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ANALYSIS OF ROADSIDE ACCIDENT FREQUENCY AND SEVERITY AND ROADSIDE SAFETY MANAGEMENT

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In Washington State, priority programming for evaluating accident prevention and mitigation (safety improvement) involves analysis of roadside features, but the effects that such features have on the frequency and severity of accidents is not well understood. This study investigated the relationships among roadway geometry, roadside characteristics, and run-off-roadway accident frequency and severity to provide a basis for identifying cost-effective ways to improve highway designs that will reduce the probability of vehicles leaving the roadway and the severity of accidents when they do.

To better understand the effects of roadside features on accident frequency and severity, the researchers surveyed other states' priority programming practices. The survey showed that proactive approaches, in general, are in their infancy, and none of them adequately accounts for the effects of roadside features on accidents.

To quantify the effects of roadside features on accident frequency and severity, the researchers gathered data from the northbound direction of State Route 3 in Washington State. For accident frequency analysis, negative binomial and zero-inflated negative binomial models of monthly accident frequency were estimated. The findings showed both significant differences and similarities in the factors that affect urban and rural accident frequencies. The results indicated that run-off-roadway accident frequencies can be significantly reduced by increasing lane and shoulder widths; widening medians; expanding approaches to bridges; shielding, relocating, and removing roadside hazardous objects; and flattening side slopes and medians. The statistical analysis also provided an estimate of the magnitude of the influence of these factors.

The effects of roadside features on run-off-roadway accident severity were studied with a nested logit model. Roadside features that were found to significantly affect the severity of run-off-roadway accidents included bridges, cut-type slopes, ditches, culverts, fences, tree groups, sign supports, utility poles, isolated trees, and guardrails. As was the case for the frequency analysis, elasticity estimates allowed quantification of the effects of roadside features on accident severity.

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Analysis of Roadside Accident Severity &
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ANALYSIS OF ROADSIDE ACCIDENT FREQUENCY AND SEVERITY AND ROADSIDE SAFETY MANAGEMENT

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EXECUTIVE SUMMARY

In Washington State, priority programming for evaluating accident prevention and mitigation (safety improvement) currently involves the analysis of roadside features, but the effects that such features have on the frequency and severity of accidents are not well understood. The need to better understand the effects of roadside features on accident frequency and severity and to incorporate this knowledge into Washington State Department of Transportation's (WSDOT) priority programming is undeniable. The latest statistics in Washington State indicate that about one-fourth of traffic accidents are associated with vehicles running off the road, and roadside features play a key role in these accidents. Nationally, single vehicle run-off-roadway accidents result in a million highway crashes with roadside features every year, and such accidents account for one third of all highway fatalities, with an estimated societal cost of over $80 billion (NCHRP, 1997).

SURVEY OF STATE TRANSPORTATION DEPARTMENTS

To better understand the effects of roadside features on accident frequency and severity, a survey of other states' priority programming practices was conducted. Although 73 percent of the responding states had methods for inventorying roadside features along roadways, none employed methods for studying the impact of such features on the frequency and severity of accidents. In fact, only 33 percent of the responding states used some type of accident severity analysis methods, and most of these states used safety improvement methods that were reactive, as improvement funds were allocated to locations where severe accidents had previously occurred. Because of the random nature of accidents, reactive methods do not necessarily take into account road design flaws that may exist. In contrast, proactive approaches can improve potentially problematic areas before severe accidents occur. Several state transportation departments recognize the advantages of proactive approaches, and a few have attempted to be proactive in their priority programming (for example, Alabama, Maryland, Oregon, and South Dakota). The survey of state practices showed that proactive approaches, in general, are in their infancy, and none of them adequately accounts for the effects of roadside features on accidents.

EMPIRICAL SETTING

To quantify the effects of roadside features on accident frequency and severity, data were gathered from the northbound direction of State Route 3 in Washington State. Unfortunately, this was the only section of roadway in the state for which WSDOT had the detailed level of roadside feature data required for a rigorous statistical analysis of the effects of roadside features on the frequency and severity of accidents. The studied roadway section consisted of 96.6 kilometers of State Route 3 (SR 3) located 37 kilometers west of Seattle. The reasons that WSDOT selected SR 3 as the first roadside inventory site were that it has varying terrain, its surrounding environment is diverse, and it has both urban and rural sections. To investigate the relationship between run-off-roadway accidents, roadway geometry, and roadside features, databases from three sources were used:

- the WSDOT accident database (MicroCARS);
- the Transportation Information and Planning Support (TRIPS) database, which includes geometric and traffic data; and

- for roadside features, the Roadway Object and Attribute Data (ROAD) inventory system.

Accident data from January 1, 1994, to December 31, 1996, reported on SR 3 were used for the statistical analysis.

ROADSIDE FEATURES AND THE FREQUENCY OF RUN-OFF-ROADWAY ACCIDENTS

The findings showed significant differences in the factors that affect urban and rural accident frