	0.0047
	Ratio	**1.0824**	0.7980	1.0118	0.8818	0.8791	0.8813
	Elasticities	**0.0824**	-0.2020	0.0118	-0.1182	-0.1209	-0.1187

Table 26 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in covariance heterogeneity two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.6053	0.1541	0.7593	**0.2072**	**0.0269**	**0.0066**
	currently set to ONE for all observations	0.6848	0.1794	0.8642	**0.1064**	**0.0202**	**0.0092**
	Ratio	1.1314	1.1644	1.1381	**0.5133**	**0.7527**	**1.4067**
	Elasticities	0.1314	0.1644	0.1381	**-0.4867**	**-0.2473**	**0.4067**
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	currently ZERO for all observations	0.5967	0.1533	0.7500	**0.1891**	**0.0492**	**0.0117**
	currently set to ONE for all observations	0.6299	0.1640	0.7940	**0.1636**	**0.0296**	**0.0128**
	Ratio	1.0557	1.0699	1.0586	**0.8653**	**0.6017**	**1.0959**
	Elasticities	0.0557	0.0699	0.0586	**-0.1347**	**-0.3983**	**0.0959**
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	currently ZERO for all observations	0.6992	**0.2090**	**0.9083**	**0.0798**	0.0072	0.0048
	currently set to ONE for all observations	0.6193	**0.1834**	**0.8027**	**0.1525**	0.0269	0.0179
	Ratio	0.8856	**0.8775**	**0.8838**	**1.9116**	3.7558	3.7405
	Elasticities	-0.1144	**-0.1225**	**-0.1162**	**0.9116**	2.7558	2.7405
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.6020	0.1578	0.7598	**0.1931**	**0.0346**	**0.0125**
	currently set to ONE for all observations	0.6162	0.1635	0.7797	**0.1737**	**0.0329**	**0.0137**
	Ratio	1.0235	1.0359	1.0261	**0.8998**	**0.9510**	**1.0958**
	Elasticities	0.0235	0.0359	0.0261	**-0.1002**	**-0.0490**	**0.0958**
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	currently ZERO for all observations	0.6899	0.1854	0.8753	**0.1000**	**0.0209**	**0.0038**
	currently set to ONE for all observations	0.6383	0.1714	0.8097	**0.1482**	**0.0248**	**0.0173**
	Ratio	0.9253	0.9243	0.9251	**1.4820**	**1.1860**	**4.5159**
	Elasticities	-0.0747	-0.0757	-0.0749	**0.4820**	**0.1860**	**3.5159**
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.5128	0.1587	0.6715	0.2604	**0.0508**	**0.0172**
	currently set to ONE for all observations	0.5191	0.1711	0.6902	0.2494	**0.0445**	**0.0159**
	Ratio	1.0122	1.0783	1.0278	0.9574	**0.8770**	**0.9233**
	Elasticities	0.0122	0.0783	0.0278	-0.0426	**-0.1230**	**-0.0767**

Table 26 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in covariance heterogeneity two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NOINJ)	P(NODIS)	P(DIS)	P(FATAL)
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	currently ZERO for all observations	0.7342	0.1673	0.9015	0.0784	0.0135	**0.0067**
	currently set to ONE for all observations	0.7328	0.1684	0.9012	0.0781	0.0133	**0.0074**
	Ratio	0.9982	1.0063	0.9997	0.9964	0.9883	**1.1071**
	Elasticities	-0.0018	0.0063	-0.0003	-0.0036	-0.0117	**0.1071**
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	0.6086	**0.1527**	**0.7612**	0.1941	0.0324	0.0124
	currently set to ONE for all observations	0.6680	**0.1703**	**0.8384**	0.1314	0.0219	0.0084
	Ratio	1.0977	**1.1158**	**1.1013**	0.6769	0.6755	0.6820
	Elasticities	0.0977	**0.1158**	**0.1013**	-0.3231	-0.3245	-0.3180
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	currently ZERO for all observations	0.7340	**0.1878**	**0.9218**	0.0604	0.0103	0.0075
	currently set to ONE for all observations	0.6292	**0.1597**	**0.7889**	0.1628	0.0281	0.0202
	Ratio	0.8572	**0.8506**	**0.8558**	2.6953	2.7162	2.7061
	Elasticities	-0.1428	**-0.1494**	**-0.1442**	1.6953	1.7162	1.7061

Table 27 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in heteroskedastic extreme-value two-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	currently ZERO for all observations	**0.6191**	0.2870	0.0785	0.0376	0.0129
	currently set to ONE for all observations	**0.6280**	0.2807	0.0772	0.0369	0.0122
	Ratio	**1.0143**	0.9779	0.9837	0.9815	0.9445
	Elasticities	**0.0143**	-0.0221	-0.0163	-0.0185	-0.0555
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	currently ZERO for all observations	**0.6171**	0.2884	0.0791	0.0379	0.0127
	currently set to ONE for all observations	**0.6294**	0.2800	0.0772	0.0368	0.0116
	Ratio	**1.0199**	0.9707	0.9748	0.9715	0.9130
	Elasticities	**0.0199**	-0.0293	-0.0252	-0.0285	-0.0870
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	currently ZERO for all observations	**0.6273**	**0.2819**	0.0775	0.0365	0.0115
	currently set to ONE for all observations	**0.5854**	**0.2853**	0.0972	0.0484	0.0250
	Ratio	**0.9332**	**1.0122**	1.2540	1.3248	2.1683
	Elasticities	**-0.0668**	**0.0122**	0.2540	0.3248	1.1683
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ZERO for all observations	**0.6269**	0.2754	0.0829	0.0375	0.0130
	currently set to ONE for all observations	**0.6261**	0.2750	0.0838	0.0378	0.0133
	Ratio	**0.9987**	0.9984	1.0107	1.0069	1.0219
	Elasticities	**-0.0013**	-0.0016	0.0107	0.0069	0.0219
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	currently ZERO for all observations	**0.6295**	0.2713	0.0842	0.0378	0.0133
	currently set to ONE for all observations	**0.6389**	0.2647	0.0828	0.0370	0.0123
	Ratio	**1.0149**	0.9758	0.9831	0.9764	0.9298
	Elasticities	**0.0149**	-0.0242	-0.0169	-0.0236	-0.0702
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	currently ZERO for all observations	0.6335	0.2832	**0.0694**	**0.0368**	**0.0116**
	currently set to ONE for all observations	0.5125	0.2587	**0.2119**	**0.0413**	**0.0203**
	Ratio	0.8090	0.9134	**3.0522**	**1.1236**	**1.7443**
	Elasticities	-0.1910	-0.0866	**2.0522**	**0.1236**	**0.7443**

Table 27Average probabilities when sub-sampled observed indicator is 0 and elasticity results in heteroskedastic extreme-value two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	currently ZERO for all observations	0.6333	0.2905	**0.0632**	**0.0362**	**0.0101**
	currently set to ONE for all observations	0.5113	0.2650	**0.2008**	**0.0427**	**0.0271**
	Ratio	0.8074	0.9122	**3.1758**	**1.1774**	**2.6917**
	Elasticities	-0.1926	-0.0878	**2.1758**	**0.1774**	**1.6917**
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	currently ZERO for all observations	0.6789	**0.2087**	**0.0970**	0.0403	0.0159
	currently set to ONE for all observations	0.5312	**0.3621**	**0.0906**	0.0353	0.0130
	Ratio	0.7825	**1.7354**	**0.9346**	0.8767	0.8186
	Elasticities	-0.2175	**0.7354**	**-0.0654**	-0.1233	-0.1814
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ZERO for all observations	0.6271	0.2826	**0.0758**	**0.0372**	**0.0122**
	currently set to ONE for all observations	0.5089	0.2581	**0.2164**	**0.0388**	**0.0209**
	Ratio	0.8114	0.9132	**2.8558**	**1.0441**	**1.7114**
	Elasticities	-0.1886	-0.0868	**1.8558**	**0.0441**	**0.7114**
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	currently ZERO for all observations	0.6213	0.2915	**0.0736**	**0.0366**	**0.0104**
	currently set to ONE for all observations	0.6192	0.2897	**0.0749**	**0.0366**	**0.0134**
	Ratio	0.9966	0.9940	**1.0174**	**0.9978**	**1.2919**
	Elasticities	-0.0034	-0.0060	**0.0174**	**-0.0022**	**0.2919**
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	currently ZERO for all observations	0.6243	0.2810	0.0807	**0.0370**	**0.0122**
	currently set to ONE for all observations	0.3140	0.2308	0.0621	**0.2480**	**0.2055**
	Ratio	0.5030	0.8215	0.7696	**6.7095**	**16.8585**
	Elasticities	-0.4970	-0.1785	-0.2304	**5.7095**	**15.8585**
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	currently ZERO for all observations	0.6218	0.2831	0.0810	0.0372	**0.0121**
	currently set to ONE for all observations	0.6130	0.2810	0.0813	0.0372	**0.0242**
	Ratio	0.9858	0.9929	1.0037	0.9989	**2.0087**
	Elasticities	-0.0142	-0.0071	0.0037	-0.0011	**1.0087**

Table 27 Average probabilities when sub-sampled observed indicator is 0 and elasticity results in heteroskedastic extreme-value two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	currently ZERO for all observations	0.6242	**0.2811**	0.0802	0.0372	0.0125
	currently set to ONE for all observations	0.6212	**0.2835**	0.0806	0.0372	0.0126
	Ratio	0.9952	**1.0084**	1.0054	1.0015	1.0106
	Elasticities	-0.0048	**0.0084**	0.0054	0.0015	0.0106
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	currently ZERO for all observations	0.5806	**0.3159**	0.0876	0.0365	0.0133
	currently set to ONE for all observations	0.5988	**0.2960**	0.0899	0.0373	0.0138
	Ratio	1.0313	**0.9368**	1.0257	1.0216	1.0399
	Elasticities	0.0313	**-0.0632**	0.0257	0.0216	0.0399

Table 28 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in heteroskedastic extreme-value two-vehicle driver only occupant severity model

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	currently ONE for all observations	**0.6264**	0.2772	0.0822	0.0371	0.0124
	currently set to ZERO for all observations	**0.6184**	0.2810	0.0848	0.0381	0.0135
	Ratio	**0.9872**	1.0138	1.0316	1.0277	1.0885
	Elasticities	**-0.0128**	0.0138	0.0316	0.0277	0.0885
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	currently ONE for all observations	**0.6276**	0.2763	0.0818	0.0369	0.0125
	currently set to ZERO for all observations	**0.6161**	0.2823	0.0852	0.0383	0.0141
	Ratio	**0.9816**	1.0214	1.0410	1.0383	1.1250
	Elasticities	**-0.0184**	0.0214	0.0410	0.0383	0.1250
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	currently ONE for all observations	**0.5524**	**0.2608**	0.1455	0.0519	0.0339
	currently set to ZERO for all observations	**0.6037**	**0.2591**	0.1179	0.0402	0.0172
	Ratio	**1.0928**	**0.9936**	0.8104	0.7738	0.5077
	Elasticities	**0.0928**	**-0.0064**	-0.1896	-0.2262	-0.4923
Driver contributing circumstances indicator (1 if the other vehicle had exceeded reasonably safe speed, 0 otherwise)	currently ONE for all observations	**0.5988**	0.3229	0.0647	0.0355	0.0096
	currently set to ZERO for all observations	**0.6013**	0.3191	0.0658	0.0356	0.0098
	Ratio	**1.0042**	0.9885	1.0167	1.0051	1.0240
	Elasticities	**0.0042**	-0.0115	0.0167	0.0051	0.0240
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	currently ONE for all observations	**0.5783**	0.3559	0.0540	0.0328	0.0075
	currently set to ZERO for all observations	**0.5683**	0.3624	0.0555	0.0338	0.0082
	Ratio	**0.9828**	1.0183	1.0291	1.0286	1.0997
	Elasticities	**-0.0172**	0.0183	0.0291	0.0286	0.0997
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	currently ONE for all observations	0.4878	0.2482	**0.2383**	**0.0442**	**0.0261**
	currently set to ZERO for all observations	0.6235	0.2737	**0.0823**	**0.0407**	**0.0169**
	Ratio	1.2783	1.1030	**0.3456**	**0.9217**	**0.6452**
	Elasticities	0.2783	0.1030	**-0.6544**	**-0.0783**	**-0.3548**

Table 28 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in heteroskedastic extreme-value two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	currently ONE for all observations	0.5423	0.1988	**0.2298**	**0.0460**	**0.0340**
	currently set to ZERO for all observations	0.6877	0.2204	**0.0775**	**0.0404**	**0.0142**
	Ratio	1.2681	1.1088	**0.3372**	**0.8784**	**0.4162**
	Elasticities	0.2681	0.1088	**-0.6628**	**-0.1216**	**-0.5838**
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	currently ONE for all observations	0.5475	**0.3805**	**0.0585**	0.0331	0.0081
	currently set to ZERO for all observations	0.7051	**0.2211**	**0.0639**	0.0382	0.0102
	Ratio	1.2879	**0.5812**	**1.0915**	1.1546	1.2610
	Elasticities	0.2879	**-0.4188**	**0.0915**	0.1546	0.2610
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	currently ONE for all observations	0.5208	0.2275	**0.2319**	**0.0401**	**0.0242**
	currently set to ZERO for all observations	0.6491	0.2503	**0.0846**	**0.0391**	**0.0147**
	Ratio	1.2463	1.1002	**0.3651**	**0.9754**	**0.6097**
	Elasticities	0.2463	0.1002	**-0.6349**	**-0.0246**	**-0.3903**
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	currently ONE for all observations	0.6271	0.2657	**0.0911**	**0.0382**	**0.0157**
	currently set to ZERO for all observations	0.6305	0.2648	**0.0912**	**0.0386**	**0.0125**
	Ratio	1.0053	0.9967	**1.0010**	**1.0109**	**0.7950**
	Elasticities	0.0053	-0.0033	**0.0010**	**0.0109**	**-0.2050**
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	currently ONE for all observations	0.2043	0.1656	0.1383	**0.2557**	**0.2944**
	currently set to ZERO for all observations	0.5530	0.2279	0.1870	**0.0455**	**0.0306**
	Ratio	2.7067	1.3762	1.3520	**0.1781**	**0.1040**
	Elasticities	1.7067	0.3762	0.3520	**-0.8219**	**-0.8960**
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	currently ONE for all observations	0.6617	0.2377	0.0773	0.0382	**0.0229**
	currently set to ZERO for all observations	0.6701	0.2387	0.0773	0.0386	**0.0120**
	Ratio	1.0126	1.0041	1.0008	1.0101	**0.5232**
	Elasticities	0.0126	0.0041	0.0008	0.0101	**-0.4768**

Table 28 Average probabilities when sub-sampled observed indicator is 1 and elasticity results in heteroskedastic extreme-value two-vehicle driver only occupant severity model (Continued)

Variable		P(PDO)	P(PINJ)	P(NODIS)	P(DIS)	P(FATAL)
Interaction variable between driver restraint system usage and vehicle type (1 if the severity-considered driver did not use any restraints and his/her vehicle type is pick-up, 0 otherwise)	currently ONE for all observations	0.5905	**0.2645**	0.1194	0.0429	0.0211
	currently set to ZERO for all observations	0.5977	**0.2609**	0.1182	0.0419	0.0196
	Ratio	1.0121	**0.9867**	0.9895	0.9752	0.9292
	Elasticities	0.0121	**-0.0133**	-0.0105	-0.0248	-0.0708
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	currently ONE for all observations	0.7161	**0.2056**	0.0662	0.0390	0.0112
	currently set to ZERO for all observations	0.7018	**0.2214**	0.0659	0.0387	0.0111
	Ratio	0.9800	**1.0769**	0.9967	0.9915	0.9937
	Elasticities	-0.0200	**0.0769**	-0.0033	-0.0085	-0.0063

5.4 Structural Change / Model Transferability Test

In this section, tests of structural change / model transferability within the samples for single- and two vehicle models are presented. Please note that the original single- and two-vehicle models were estimated using six and a half-year of data. The test of structural change / transferability within samples will not only give an insight on the stability of parameters but also help find out the proper time length of data in order to have more stable structures.

A log-likelihood ratio test is conducted to test whether or not their estimated coefficients are transferable temporally. Overall data are sub-sampled into two samples by two time periods and then the log-likelihoods of two sub-samples are computed to compare with the log-likelihood of the overall sample. In this test, the same set of specifications is used to calculate log-likelihoods. A log-likelihood ratio, LL, is χ^2 distributed with the degrees of freedom equal the number of estimated parameters in the model. The log-likelihood ratio is shown below.

$$\text{LL ratio} = -2(\text{LL(All)} - \text{LL(SubsampleA)} - \text{LL(SubsampleB)}) \qquad (5.4.1)$$

where LL(All) is the log-likelihood at convergence of the model estimated using entire dataset, LL(SubsampleA) and LL(SubsampleB)) are the log-likelihoods at convergence of the sub models estimated using sub-sample A and sub-sample B. This log-likelihood ratio is tested against the null hypothesis that all estimated parameters are transferable. In this research, in order to find out the proper time length of data, two tests are conducted. One test is the six-year sub-sample (1990-1995) against a half-year sub-sample for 1996, and the other is a three-year sub-sample (1990-1992) against three and a-half-year sub-sample (1993-1996). Table 29 to 32 show the log-likelihood ratio test results for both single- and two-vehicle driver only occupant severity nested logit models. The degrees of freedom for single- and two-vehicle NL models are 23 and 31 respectively.

Table 29 shows that the parameters in single-vehicle NL model are transferable between year 1990-1995 and 1996 at a 95% confidence interval with 23 degree of freedom. But the parameters are not transferable between the periods 1990-1992 and 1993-1996 shown in Table 30. Furthermore, as can be seen in Table 31 and 32, parameters in two-vehicle NL model are not transferable between the periods 1990-1995 and 1996 as well as between the periods 1990-1992 and 1993-1996 at 95% confidence interval with 31 degree of freedom by comparing the calculated chi-square value with the critical value. From the trends it appears longer time period of data would be necessary for more stable structures.

Table 29 Temporal transferability test for single-vehicle driver only occupant severity nested logit model (test for year 1990-1995 and 1996)

	All	1990-1995	1996	Chi-Square	Critical Chi-square value at 95% confidence interval
No of Obs.	31360	28318	3042		
LL	-32814.14	-29741.12	-3056.83	32.386	35.17

Table 30 Temporal transferability test for single-vehicle driver only occupant severity nested logit model (test for year 1990-1992 and 1993-1996)

	All	1990-1992	1993-1996	Chi-Square	Critical Chi-square value at 95% confidence interval
No of Obs.	31360	14040	17320		
LL	-32814.14	-14960.53	-17817.81	71.600	35.17

Table 31 Temporal transferability test for two-vehicle driver only occupant severity nested logit model (test for year 1990-1995 and 1996)

	All	1990-1995	1996	Chi-Square	Critical Chi-square value at 95% confidence interval
No of Obs.	96600	87042	9558		
LL	-86902.26	-78171.78	-8697.49	65.98	44.9

Table 32 Temporal transferability test for two-vehicle driver only occupant severity nested logit model (test for year 1990-1992 and 1993-1996)

	All	1990-92	1993-96	Chi-Square	Critical Chi-square value at 95% confidence interval
No of Obs.	96600	40792	55808		
LL	-86902.26	-36466.18	-50307.33	257.50	44.9

5.5 Summary

After developing three models, the NL model, the CHM and the HEV model, for both single-and two-vehicle driver only occupant severity, the commonly significant factors were identified. In the single-vehicle driver only occupant severity models, driver's gender, driver sobriety, driver seat belt usage, driver ejection and over turn accident type strongly associate with severities. Furthermore, fatality would be the most critical severity type for the consideration of reduction in severity in order to have safer roadway systems. Table 33 shows the variables in the functions of fatal outcomes in all three single-vehicle driver only occupant severity models. Comparing to three models, it can be seen that the variables in the CHM become statistically insignificant. Some variables in the CHM have inconsistent signs with the NL model and HEV model. Poor parameter behavior and the results of model instability from the algorithm involved in optimization might be suspected in contributing to this inconsistency. By looking at the variable coefficients in NL model, driver had been drinking, driver had been totally ejected, driver struck trees or stumps, light poles, utility poles and so on, driver truck guardrail or bridge rail leading end and if driver's age is greater than 55 and the accident occurred in rural area would increase the probability of fatality significantly.

Table 33 Variables in the functions of fatal outcomes in all three single-vehicle driver only occupant severity models

Variable	NL model		CHM		HEV model	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Driver characteristics						
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	**1.48644**	**11.550**	-0.22582	-1.866	**0.31912**	**5.157**
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	**4.06972**	**28.229**	0.19915	1.711	**3.29940**	**27.197**
Accident characteristics						
Object struck indicator (1 if driver struck Tree or Stump, Light Pole, Utility Pole, Railway Pole, Traffic Signal Pole, Overheard Sign Support Pole, Sign Box , Bridge Column or Pillar, 0 otherwise)	**0.50690**	**7.092**	-0.06892	-0.991	**0.15098**	**2.649**
Object struck indicator (1 if driver struck Guardrail or Bridge Rail Leading End, 0 otherwise)	**0.92933**	**2.818**	-0.01302	-0.045	0.06425	0.647

Table 33 Variables in the functions of fatal outcomes in all three single-vehicle driver only occupant severity models (Continued)

Variable	**NL model**		CHM		HEV model	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction between driver and location characteristics						
Interaction Variables between Driver's age and accident location (1 if driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	**1.44886**	**8.038**	-0.10504	-0.568	**0.26507**	**3.352**

Table 34 shows the corresponding coefficients and t-statistics of variables which are significant in all three models. As can be seen, a male driver strongly associates with PDO. Other variables all strongly increase the propensity towards high severities.

Table 34 Variables which are statistically significant in all three single-vehicle driver only occupant severity models

Variable	Severity	NL model		CHM		HEV model	
		Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Driver characteristics							
Driver's sex indicator (1 if driver is male, 0 otherwise)	PDO	0.75299	22.285	0.32101	13.187	0.09072	2.808
Driver sobriety indicator (1 if driver had been drinking, 0 otherwise)	NONDIS	0.59475	17.568	0.63841	12.607	1.80870	14.17
	DIS	0.91271	15.742	0.59265	8.354	0.72742	4.444
Driver ejection indicator (1 if driver had totally ejected, 0 otherwise)	DIS	2.58620	23.062	0.33984	3.869	4.01186	11.305
Accident characteristics							
Collision type indicator (1 if the collision type is over turn, 0 otherwise)	NONDIS	0.37454	11.059	0.43039	10.675	0.13113	2.118
Interaction between driver and vehicle characteristics							
Interaction variable between driver restraint system usage and vehicle type (1 if driver did not use any restraints and the vehicle type is passenger car, 0 otherwise)	PDO	-0.89470	-13.527	-0.93285	-14.446	-1.51862	-16.945
	NONINJ (PINJ in HEV model)	-0.95784	-15.698	-0.49916	-3.935	-1.26168	-8.233

In the two-vehicle driver only occupant severity models, driver's gender, driver sobriety, driver seat belt usage, driver ejection, driver's contributing action such as following too close, junction relationship, such as whether the accident happened at an intersection or related area, interaction of driver's age and accident location, such as if the driver was older than 55 years of age and accident was in a rural area, and same direction, rear end and opposite direction accident types strongly associate with high severities. Fatality drives the societal costs the most. One fatal accident would approximately cost 4,000,000 dollars. Table 35 shows the variables in the functions of fatal outcomes in all three single-vehicle driver only occupant severity models. Comparing to three models, Junction relationship indicator (if the accident was at intersection and related) is the commonly significant variable across all three models. In the NL model and CHM, the probability of driver fatality would be less if the accident happened at an intersection and related. But the coefficient of this variable shows a different effect in the HEV model. The other variables in the CHM become insignificantly associate with the fatality and some variables have inconsistent signs with the NL model and HEV model. Poor parameter behavior and the results of model instability from the algorithm involved in optimization might be suspected in contributing to this inconsistency. By looking at the variable coefficients in NL model, in addition to the junction characteristics, either driver had been drinking, either driver had been totally ejected, if the driver was hit by a truck, if the collision type was opposite direction and if the severity-considered driver's age is greater than 55 and the accident occurred in rural area would increase the probability of fatality significantly.

Table 35 Variables in the functions of fatal outcomes in all three two-vehicle driver only occupant severity models

Variable	NL model		CHM		HEV model	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Driver characteristics						
Driver ejection indicator (1 if either driver had totally ejected, 0 otherwise)	**4.20277**	**16.153**	0.10087	0.592	**3.36004**	**14.618**
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	**1.24652**	**9.938**	-0.06125	-0.528	**0.74038**	**9.805**
Vehicle characteristics						
Vehicle type indicator (1 if the other vehicle is a truck, 0 otherwise)	**1.06024**	**6.479**	-0.09673	-0.658	**0.66574**	**8.747**
Roadway characteristics						
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	**-1.64707**	**-12.054**	**-1.63997**	**-10.667**	**0.23147**	**9.315**
Accident characteristics						
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	**2.46106**	**19.771**	0.02471	0.185	**1.09572**	**10.948**
Interaction between driver and location characteristics						
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	**1.35117**	**8.389**	-0.04661	-0.299	**0.74238**	**7.788**

Table 36 shows the corresponding coefficients and t-statistics of variables which are significant in all three models. The variable, driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise), in the HEV model has a positive effect on PDO but it has a negative effect in both the NL model and CHM. Furthermore, the positive effect of the junction relationship indicator (1 if the accident was at intersection and related area, 0 otherwise) in the HEV model is not consistent with both the NL model and CHM.

Table 36 Variables which are statistically significant in all three two-vehicle driver only occupant severity models

Variable	Severity	NL model		CHM		HEV model	
		Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Driver characteristics							
Driver's sex indicator (1 if the severity-considered driver is male, 0 otherwise)	PDO	0.32834	20.402	0.37690	25.633	0.08089	5.643
Driver's sex indicator (1 if the other driver is male, 0 otherwise)	PDO	0.33258	20.648	0.38097	25.928	0.11600	7.550
Driver contributing circumstances indicator (1 if the other vehicle was too close, 0 otherwise)	PDO	-0.34722	-14.109	-0.31080	-13.577	0.09456	2.227
Driver sobriety indicator (1 if either driver had been drinking, 0 otherwise)	NONDIS	0.76302	21.644	0.92537	26.589	3.90799	5.711
	DIS	0.92556	15.065	0.55932	9.309	0.58501	2.914
Roadway characteristics							
Junction relationship indicator (1 if the accident was at intersection and related, 0 otherwise)	Fatality	-1.64707	-12.054	-1.63997	-10.667	0.23147	9.315
Accident characteristics							
Collision type indicator (1 if the collision type is same direction collision, 0 otherwise)	NONINJ (PINJ in HEV model)	0.92626	25.802	1.23331	34.834	-0.28103	-3.685
Collision type indicator (1 if the collision type is rear end collision, 0 otherwise)	NONINJ (PINJ in HEV model)	1.11302	18.487	1.49477	25.597	2.36014	34.620
Collision type indicator (1 if the collision type is opposite direction collision, 0 otherwise)	NONDIS	0.19673	5.298	0.25431	6.995	3.94042	5.801
	DIS	0.68965	11.922	0.60570	10.570	0.68606	3.613

Table 36 Variables which are statistically significant in all three two-vehicle driver only occupant severity models (Continued)

Variable	Severity	NL model		CHM		HEV model	
		Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Interaction between driver and vehicle characteristics							
Interaction variable between driver restraint system usage and vehicle type (1 if either driver did not use any restraints and either vehicle type is passenger car, 0 otherwise)	PDO	-0.62211	-17.285	-0.93692	-26.786	-0.79271	-10.197
	NONINJ (PINJ in HEV model)	-1.19215	-30.144	-0.69798	-18.947	-0.64084	-5.519
Interaction between driver and location characteristics							
Interaction Variables between Driver's age and accident location (1 if severity-considered driver's age is greater than 55 and the accident occurred in rural area, 0 otherwise)	NONDIS	0.50832	9.585	0.15803	2.876	3.75769	5.601

Factors relating to driver sobriety, seat belt use, human error in driving, vehicle type, type of collision and location of accident appeared to strongly associate with injury. The findings reinforce in a single multi-variate framework insights from case-controlled studies on seat belt use and driver sobriety as well as the speed reinforcement. Furthermore, accidents occurring in rural areas are associated with higher severities. Improving hospital networks would be a significant injury prevention benefit.

From the policy analyst standpoint, these variables, which commonly appeared to strongly associate with severities, could be considered as important factors. Driver sobriety and restraints usage could be strong policy variables. Therefore, accident reduction and safety improvement could be taken care of while these variables are analyzed and considered in safety projects. It also can be shown that the objective of this research is to develop a framework with commonly available data without placing undue demands on data collection. This research has shown that longer time periods of data with commonly available variables is a necessity. While this imposes a cost burden in terms of consistent maintenance of data over time, the cost constraints are significantly lower than compared to the requirements posed by diverse databases consisting of hundreds of accident specific variables.

In the analysis of elasticities, several observations can be made. The elastic variables corresponding to particular severities are summarized as follows.

- In single-vehicle driver only occupant severity models:

1. The cross-elasticity of interaction of “driver did not use any restraints and vehicle type is passenger car” appeared to strongly increase the probabilities of NONDIS (NL, CHM), DIS (CHM, HEV) and Fatality (CHM, HEV).
2. The cross-elasticity of interaction of “driver did not use any restraints and vehicle type is pick-up” appeared to strongly increase the probabilities of NONDIS and DIS in NL only.
3. The direct-elasticity of driver sobriety appeared to strongly increase the probabilities of fatality in NL only.
4. The direct-elasticity of object struck (guardrail or bridge rail leading end) appeared to strongly increase the probabilities of fatality in NL only.
5. The direct-elasticity of “driver had totally ejected” appeared to strongly increase the probabilities of DIS and Fatality in NL and HEV.

- In two-vehicle driver only occupant severity models:
    1. The cross-elasticity of interaction of “either driver did not use any restraints and either vehicle type is passenger car” commonly appeared to strongly increase the probability of Fatality and appeared to strongly increase the probabilities of NONDIS and DIS in NL and CHM.
    2. The direct-elasticity of driver sobriety indicator appeared to strongly increase the probabilities of DIS and Fatality in NL and NONDIS in CHM and HEV.

3. The direct-elasticity of opposite direction collision appeared to strongly increase the probability of Fatality in NL and HEV.
4. The direct-elasticity of “either driver had totally ejected” appeared to strongly increase the probabilities of DIS and Fatality in NL and HEV.
5. the direct-elasticity of “the other vehicle is truck” appeared to strongly increase the probability of Fatality in NL and HEV.

According to the structural change / transferability test using the log-likelihood ratio test, the results show that both the single- and two-vehicle model are not transferable temporally except the test for single-vehicle model between year 1990-1995 and 1996. They indicate that 6 and half years of data were not long enough and longer time periods of data (long panel) would make the models more stable.

Summarizing the models goodness of fit, Table 37 and 38 show the detailed log-likelihoods at convergence with coefficient vector β, at 0 and constant only as well as the adjusted ρ^2 for both LL(0) and LL(C) as bases for single- and two-vehicle models. From these two tables, the NL model has a better goodness fit than the other two models, the CHM and HEV model, using the adjusted ρ^2 with LL(0) as a base for both single- and two vehicle models. Using the adjusted ρ^2 with LL(C) as a base, the HEV model becomes a better model than the other two for both single- and two-vehicle models. It can be explained that the constants in the severity outcome functions in both single- and two-vehicle NL models have more significant explanation than the CHM and HEV model.

Table 37 Model goodness of fit for single-vehicle driver only occupant severity models

	NL model	CHM	HEV model
Number of observations	31360		
Log-likelihood at constant only	-35649.78		
Log-likelihood at zero	-59195.46	-59195.46	-50471.97
Log-likelihood at convergence	-32814.14	-34057.91	-32212.20
Adjusted $\rho^2 = 1 - \frac{LL(\beta) - k}{LL(C)}$	0.08	0.04	0.10
Adjusted $\rho^2 = 1 - \frac{LL(\beta) - k}{LL(0)}$	0.45	0.42	0.36

Table 38 Model goodness of fit for two-vehicle driver only occupant severity models

	NL model	CHM	HEV model
Number of observations	96600		
Log-likelihood at constant only	-90916.4		
Log-likelihood at zero	-192797.50	-192797.50	-155471.70
Log-likelihood at convergence	-86902.26	-89518.24	-85150.42
Adjusted $\rho^2 = 1 - \frac{LL(\beta) - k}{LL(C)}$	0.04	0.01	0.06
Adjusted $\rho^2 = 1 - \frac{LL(\beta) - k}{LL(0)}$	0.55	0.54	0.45

Chapter 6: Conclusions and Recommendations

This research involved the analysis of driver occupant only accidents using empirical data from the Washington State Patrol's accident database. Single- and two vehicle accidents were analyzed and accidents which involved more than two vehicles were not analyzed in this research due to data limitations. Over a 79-month period in Washington State from 1990 to 1996, data were compiled, resulting in detailed accident reports on over 127,000 cases.

The objective of this research is to develop a multi-variate analytical framework that is robust and helps identify the marginal impact of important policy variables related to seat belt use, drunk driving enforcement and driving age related issues. It also involved the development of a framework with commonly significant variables which strongly associate with driver injury severities. Therefore, commonly available data can be introduced in the implementation of such severity models without placing undue demands on data collection.

This chapter will present a summary of the critical modeling issues, the findings of this research and recommendations with respect to policy implications and future research.

6.1 Reviews of Critical Modeling Issues

Revisiting the methodological issues is a necessary part of the summary since it provides the beginning points and defines the paths or guidance to the end point. Furthermore, it would suggest whether the issues have been evaluated and attempted. In other words, it provides the questions to search for the answers related to the findings.

The purpose of the research is to shed some lights on methodological issues in accident injury contexts. The research has employed various types of modeling techniques in order to incorporate several modeling issues, such as correlation, heterogeneity and heteroskedastic errors, and to find robust variables that can be cast in a broader spectrum as variations of information may play a significant role. What is considered to be the greatest advantage of the findings from the research is the use of the basic element structure as an extension to a larger scale. The basic elements of the proposed structure are the common denominator factors across the tested models.

The main modeling issues faced in the accident severity context are as follows:

1. Shared unobserved effects among alternatives
   - Violation of independent and irrelevant alternatives (IIA)
   - Violation of independent and identical distribution (IID) of unobserved component
2. Heterogeneity and correlation
   - unmeasured effects

- un-identical and correlated random errors
- biased and inconsistent estimates of effects
- loss in statistical efficiency of parameters in the model

From the agency point of view, the primary issues observed in the Washington State highway system dataset are summarized below:

1. Impact of heterogeneity and correlation that exists in severity contexts has rarely been incorporated due to lack of techniques.
2. Most of the accident injury analysis techniques cause undue demand on data collection.
3. From a programming standpoint, lack of a multivariate analytical framework leads to inefficient safety programming and prioritization.
4. From a policy standpoint, lack of identification of marginal impact of important policy variables leads to insufficient policy direction.

In order to incorporate these issues, statistical methods relating to the analysis of ordinal and discrete outcomes were employed. The developed models also incorporated heterogeneity. Heterogeneity refers to effects that are not measured for various reasons. In our context, not measured implies not measurable, can be measured but not measured for economic reasons, as well as unknown and hence not measurable. The impact of heterogeneity and correlation that exists in severity contexts is at the very least, loss in statistical efficiency of parameters in the model. As a result, strong associations can be imprecisely identified. Using a variety of techniques within this broad category of analysis, common denominator variables that were found to be strongly associated with driver only occupant severities were identified.

The multinomial logit is the simplest and most popular form. However, its structure impedes incorporation of heterogeneity. By definition, the multinomial logit assumes all outcomes are identically and independently influenced by random effects that are unobserved. As alternatives, in order to address the heterogeneity problem, three model types known as extensions of the generalized extreme value model were examined: namely, the nested logit model, the covariance heterogeneity model and the heteroskedastic extreme-value model. These structures are uniquely flexible in accommodating heterogeneity. The idea behind examining these structures is the need for robustly identifying a set of strong associations in terms of infrastructure variables.

Several hundred model specifications were tested prior to the finalization of model structures. Due to the variety of structures that are possible within the nested logit class of models, the modeling requirement extended to over a thousand specifications in order to identify the preferred structure. Nlogit version 3.0 is the main econometric software employed in this research. The software is widely recognized and utilized by most econometricians. The main findings are described in the following section.

6.2 Findings

The first finding from this research is the technique of incorporation of heterogeneity and heteroskedasticity in the accident severity context. The nested logit model accommodates the violation of IID in the nest and IIA in the model. But it can not incorporate the heterogeneity issues. Furthermore, a restrictive constraint is the inclusive value ρ is to be equal across individuals in the NL model. However, the sensitivity between nested alternatives may be a function of relevant observed individual accident characteristics. The covariance heterogeneity model incorporated individual specific heterogeneity through the inclusive value parameters. To relax the IID assumption of the MNL, the heteroskedastic extreme-value model allowed variance of unobserved factors to differ over alternatives. The random component has an independent non-identical extreme value distribution.

The second finding relates to common variables across all estimated models. The common variables were the factors statistically significant in all models. These variables strongly associate with driver severity and are shown below.

For single-vehicle driver only occupant severity:

1. Driver characteristics
   - Driver's sex indicator
   - Driver sobriety indicator
   - Driver ejection indicator

2. Accident characteristics
    - Collision type indicator, over turn
3. Interaction between driver and vehicle characteristics
    - Interaction variable between driver restraint system usage and vehicle type, any restraints usage and the vehicle type is passenger car

For two-vehicle driver only occupant severity:

1. Driver characteristics
    - Driver's sex indicator
    - Driver sobriety indicator
    - Driver contributing circumstances, following too close
2. Roadway characteristics
    - Junction relationship indicator, at intersection and related
3. Accident characteristics
    - Collision type indicator, same direction, rear end or opposite direction
4. Interaction between driver and vehicle characteristics
    - Interaction variable between driver restraint system usage and vehicle type, any restraints usage and the vehicle type is a passenger car
5. Interaction between driver and location characteristics
    - Interaction variable between driver's age (older than 55) and the accident location being in a rural area

By identifying these common variables, the strategy is to identify and then monitor any related policy area in which these variables are influential. The next step is to combine findings from frequency models with these findings and set priorities for safety improvement.

The following table shows the corrected predicted probabilities from the three models for single- and two-vehicle accidents. The highest estimated probability was picked as a predicted outcome among five severities. The correctly predicted probabilities were computed by the number of matched cases divided by the total number of observations. As can be seen that the NL models has the highest correctly predicted probabilities for single- and two-vehicle models.

Table 39 Correctly predicted probabilities

Model type	Single-vehicle model	Two-vehicle model
NL	0.5943	0.6347
CHM	0.5844	0.6331
HEV	0.5844	0.6299

However, it would not be sufficient to choose a model if the predicted power of a model or the goodness of fit of a model were considered as the only criteria. From a modeling aspect, model convergence, ease of estimation and the plausibility of parameter effects are also important criteria for choosing a “better” model. A “better” model here means the model not only has better explanatory power but also is simpler in estimation and implementation and easier to interpret.

Table 40 shows the better model by different criteria. As can be seen the NL model is a better model than the CHM and HEV, except when the adjusted ρ2 with the LL(C) as a base is considered as a criterion. As known that NL is well developed and commonly used model in the generalized extreme value (GEV) model class which was proposed by McFadden in 1981. Many software and algorithms are available for NL models. Parameter estimations are more stable and plausible than other types of GEV models which can incorporate unobserved heterogeneity. Hence, based on this research, it can be said that the NL model is more plausible than the CHM and HEV model in accident severity contexts.

Table 40 Criteria for model choosing

Criterion	Better model
Adjusted $\rho^2 = 1 - \frac{LL(\beta) - k}{LL(C)}$	HEV
Adjusted $\rho^2 = 1 - \frac{LL(\beta) - k}{LL(0)}$	NL
Prediction	NL
Model Convergence	NL
Ease of Estimation	NL
Elasticities and Plausibility of Parameter Effects	NL

6.3 Recommendations

6.3.1 Policy Implications

Several major policy implications arise from this research. The first relates to the consideration of interactions in policy formulation. Conventional methods have relied heavily on the impact of main infrastructure effects in formulating policy on roadway design. It was derived mainly from frequency analysis. This research presents a multi-variate analytical framework that is robust by incorporating the heterogeneity issue in modeling and helps identify the marginal impact of important policy variables related to seat belt use, drunk driving enforcement and driving age related issues, while addressing critical infrastructure issues as well. For example, addressing the sensitivity of injury probabilities to the removal of fixed objects is a critical infrastructure issue. A decision maker can use the results of this model to estimate benefits in terms of societal cost reductions and compute the benefit/cost of fixed object removals or collision protection.

Reducing severities in addition to reducing the frequency of accidents would also reduce the social-economic costs significantly. From an infrastructure standpoint, fatalities contribute to significant increases in lifecycle costs including transportation, social and emergency infrastructure. Since a severity model is based on accidents which have already happened, it would mainly focus on the contribution of factors to severities. This research identifies several important interactions, including those related to driver, accident type, location and roadway effects. It provides wider insights including those on design infrastructure policy and on policy related to driver behavior.

The second policy implication relates to the implementation of models developed in this research for safety programming. These models were developed from a fairly comprehensive database including more than 127000 observations over 79 months. To be able to sustain this level of modeling with the amount of data required, programming policy needs to be formulated in a manner such that information from such sophisticated methods are used as supplementary design guidance as a start. At present, given the body of evidence in this research, even a parsimonious structure using the "common" variables will require a thorough examination of predictive capabilities. This research highlights the importance of data types that need to be collected for robust policy development on traffic accident injury prevention.

Finally, from the safety programming standpoint, the WSDOT recently began developing a safety evaluation program, which mainly focuses on accident reductions. Accident prevention is also a part of this program. Combining both frequency and detailed severity analysis would develop a comprehensive evaluation program. It could provide an integrated benefit cost analysis incorporating both frequency and severity insights and help optimize project life cycle costs. Such an approach has potential to greatly enhance the "safety conscious" dimension of large-scale transportation planning of highway networks.

6.3.2 Recommendations for Future Research

For model transferability, this research suggests that longer time periods of data (six years or more) would be necessary for temporally stable severity specifications. While at a minimum six years of data appears sufficient, decadal data could be recommended for the future research. Using commonly significant variables and increasing the time periods available for data collection would ensure the development of more stable and robust model. For spatial transferability, multi-state analysis of severity data would be required involving the set of common denominator variables found in this research. The model results show that accidents happening in rural areas have higher probability of fatality. Future research could be recommended to address the differences between the urban and rural areas and parse out the main impacts in the rural areas so that the information could be provided for balanced safety programming and prioritizations.

Three models were applied in this research to uniquely and partially relax the assumptions relating to the random component in the severity context. The mixed logit model could be the next level of severity analysis. It is a highly flexible model that can approximate any random severity based outcome (McFadden and Train, 2000). It obviates the three limitations of the standard logit by allowing for random taste variation, unrestricted severity outcome possibilities, and correlation in unobserved factors over time (Train, 2003).

These modeling techniques in the 'frequentists' sense can then be extended through a Bayesian approach for accident severity.

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Appendix A Other Nested Structure Models for Single-Vehicle Driver Only Occupant Severity Model

Structure 2:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ,AVHNODIS),DIS(AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(NOINJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB;
    IVSET:(DIS,FATALITY)=[1,1];
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 09, 2005 at 11:48:53AM. |
| Dependent variable                 DINJ      |
| Weighting variable                 None      |
| Number of observations           156800      |
| Iterations completed                 30      |
| Log likelihood function       -33195.44      |
| Restricted log likelihood     -66798.92      |
| Chi squared                    67206.96      |
| Degrees of freedom                   23      |
| Prob[ChiSqd > value] =         .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients -66798.9230  .50305  .50296  |
| Constants only  -35649.7777  .06885  .06867  |
| At start values -50471.9729  .34230  .34218  |
| Response data are given as ind. choice.      |
+----------------------------------------------+
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 31360, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	1.03169351	.02397702	43.028	.0000
A1	.53643133	.02609212	20.559	.0000
A2	-1.10131425	.04986540	-22.086	.0000
C0	-.05642791	.02400164	-2.351	.0187
C1	.93168816	.03181555	29.284	.0000
C2	.47882335	.03141055	15.244	.0000
C3	.36940710	.05471106	6.752	.0000
D0	2.27279092	.11704024	19.419	.0000
D1	2.24071490	.11678934	19.186	.0000
D2	.83417634	.08765254	9.517	.0000
D3	.39799455	.07179667	5.543	.0000
D4	.43508605	.07577362	5.742	.0000
D5	.62938588	.10059347	6.257	.0000
E1	3.73817403	.14761629	25.324	.0000
E2	1.41304477	.14374978	9.830	.0000
E3	.83658498	.32835036	2.548	.0108
E4	1.46951659	.18266947	8.045	.0000
Attributes of Branch Choice Equations (alpha)				
F0	4.22046428	.35880902	11.762	.0000
F1	-.40907278	.05532933	-7.393	.0000
F2	-.91162153	.11841338	-7.699	.0000
F3	-1.41656769	.07586947	-18.671	.0000
F4	.33787299	.07337204	4.605	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	1.11791532	.19169561	5.832	.0000
DIS	1.00000000	......(Fixed Parameter).......		
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 3:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ),INJURY(AVHPINJ,AVHNODIS),DIS(AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(INJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB;
    IVSET:(NOINJURY,DIS,FATALITY)=[1,1,1];
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 09, 2005 at 00:13:28PM.|
| Dependent variable                 DINJ     |
| Weighting variable                 None     |
| Number of observations           156800     |
| Iterations completed                 31     |
| Log likelihood function       -33148.02     |
| Restricted log likelihood     -51475.19     |
| Chi squared                    36654.34     |
| Degrees of freedom                   23     |
| Prob[ChiSqd > value] =         .0000000     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients -51475.1891  .35604  .35592 |
| Constants only  -35649.7777  .07018  .07001 |
| At start values -35925.1414  .07730  .07713 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 31360, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
	Attributes in the Utility Functions (beta)			
A0	5.20642145	.11235466	46.339	.0000
A1	.58776031	.02609218	22.526	.0000
A2	-1.70913102	.07302976	-23.403	.0000
C0	.01399532	.02620543	.534	.5933
C1	.72079671	.04493764	16.040	.0000
C2	.39101708	.03020835	12.944	.0000
C3	.26580539	.05233696	5.079	.0000
D0	2.22755637	.11634112	19.147	.0000
D1	3.06330856	.11701658	26.178	.0000
D2	1.16953226	.05965291	19.606	.0000
D3	.55934034	.06295728	8.884	.0000
D4	.63943973	.07186877	8.897	.0000
D5	.70504217	.09725202	7.250	.0000
E1	4.59995291	.14805479	31.069	.0000
E2	1.72035789	.12964721	13.270	.0000
E3	1.01708574	.33545429	3.032	.0024
E4	1.53987144	.18072908	8.520	.0000
	Attributes of Branch Choice Equations (alpha)			
F0	3.82208315	.14184519	26.945	.0000
F1	.31881142	.02456085	12.980	.0000
F2	-.58809764	.06749205	-8.714	.0000
F3	.72960927	.05038261	14.481	.0000
F4	-.17916247	.02936039	-6.102	.0000
	IV parameters, tau(j|i,l),sigma(i|l),phi(l)			
NOINJURY	1.00000000	......(Fixed Parameter).......		
INJURY	1.26990896	.10209194	12.439	.0000
DIS	1.00000000	......(Fixed Parameter).......		
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 4:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ),INJURY(AVHPINJ,AVHNODIS,AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(INJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB;
    IVSET:(NOINJURY,FATALITY)=[1,1];
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 09, 2005 at 00:27:23PM.|
| Dependent variable                DINJ      |
| Weighting variable                None      |
| Number of observations          156800      |
| Iterations completed                32      |
| Log likelihood function      -32996.01      |
| Restricted log likelihood    -48871.77      |
| Chi squared                   31751.51      |
| Degrees of freedom                  23      |
| Prob[ChiSqd > value] =        .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients -48871.7677  .32485  .32472 |
| Constants only  -35649.7777  .07444  .07427 |
| At start values -50471.9729  .34625  .34613 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 31360, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	5.14641474	.11363622	45.289	.0000
A1	.61942548	.02629655	23.555	.0000
A2	-1.29971430	.14616956	-8.892	.0000
C0	.04539610	.02663744	1.704	.0883
C1	.61579262	.04547127	13.542	.0000
C2	.37201754	.02948973	12.615	.0000
C3	.22395465	.05083338	4.406	.0000
D0	-1.77520197	.04845392	-36.637	.0000
D1	2.75719408	.10638097	25.918	.0000
D2	.92438838	.06494707	14.233	.0000
D3	.35591987	.06124460	5.811	.0000
D4	.57055370	.06920827	8.244	.0000
D5	.53177470	.09453201	5.625	.0000
E1	5.00616279	.18898374	26.490	.0000
E2	1.85113906	.13246650	13.974	.0000
E3	1.06916507	.33667420	3.176	.0015
E4	1.54895131	.18158396	8.530	.0000
Attributes of Branch Choice Equations (alpha)				
F0	3.57315885	.14938349	23.919	.0000
F1	.37262560	.02443448	15.250	.0000
F2	-.05877618	.14186198	-.414	.6786
F3	1.09867519	.05355909	20.513	.0000
F4	-.20317915	.02956594	-6.872	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	1.00000000	......(Fixed Parameter).......		
INJURY	1.40389914	.10636842	13.198	.0000
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 5:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ),PINJ(AVHPINJ),INJURY(AVHNODIS,AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(INJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB;
    IVSET:(NOINJURY,PINJ,FATALITY)=[1,1,1];
    tlf=.001;tlg=.001;tlb=.001$

Normal exit from iterations. Exit status=0.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 09, 2005 at 01:36:56PM. |
| Dependent variable                  DINJ     |
| Weighting variable                  None     |
| Number of observations            156800     |
| Iterations completed                  37     |
| Log likelihood function        -35413.77     |
| Restricted log likelihood      -49257.81     |
| Chi squared                     27688.09     |
| Degrees of freedom                    22     |
| Prob[ChiSqd > value] =          .0000000     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients -49257.8112  .28105  .28093  |
| Constants only  -35649.7777  .00662  .00645  |
| At start values -50471.9729  .29835  .29822  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 31360, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	1.57050368	.02390936	65.686	.0000
A1	.53497327	.02571695	20.802	.0000
A2	-1.12830075	.06269486	-17.997	.0000
C0	1.62479462	.04477863	36.285	.0000
C1	.29415264	.04737728	6.209	.0000
C2	.24081469	.03768860	6.390	.0000
C3	.09324572	.04045089	2.305	.0212
D1	2.29523049	.11622179	19.749	.0000
D2	.53256130	.07585475	7.021	.0000
D3	.10082676	.06215626	1.622	.1048
D4	-.31449573	.06350905	-4.952	.0000
D5	.29969433	.09458932	3.168	.0015
E1	3.44430423	.17612058	19.557	.0000
E2	-1.17580133	.07684167	-15.302	.0000
E3	-.77423366	.28489515	-2.718	.0066
E4	-1.41415177	.15314539	-9.234	.0000
Attributes of Branch Choice Equations (alpha)				
F0	-2.40275886	.36958286	-6.501	.0000
F1	.47201075	.02785351	16.946	.0000
F2	.37516087	.05882375	6.378	.0000
F3	1.27479259	.05179663	24.611	.0000
F4	-.30366527	.03457057	-8.784	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	1.00000000	......(Fixed Parameter).......		
PINJ	1.00000000	......(Fixed Parameter).......		
INJURY	1.60312677	.20667552	7.757	.0000
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 6:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;

tree=NOINJURY(AVHNOINJ),PINJ(AVHPINJ),INJURY(AVHNODIS,AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(INJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB;
    IVSET:(NOINJURY,PINJ)=[1,1];
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 09, 2005 at 02:08:44PM. |
| Dependent variable                   DINJ    |
| Weighting variable                   None    |
| Number of observations             156800    |
| Iterations completed                   54    |
| Log likelihood function         -32820.61    |
| Restricted log likelihood       -43987.34    |
| Chi squared                      22333.45    |
| Degrees of freedom                     23    |
| Prob[ChiSqd > value] =           .0000000    |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients -43987.3374  .25386  .25373  |
| Constants only  -35649.7777  .07936  .07919  |
| At start values -50471.9729  .34973  .34961  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 31360, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
	Attributes in the Utility Functions (beta)			
A0	.98596918	.02393513	41.193	.0000
A1	.57865592	.02584368	22.391	.0000
A2	-.88867549	.06553392	-13.561	.0000
C0	4.11380617	.11005377	37.380	.0000
C1	.26060411	.03847947	6.773	.0000
C2	.19795187	.02601304	7.610	.0000
C3	.10003000	.03708007	2.698	.0070
D0	2.30764305	.11516047	20.038	.0000
D1	2.18559936	.11659732	18.745	.0000
D2	.57757974	.05990238	9.642	.0000
D3	.20406095	.05925286	3.444	.0006
D4	.44225897	.06154552	7.186	.0000
D5	.40730774	.08784558	4.637	.0000
E1	3.60881505	.15137771	23.840	.0000
E2	1.15287272	.12831583	8.985	.0000
E3	1.20711554	.31532068	3.828	.0001
E4	1.22189118	.17381305	7.030	.0000
	Attributes of Branch Choice Equations (alpha)			
F0	-9.03502615	.90504145	-9.983	.0000
F1	.48872321	.02797845	17.468	.0000
F2	.58530129	.06201930	9.437	.0000
F3	1.34668424	.05310559	25.359	.0000
F4	-.25792899	.03539468	-7.287	.0000
	IV parameters, tau(j|i,l),sigma(i|l),phi(l)			
NOINJURY	1.00000000	......(Fixed Parameter).......		
PINJ	1.00000000	......(Fixed Parameter).......		
INJURY	2.07334454	.20450331	10.138	.0000

Structure 7:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ),PINJ(AVHPINJ),NONDIS(AVHNODIS),
    INJURY(AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(INJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB;
    IVSET:(NOINJURY,PINJ,NONDIS)=[1,1,1];
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 09, 2005 at 02:32:43PM.|
| Dependent variable                DINJ      |
| Weighting variable                None      |
| Number of observations          156800      |
| Iterations completed                87      |
| Log likelihood function      -33194.05      |
| Restricted log likelihood    -44802.95      |
| Chi squared                   23217.81      |
| Degrees of freedom                  23      |
| Prob[ChiSqd > value] =        .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients -44802.9543  .25911  .25897 |
| Constants only  -35649.7777  .06888  .06871 |
| At start values -50471.9729  .34233  .34221 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 31360, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	1.02960672	.02377011	43.315	.0000
A1	.53997501	.02558800	21.103	.0000
A2	-1.10153511	.04988876	-22.080	.0000
C0	-.05800956	.02400572	-2.416	.0157
C1	.93317924	.03180673	29.339	.0000
C2	.48396425	.03143560	15.395	.0000
C3	.36989539	.05475747	6.755	.0000
D0	2.26888355	.11298642	20.081	.0000
D1	1.19639869	.54692355	2.188	.0287
D2	.44619723	.18688173	2.388	.0170
D3	.26367058	.08764378	3.008	.0026
D4	.27379032	.10119322	2.706	.0068
D5	.32121387	.16613089	1.933	.0532
E1	2.64408833	.58098513	4.551	.0000
E2	.99266980	.23788224	4.173	.0000
E3	.77678123	.28727545	2.704	.0069
E4	1.12004898	.24288038	4.612	.0000
Attributes of Branch Choice Equations (alpha)				
F0	-6.06523918	1.44026079	-4.211	.0000
F1	.40763950	.05534230	7.366	.0000
F2	.97434220	.06961145	13.997	.0000
F3	1.41490626	.07572264	18.685	.0000
F4	-.31114460	.07527248	-4.134	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	1.00000000	......(Fixed Parameter).......		
PINJ	1.00000000	......(Fixed Parameter).......		
NONDIS	1.00000000	......(Fixed Parameter).......		
INJURY	1.68391750	.60043548	2.804	.0050

Structure 8:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;

tree=NOINJURY(AVHNOINJ,AVHPINJ),NONDIS(AVHNODIS),INJURY(AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(NOINJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB/
    U(INJURY)=0;
    IVSET:(NONDIS)=[1];
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+-----------------------------------------------+
| FIML Nested Multinomial Logit Model           |
| Maximum Likelihood Estimates                  |
| Model estimated: Nov 09, 2005 at 04:28:34PM.  |
| Dependent variable                 DINJ       |
| Weighting variable                 None       |
| Number of observations           156800       |
| Iterations completed                 57       |
| Log likelihood function       -32812.56       |
| Restricted log likelihood     -51502.52       |
| Chi squared                    37379.92       |
| Degrees of freedom                   24       |
| Prob[ChiSqd > value] =         .0000000       |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj   |
| No coefficients -51502.5157  .36289  .36277   |
| Constants only  -35649.7777  .07959  .07941   |
| At start values -38951.2653  .15760  .15744   |
| Response data are given as ind. choice.       |
+-----------------------------------------------+

+-----------------------------------------------+
| FIML Nested Multinomial Logit Model           |
| The model has 2 levels.                       |
| Nested Logit form:IV parms = tauj|i,l,si|l    |
| and fl. No normalizations imposed a priori.   |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum        |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/   |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum    |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...             |
| Coefs. for branch level begin with F0         |
| Number of obs.= 31360, skipped   0 bad obs.   |
+-----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
	Attributes in the Utility Functions (beta)			
A0	.88532891	.02646147	33.457	.0000
A1	.75299562	.03379053	22.284	.0000
A2	-.89420752	.06614232	-13.519	.0000
C0	5.93502474	1.25249627	4.739	.0000
C1	.59564852	.03386211	17.590	.0000
C2	.38064721	.03405736	11.177	.0000
C3	.28942701	.05584614	5.183	.0000
D0	2.28281763	.11280826	20.236	.0000
D1	1.32689465	.48689186	2.725	.0064
D2	.48780378	.16623576	2.934	.0033
D3	.24547667	.07225215	3.398	.0007
D4	.29854579	.09315656	3.205	.0014
D5	.29554370	.13445401	2.198	.0279
E1	2.76373915	.51723835	5.343	.0000
E2	1.03706918	.21714120	4.776	.0000
E3	.86899059	.27748448	3.132	.0017
E4	1.10084297	.21435575	5.136	.0000
	Attributes of Branch Choice Equations (alpha)			
F0	7.08814075	1.25623217	5.642	.0000
F1	-.48510375	.02784721	-17.420	.0000
F2	-.95843295	.06104039	-15.702	.0000
F3	-1.35739474	.05243319	-25.888	.0000
F4	.27361452	.03470332	7.884	.0000
	IV parameters, tau(j|i,l),sigma(i|l),phi(l)			
NOINJURY	.45834021	.05556727	8.248	.0000
NONDIS	1.00000000	......(Fixed Parameter).......		
INJURY	1.76386447	.51906743	3.398	.0007

Structure 9:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ,AVHNODIS),INJURY(AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(NOINJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB/
    U(INJURY)=0;
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 09, 2005 at 04:47:39PM.|
| Dependent variable                DINJ      |
| Weighting variable                None      |
| Number of observations          156800      |
| Iterations completed                58      |
| Log likelihood function      -33193.49      |
| Restricted log likelihood    -55412.30      |
| Chi squared                   44437.62      |
| Degrees of freedom                  24      |
| Prob[ChiSqd > value] =        .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients -55412.3003  .40097  .40086 |
| Constants only  -35649.7777  .06890  .06872 |
| At start values -36327.2171  .08626  .08609 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 31360, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	1.03315521	.02402664	43.000	.0000
A1	.53413700	.02619810	20.388	.0000
A2	-1.10208638	.04985044	-22.108	.0000
C0	-.05754314	.02400261	-2.397	.0165
C1	.93188826	.03181270	29.293	.0000
C2	.48282403	.03141684	15.368	.0000
C3	.37078561	.05469322	6.779	.0000
D0	2.27359857	.11268299	20.177	.0000
D1	1.02929249	.44119512	2.333	.0197
D2	.42327238	.15999878	2.645	.0082
D3	.25669094	.07980881	3.216	.0013
D4	.24555595	.08451830	2.905	.0037
D5	.28550304	.13919019	2.051	.0403
E1	2.47637234	.47566284	5.206	.0000
E2	.96803935	.21769133	4.447	.0000
E3	.75064296	.27701347	2.710	.0067
E4	1.08282099	.22264379	4.863	.0000
Attributes of Branch Choice Equations (alpha)				
F0	6.21909731	1.45183604	4.284	.0000
F1	-.40884418	.05535661	-7.386	.0000
F2	-.87540834	.12078167	-7.248	.0000
F3	-1.42167281	.07598326	-18.710	.0000
F4	.30873791	.07507718	4.112	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	1.20126133	.19824202	6.060	.0000
INJURY	1.89167234	.61244178	3.089	.0020

Structure 10:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ),INJURY(AVHNODIS,AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*NORPCAR/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OT+C3*OLDRURAL/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OT+D4*OSPOLE+D5*OLDRURAL/
    U(AVHFATAL)=E1*TOTEJCT+E2*HBD+D4*OSPOLE+E3*OSGRLE+E4*OLDRURAL/
    U(NOINJURY)=F0+F1*DRYSURF+F2*NORPCAR+F3*NORPKUP+F4*POSGRFCB/
    U(INJURY)=0;
    tlf=.001;tlg=.001;tlb=.001$
```

```
Normal exit from iterations. Exit status=0.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 09, 2005 at 04:59:44PM. |
| Dependent variable                DINJ       |
| Weighting variable                None       |
| Number of observations          156800       |
| Iterations completed                51       |
| Log likelihood function      -32789.22       |
| Restricted log likelihood    -46993.22       |
| Chi squared                   28408.00       |
| Degrees of freedom                  24       |
| Prob[ChiSqd > value] =        .0000000       |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients -46993.2228  .30226  .30212  |
| Constants only  -35649.7777  .08024  .08006  |
| At start values -36250.3640  .09548  .09531  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 31360, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	.88530681	.02646261	33.455	.0000
A1	.75299929	.03379025	22.285	.0000
A2	-.89443208	.06614370	-13.523	.0000
C0	4.11466137	.11007035	37.382	.0000
C1	.24937128	.03752581	6.645	.0000
C2	.19521206	.02586960	7.546	.0000
C3	.10026031	.03715676	2.698	.0070
D0	2.30846315	.11520349	20.038	.0000
D1	2.18996707	.11648292	18.801	.0000
D2	.56710843	.05930476	9.563	.0000
D3	.20105719	.05919823	3.396	.0007
D4	.43881026	.06167113	7.115	.0000
D5	.40779505	.08789387	4.640	.0000
E1	3.61301396	.15100905	23.926	.0000
E2	1.14271851	.12782236	8.940	.0000
E3	1.19518247	.31559043	3.787	.0002
E4	1.22144587	.17380723	7.028	.0000
Attributes of Branch Choice Equations (alpha)				
F0	9.80594091	.90118336	10.881	.0000
F1	-.48348773	.02791381	-17.321	.0000
F2	-.92583151	.06147879	-15.059	.0000
F3	-1.31738731	.05307588	-24.821	.0000
F4	.25386819	.03531375	7.189	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	.46098551	.05569030	8.278	.0000
INJURY	2.05634689	.20230512	10.165	.0000

Appendix B Other Nested Structure Models for Two-Vehicle Driver Only Occupant Severity Model

Structure 2:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ,AVHNODIS),DIS(AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE;
    IVSET:(DIS,FATALITY)=[1,1];
    tlf=.001;tlg=.001;tlb=.001$
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Aug 22, 2005 at 10:44:27AM. |
| Dependent variable                 DINJ      |
| Weighting variable                 None      |
| Number of observations           483000      |
| Iterations completed                 40      |
| Log likelihood function       -87338.36      |
| Restricted log likelihood     -209566.9      |
| Chi squared                    244457.0      |
| Degrees of freedom                   31      |
| Prob[ChiSqd > value] =         .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients ***********  .58324  .58321  |
| Constants only  -90916.4154  .03936  .03928  |
| At start values -95972.2201  .08996  .08989  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 96600, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	.88956445	.01568737	56.706	.0000
A1	.27576104	.01437744	19.180	.0000
A2	.27948721	.01437662	19.440	.0000
A3	-.91278749	.03009597	-30.329	.0000
A4	-.35119300	.02187142	-16.057	.0000
A5	-.35202105	.02187931	-16.089	.0000
A6	-.27392945	.02291365	-11.955	.0000
C0	-.97369589	.02071639	-47.001	.0000
C1	.98190365	.03387076	28.990	.0000
C2	.73346306	.03231998	22.694	.0000
C3	-.19800370	.02514580	-7.874	.0000
C4	.57000215	.05227569	10.904	.0000
C5	-.03931863	.02332179	-1.686	.0918
D0	2.64236924	.11683001	22.617	.0000
D1	2.53522593	.21936870	11.557	.0000
D2	.74645935	.07412026	10.071	.0000
D3	.36423576	.06888228	5.288	.0000
D4	.56331774	.09679264	5.820	.0000
D5	-.79524413	.05641899	-14.095	.0000
E1	4.12937141	.26332372	15.682	.0000
E2	2.04457019	.13189341	15.502	.0000
E3	1.05316635	.13425700	7.844	.0000
E4	1.11017039	.16477919	6.737	.0000
E5	1.30012501	.16259243	7.996	.0000
E6	-1.67527459	.13696023	-12.232	.0000
Attributes of Branch Choice Equations (alpha)				
F0	4.82476905	.25149283	19.185	.0000
F1	-1.13325660	.09109696	-12.440	.0000
F2	-1.01258092	.09552030	-10.601	.0000
F3	1.42267683	.07652145	18.592	.0000
F4	1.41826946	.07337601	19.329	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	.54220853	.14785037	3.667	.0002
DIS	1.00000000	......(Fixed Parameter).......		
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 3:

```
nlogit;lhs=DINJ;
choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
tree=PDO(AVHNOINJ),NOINJURY(AVHNODIS,AVHPINJ),DIS(AVHDIS),
     FATALITY(AVHFATAL);
model:
U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
            A5*BEXSFSPD+A6*BTOOCLOS/
U(AVHPINJ)=0/
U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
            E5*AOLDRURL+E6*ATINRE/
U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE;
IVSET:(PDO,DIS,FATALITY)=[1,1,1];
tlf=.001;tlg=.001;tlb=.001$
```

```
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Aug 22, 2005 at 11:49:08AM. |
| Dependent variable                 DINJ      |
| Weighting variable                 None      |
| Number of observations           483000      |
| Iterations completed                 41      |
| Log likelihood function       -86615.73      |
| Restricted log likelihood     -155381.4      |
| Chi squared                    137531.4      |
| Degrees of freedom                   31      |
| Prob[ChiSqd > value] =         .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients ***********  .44256  .44252  |
| Constants only  -90916.4154  .04730  .04723  |
| At start values -94887.3294  .08717  .08710  |
| Response data are given as ind. choice.      |
+----------------------------------------------+
```

```
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 96600, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	6.24355212	.11174638	55.873	.0000
A1	.27404902	.01434553	19.103	.0000
A2	.26684354	.01432120	18.633	.0000
A3	-1.85001968	.05605747	-33.002	.0000
A4	-.18685372	.02228344	-8.385	.0000
A5	-.18637979	.02230882	-8.355	.0000
A6	.02007248	.02419930	.829	.4068
C0	-.66625492	.02205021	-30.215	.0000
C1	.80906362	.03584222	22.573	.0000
C2	.44071652	.03178915	13.864	.0000
C3	-.64581079	.02740934	-23.562	.0000
C4	.42643517	.04750261	8.977	.0000
C5	-.14460270	.02167057	-6.673	.0000
D0	2.64159144	.11480238	23.010	.0000
D1	2.87357548	.21708491	13.237	.0000
D2	1.01928318	.06315123	16.140	.0000
D3	1.40847311	.05293744	26.606	.0000
D4	.75572603	.09523245	7.936	.0000
D5	-.26632217	.04773516	-5.579	.0000
E1	4.38423419	.26860323	16.322	.0000
E2	3.29559354	.12228284	26.951	.0000
E3	1.34406404	.12733583	10.555	.0000
E4	1.16892617	.16446383	7.107	.0000
E5	1.43925953	.16218723	8.874	.0000
E6	-1.45600294	.13815333	-10.539	.0000
Attributes of Branch Choice Equations (alpha)				
F0	5.10236280	.12133600	42.052	.0000
F1	-.94565279	.05522519	-17.124	.0000
F2	.47884745	.05044066	9.493	.0000
F3	-.44223864	.02201559	-20.088	.0000
F4	.50354281	.03129978	16.088	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
PDO	1.00000000	......(Fixed Parameter).......		
NOINJURY	1.57611789	.10383738	15.179	.0000
DIS	1.00000000	......(Fixed Parameter).......		
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 4:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=PDO(AVHNOINJ),NOINJURY(AVHNODIS,AVHPINJ,AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE;
    IVSET:(PDO,FATALITY)=[1,1];
    tlf=.001;tlg=.001;tlb=.001$
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 14, 2005 at 10:17:57AM.|
| Dependent variable                 DINJ     |
| Weighting variable                 None     |
| Number of observations           483000     |
| Iterations completed                 43     |
| Log likelihood function       -86718.49     |
| Restricted log likelihood     -142430.7     |
| Chi squared                    111424.4     |
| Degrees of freedom                   31     |
| Prob[ChiSqd > value] =         .0000000     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients ***********  .39115  .39110 |
| Constants only  -90916.4154  .04617  .04610 |
| At start values ***********  .44222  .44218 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 96600, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	6.33709479	.11608551	54.590	.0000
A1	.27629646	.01436582	19.233	.0000
A2	.26662266	.01434027	18.593	.0000
A3	-2.19015713	.12461380	-17.576	.0000
A4	-.19779976	.02234776	-8.851	.0000
A5	-.19755618	.02237418	-8.830	.0000
A6	.00214593	.02436005	.088	.9298
C0	-.68302092	.02233054	-30.587	.0000
C1	.81816871	.03527762	23.192	.0000
C2	.41332961	.03433081	12.040	.0000
C3	-.59912096	.02740753	-21.860	.0000
C4	.44870903	.04950682	9.064	.0000
C5	-.16282973	.02242159	-7.262	.0000
D0	-2.64295111	.03314497	-79.739	.0000
D1	2.95692986	.18652200	15.853	.0000
D2	1.00704987	.06101609	16.505	.0000
D3	1.34711602	.05340123	25.226	.0000
D4	.69167055	.09240212	7.485	.0000
D5	-.28020062	.04643746	-6.034	.0000
E1	4.55789503	.28677267	15.894	.0000
E2	3.29947453	.12365095	26.684	.0000
E3	1.25583933	.13171494	9.535	.0000
E4	1.22006924	.16572606	7.362	.0000
E5	1.47395251	.16327972	9.027	.0000
E6	-1.45321841	.13884533	-10.466	.0000
Attributes of Branch Choice Equations (alpha)				
F0	5.29827975	.12158022	43.578	.0000
F1	-1.20628580	.12350779	-9.767	.0000
F2	.62051203	.05033666	12.327	.0000
F3	-.49340843	.02132508	-23.137	.0000
F4	.37417904	.02655357	14.091	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
PDO	1.00000000	......(Fixed Parameter).......		
NOINJURY	1.40759364	.07630230	18.448	.0000
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 5:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=PDO(AVHNOINJ),PINJ(AVHPINJ),NOINJURY(AVHNODIS,AVHDIS),
    FATALITY(AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE;
    IVSET:(PDO,PINJ,FATALITY)=[1,1,1];
    tlf=.001;tlg=.001;tlb=.001$
Maximum iterations reached. Exit iterations with status=1.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 14, 2005 at 11:20:09AM. |
| Dependent variable                 DINJ      |
| Weighting variable                 None      |
| Number of observations           483000      |
| Iterations completed                101      |
| Log likelihood function       -95862.07      |
| Restricted log likelihood     -141738.9      |
| Chi squared                    91753.66      |
| Degrees of freedom                   30      |
| Prob[ChiSqd > value] =         .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients ***********  .32367  .32362  |
| Constants only  -90916.4154 -.05440 -.05448  |
| At start values ***********  .38341  .38336  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Hessian was not PD. Using BHHH estimator.    |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 96600, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	1.20619953	.01541694	78.239	.0000
A1	.29058598	.01411234	20.591	.0000
A2	.26554349	.01409822	18.835	.0000
A3	-.78040902	.03489982	-22.361	.0000
A4	-.19959010	.02129857	-9.371	.0000
A5	-.19169300	.02131145	-8.995	.0000
A6	-.14073033	.02235361	-6.296	.0000
C0	1.33350706	.04204545	31.716	.0000
C1	.08293428	.01738116	4.772	.0000
C2	-.07633533	.01238904	-6.162	.0000
C3	.41718875	.05516438	7.563	.0000
C4	.06041383	.01566606	3.856	.0001
C5	.00356615	.00665070	.536	.5918
D1	.53470114	.10101286	5.293	.0000
D2	-.07736451	.03227647	-2.397	.0165
D3	.36819356	.04278439	8.606	.0000
D4	-.09266257	.05228169	-1.772	.0763
D5	-.23298812	.04223642	-5.516	.0000
E1	3.49494364	.22866252	15.284	.0000
E2	-.18800275	.07947206	-2.366	.0180
E3	-1.50350163	.11139668	-13.497	.0000
E4	-2.17738613	.14039755	-15.509	.0000
E5	-1.38842330	.14712350	-9.437	.0000
E6	-4.36778152	.12294391	-35.527	.0000
Attributes of Branch Choice Equations (alpha)				
F0	-20.7812422	4.95834597	-4.191	.0000
F1	.65030023	.03836693	16.949	.0000
F2	.85759041	.05665911	15.136	.0000
F3	-.87221642	.03760896	-23.192	.0000
F4	-5.45663551	1.08920842	-5.010	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
PDO	1.00000000	......(Fixed Parameter).......		
PINJ	1.00000000	......(Fixed Parameter).......		
NOINJURY	13.4434981	3.02432898	4.445	.0000
FATALITY	1.00000000	......(Fixed Parameter).......		

Structure 6:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=PDO(AVHNOINJ),PINJ(AVHPINJ),
    INJURY(AVHNODIS,AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(INJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE;
    IVSET:(PDO,PINJ)=[1,1];
    tlf=.001;tlg=.001;tlb=.001$
Maximum iterations reached. Exit iterations with status=1.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model           |
| Maximum Likelihood Estimates                  |
| Model estimated: Nov 18, 2005 at 11:10:08AM.  |
| Dependent variable                 DINJ       |
| Weighting variable                 None       |
| Number of observations           483000       |
| Iterations completed                101       |
| Log likelihood function       -86951.25       |
| Restricted log likelihood     -118927.0       |
| Chi squared                    63951.46       |
| Degrees of freedom                   31       |
| Prob[ChiSqd > value] =         .0000000       |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj   |
| No coefficients ***********  .26887  .26881   |
| Constants only  -90916.4154  .04361  .04354   |
| At start values ***********  .44073  .44068   |
| Response data are given as ind. choice.       |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model           |
| The model has 2 levels.                       |
| Nested Logit form:IV parms = tauj|i,l,si|l    |
| and fl. No normalizations imposed a priori.   |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum        |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/   |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum    |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...             |
| Coefs. for branch level begin with F0         |
| Number of obs.= 96600, skipped   0 bad obs.   |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	.86201050	.01556211	55.392	.0000
A1	.27851248	.01421522	19.593	.0000
A2	.27872624	.01421624	19.606	.0000
A3	-.62023249	.03581565	-17.317	.0000
A4	-.33273703	.02155898	-15.434	.0000
A5	-.33580206	.02157374	-15.565	.0000
A6	-.26449867	.02260259	-11.702	.0000
C0	3.84653508	.10570125	36.391	.0000
C1	.19449361	.02713020	7.169	.0000
C2	-.07869272	.01946558	-4.043	.0001
C3	.41028748	.05806471	7.066	.0000
C4	.12169406	.02491552	4.884	.0000
C5	-.02358099	.01504442	-1.567	.1170
D0	2.45567868	.10775661	22.789	.0000
D1	1.41566976	.16854943	8.399	.0000
D2	.22471020	.06578706	3.416	.0006
D3	.40661749	.04951148	8.213	.0000
D4	.11456192	.08638870	1.326	.1848
D5	-.28241451	.04458294	-6.335	.0000
E1	2.92642148	.22106173	13.238	.0000
E2	2.04898405	.12232140	16.751	.0000
E3	.32599924	.11555275	2.821	.0048
E4	.93073384	.11638847	7.997	.0000
E5	.42198789	.14081973	2.997	.0027
E6	-1.28011655	.13227873	-9.677	.0000
Attributes of Branch Choice Equations (alpha)				
F0	-17.5226008	2.32406932	-7.540	.0000
F1	.85321318	.03944902	21.628	.0000
F2	.91231989	.05849775	15.596	.0000
F3	-.87453996	.03682513	-23.748	.0000
F4	-2.25776135	.28763879	-7.849	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
PDO	1.00000000	......(Fixed Parameter).......		
PINJ	1.00000000	......(Fixed Parameter).......		
INJURY	4.24092889	.56295421	7.533	.0000

Structure 7:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=PDO(AVHNOINJ),PINJ(AVHPINJ),NONDIS(AVHNODIS),
    INJURY(AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(INJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE;
    IVSET:(PDO,PINJ,NONDIS)=[1,1,1];
    tlf=.001;tlg=.001;tlb=.001$
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 18, 2005 at 02:20:59PM.|
| Dependent variable                 DINJ     |
| Weighting variable                 None     |
| Number of observations           483000     |
| Iterations completed                 97     |
| Log likelihood function       -87321.00     |
| Restricted log likelihood     -135610.1     |
| Chi squared                    96578.17     |
| Degrees of freedom                   31     |
| Prob[ChiSqd > value] =         .0000000     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients ***********  .35609  .35604 |
| Constants only  -90916.4154  .03955  .03947 |
| At start values ***********  .43835  .43830 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 96600, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	.88788642	.01553544	57.152	.0000
A1	.27380313	.01418666	19.300	.0000
A2	.27777254	.01418483	19.582	.0000
A3	-.91260428	.03006819	-30.351	.0000
A4	-.34109190	.02152399	-15.847	.0000
A5	-.34304829	.02154065	-15.926	.0000
A6	-.26426918	.02259488	-11.696	.0000
C0	-.97478036	.02069202	-47.109	.0000
C1	.98309745	.03382023	29.068	.0000
C2	.73523866	.03230779	22.757	.0000
C3	-.19535597	.02512138	-7.776	.0000
C4	.57232714	.05220355	10.963	.0000
C5	-.04073302	.02331637	-1.747	.0806
D0	2.29942791	.10689246	21.512	.0000
D1	.34668343	.10761284	3.222	.0013
D2	.17786721	.03566980	4.986	.0000
D3	-.07127963	.02866622	-2.487	.0129
D4	.09082129	.03166002	2.869	.0041
D5	-.03797335	.03035426	-1.251	.2109
E1	1.49301634	.23416488	6.376	.0000
E2	1.42985498	.13061262	10.947	.0000
E3	.13071023	.08794115	1.486	.1372
E4	.48537892	.09657226	5.026	.0000
E5	.33810490	.10760319	3.142	.0017
E6	-.98913110	.13090072	-7.556	.0000
Attributes of Branch Choice Equations (alpha)				
F0	-14.3614661	2.44111943	-5.883	.0000
F1	.90909156	.05589378	16.265	.0000
F2	1.02345361	.09583256	10.680	.0000
F3	-1.19166453	.08463377	-14.080	.0000
F4	-1.25182383	.07852188	-15.942	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
PDO	1.00000000	......(Fixed Parameter).......		
PINJ	1.00000000	......(Fixed Parameter).......		
NONDIS	1.00000000	......(Fixed Parameter).......		
INJURY	5.28205125	1.06116024	4.978	.0000

Structure 8:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ),NONDIS(AVHNODIS),
    INJURY(AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE/
    U(INJURY)=0;
    IVSET:(NONDIS)=[1];
    tlf=.001;tlg=.001;tlb=.001$
Maximum iterations reached. Exit iterations with status=1.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 18, 2005 at 03:06:02PM. |
| Dependent variable                 DINJ      |
| Weighting variable                 None      |
| Number of observations           483000      |
| Iterations completed                101      |
| Log likelihood function       -86853.54      |
| Restricted log likelihood     -166701.5      |
| Chi squared                    159695.9      |
| Degrees of freedom                   32      |
| Prob[ChiSqd > value] =         .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients ***********  .47899  .47894  |
| Constants only  -90916.4154  .04469  .04461  |
| At start values ***********  .18220  .18213  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 96600, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	.82826998	.01680826	49.278	.0000
A1	.32952386	.01608929	20.481	.0000
A2	.33277711	.01609997	20.669	.0000
A3	-.62250090	.03598706	-17.298	.0000
A4	-.39424048	.02381846	-16.552	.0000
A5	-.39644590	.02384008	-16.629	.0000
A6	-.34704786	.02461609	-14.098	.0000
C0	18.7153597	4.47326069	4.184	.0000
C1	.76136052	.03527801	21.582	.0000
C2	.23017432	.03741675	6.152	.0000
C3	.30214260	.05985781	5.048	.0000
C4	.51068885	.05303925	9.629	.0000
C5	-.37006172	.02739354	-13.509	.0000
D0	2.28157079	.15073060	15.137	.0000
D1	.26872261	.07431194	3.616	.0003
D2	.13918951	.02994582	4.648	.0000
D3	-.09089670	.03145036	-2.890	.0039
D4	.07407950	.02405072	3.080	.0021
D5	.01536342	.01177489	1.305	.1920
E1	1.19343897	.21350148	5.590	.0000
E2	1.44231407	.09886210	14.589	.0000
E3	.07417489	.06441717	1.151	.2495
E4	.31996662	.06799326	4.706	.0000
E5	.20651110	.08107325	2.547	.0109
E6	-.93929723	.17907329	-5.245	.0000
Attributes of Branch Choice Equations (alpha)				
F0	20.2075869	4.47724475	4.513	.0000
F1	-1.18852002	.03959088	-30.020	.0000
F2	-.88886135	.05797153	-15.333	.0000
F3	.87083069	.03643439	23.901	.0000
F4	1.00375844	.06108800	16.431	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	.21372151	.05202332	4.108	.0000
NONDIS	1.00000000	......(Fixed Parameter).......		
INJURY	7.22136256	1.54631624	4.670	.0000

Structure 9:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ,AVHNODIS),
    INJURY(AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE/
    U(INJURY)=0;
    tlf=.001;tlg=.001;tlb=.001$
Maximum iterations reached. Exit iterations with status=1.
+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 22, 2005 at 10:14:04AM. |
| Dependent variable                 DINJ      |
| Weighting variable                 None      |
| Number of observations           483000      |
| Iterations completed                101      |
| Log likelihood function       -87317.30      |
| Restricted log likelihood     -172093.0      |
| Chi squared                    169551.4      |
| Degrees of freedom                   32      |
| Prob[ChiSqd > value] =         .0000000      |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj  |
| No coefficients ***********  .49262  .49257  |
| Constants only  -90916.4154  .03959  .03951  |
| At start values -94419.5060  .07522  .07514  |
| Response data are given as ind. choice.      |
+----------------------------------------------+

+----------------------------------------------+
| FIML Nested Multinomial Logit Model          |
| The model has 2 levels.                      |
| Nested Logit form:IV parms = tauj|i,l,si|l   |
| and fl. No normalizations imposed a priori.  |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum       |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/  |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum   |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...            |
| Coefs. for branch level begin with F0        |
| Number of obs.= 96600, skipped   0 bad obs.  |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
	Attributes in the Utility Functions (beta)			
A0	.88863579	.01567990	56.674	.0000
A1	.27603152	.01436377	19.217	.0000
A2	.28022389	.01436139	19.512	.0000
A3	-.91274170	.03009430	-30.329	.0000
A4	-.35003615	.02188890	-15.991	.0000
A5	-.35135632	.02187975	-16.059	.0000
A6	-.27303541	.02291817	-11.913	.0000
C0	-.97315029	.02070638	-46.998	.0000
C1	.98148875	.03387045	28.978	.0000
C2	.73400417	.03234363	22.694	.0000
C3	-.19789143	.02514582	-7.870	.0000
C4	.57089434	.05227772	10.920	.0000
C5	-.04092139	.02333427	-1.754	.0795
D0	2.30051625	.10154885	22.654	.0000
D1	.35649746	.10268807	3.472	.0005
D2	.16479994	.03157205	5.220	.0000
D3	-.08179954	.02822232	-2.898	.0038
D4	.08635133	.03064471	2.818	.0048
D5	-.04260511	.02866046	-1.487	.1371
E1	1.51806549	.22455308	6.760	.0000
E2	1.43619913	.11712411	12.262	.0000
E3	.08963577	.08593561	1.043	.2969
E4	.47813217	.09252647	5.168	.0000
E5	.32773575	.10478331	3.128	.0018
E6	-.99635306	.13036431	-7.643	.0000
	Attributes of Branch Choice Equations (alpha)			
F0	14.6592699	2.29819818	6.379	.0000
F1	-1.11030108	.09205829	-12.061	.0000
F2	-1.01173280	.09584167	-10.556	.0000
F3	1.20045299	.08450932	14.205	.0000
F4	1.22058069	.07937970	15.376	.0000
	IV parameters, tau(j|i,l),sigma(i|l),phi(l)			
NOINJURY	.59002310	.14989588	3.936	.0001
INJURY	5.15230287	.95112891	5.417	.0000

Structure 10:

```
nlogit;lhs=DINJ;
    choices=AVHNOINJ,AVHPINJ,AVHNODIS,AVHDIS,AVHFATAL;
    tree=NOINJURY(AVHNOINJ,AVHPINJ),
    INJURY(AVHNODIS,AVHDIS,AVHFATAL);
    model:
    U(AVHNOINJ)=A0+A1*ADRSEX+A2*BDRSEX+A3*NORPCAR+A4*AEXSFSPD+
    A5*BEXSFSPD+A6*BTOOCLOS/
    U(AVHPINJ)=0/
    U(AVHNODIS)=C0+C1*HBD+C2*OD+C3*RE+C4*AOLDRURL+C5*ATINRE/
    U(AVHDIS)=D0+D1*TOTEJCT+D2*HBD+D3*OD+D4*AOLDRURL+D5*ATINRE/
    U(AVHFATAL)=E1*TOTEJCT+E2*OD+E3*HBD+E4*BALLTRUK+
    E5*AOLDRURL+E6*ATINRE/
    U(NOINJURY)=F0+F1*NORPCAR+F2*ANORPKUP+F3*SD+F4*RE/
    U(INJURY)=0;
    tlf=.001;tlg=.001;tlb=.001$
Normal exit from iterations. Exit status=0.
+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 22, 2005 at 10:51:57AM.|
| Dependent variable                 DINJ     |
| Weighting variable                 None     |
| Number of observations           483000     |
| Iterations completed                 97     |
| Log likelihood function       -86861.76     |
| Restricted log likelihood     -138640.5     |
| Chi squared                    103557.5     |
| Degrees of freedom                   32     |
| Prob[ChiSqd > value] =         .0000000     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients ***********  .37347  .37342 |
| Constants only  -90916.4154  .04460  .04452 |
| At start values ***********  .13156  .13149 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| FIML Nested Multinomial Logit Model         |
| The model has 2 levels.                     |
| Nested Logit form:IV parms = tauj|i,l,si|l  |
| and fl. No normalizations imposed a priori. |
| p(alt=k|b=j,l=i,t=l)=exp[bX_k|jil]/Sum      |
| p(b=j|l=i,t=l)=exp[aY_j|il+tauj|ilIVj|il)]/ |
| Sum. p(l=i|t=l)=exp[cZ_i|l+si|lIVi|l)]/Sum  |
| p(t=l)=exp[exp[qW_l+flIVl]/Sum...           |
| Coefs. for branch level begin with F0       |
| Number of obs.= 96600, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Attributes in the Utility Functions (beta)				
A0	.82854669	.01680292	49.310	.0000
A1	.32855098	.01608282	20.429	.0000
A2	.33329038	.01609093	20.713	.0000
A3	-.62216927	.03599122	-17.287	.0000
A4	-.39280348	.02381978	-16.491	.0000
A5	-.39520489	.02383776	-16.579	.0000
A6	-.34615311	.02462502	-14.057	.0000
C0	3.85496792	.10725751	35.941	.0000
C1	.18300291	.02671178	6.851	.0000
C2	-.07759449	.01970055	-3.939	.0001
C3	.41587641	.05816926	7.149	.0000
C4	.12290213	.02553706	4.813	.0000
C5	-.03043482	.01643140	-1.852	.0640
D0	2.46595272	.10886683	22.651	.0000
D1	1.43909652	.17202060	8.366	.0000
D2	.22535887	.06480937	3.477	.0005
D3	.40496665	.04985812	8.122	.0000
D4	.12051082	.08676726	1.389	.1649
D5	-.29388800	.04521648	-6.500	.0000
E1	2.96281003	.22517351	13.158	.0000
E2	2.07186827	.12395918	16.714	.0000
E3	.32174536	.11785216	2.730	.0063
E4	.87299242	.11968023	7.294	.0000
E5	.44366517	.14350161	3.092	.0020
E6	-1.30238282	.13157179	-9.899	.0000
Attributes of Branch Choice Equations (alpha)				
F0	17.9947210	2.24367590	8.020	.0000
F1	-1.18162824	.03970772	-29.758	.0000
F2	-.87585496	.05834861	-15.011	.0000
F3	.88242287	.03682751	23.961	.0000
F4	2.16311478	.28278261	7.649	.0000
IV parameters, tau(j|i,l),sigma(i|l),phi(l)				
NOINJURY	.22340685	.05221631	4.278	.0000
INJURY	4.08320818	.55196595	7.398	.0000

VITA

MING-BANG SHYU

The Pennsylvania State University

2006

Ming-Bang currently serves as a lead researcher in the Transportation Infrastructure Modeling Group (TIMG) headed by Professor Venky Shankar, who is an Associate Professor in the Department of Civil and Environmental Engineering at the Pennsylvania State University. At TIMG Ming-Bang helps maintain medium-scale databases consisting of panel transportation data in excess of 500,000 records and develops customized estimation algorithms to study travel behavior, infrastructure design and performance as well as transportation safety. Ming-Bang's critical responsibilities on research projects include data assembly, statistical modeling and benefit cost analysis for decision models that drive governmental highway infrastructure programming and design policy. Specifically, he provides policy advice for 80-million-dollar transport safety improvement programs in Washington State. In addition, Ming-Bang also helps provide technical assistance on an on-call basis both to research group members and governmental officials for implementing decision models. Ming-Bang also has served as a teaching assistant for introductory transportation engineering classes offered at the junior year level, as well as a teaching assistant in transportation planning classes offered at the senior level. He has gained this experience at two major universities in the U.S., namely, the Pennsylvania State University and the University of Washington, Seattle. In addition, Ming-Bang also has significant exposure to real-world transportation work through projects at private consulting firms. His experiences in these projects span over seven years of transportation work and are geographically diverse. Ming-Bang has worked in Taiwan and in the United States. He served as a transportation engineer and planner in the City-Country Design and Development Research Center, National Central University, Taiwan for three years. This center addressed fairly large-scale transportation planning and engineering issues related to the metropolis of Taipei and surrounding counties. Ming-Bang also joined a consulting firm, Mirai Transportation Planning and Engineering, serving as a transportation engineer in Seattle, WA from 2003 to 2004. Ming-Bang's specialties in research include econometric analysis of transport infrastructure including safety, traffic engineering, geometric design, as well as investment in public works. He has published peer-reviewed journal articles in these areas, with several more in preparation for submission to journals and conferences.

Ming-Bang is joining Mirai Transportation Planning and Engineering in their Kirkland, Washington office and serves as a transportation engineer. He graduated from the undergraduate program in Civil Engineering from National Taipei University of Technology, Taipei, Taiwan, in 1994 and got a Master of Science degree in Transportation Engineering and Planning from University of Salford, Manchester, UK, in 1998 prior to his PhD study.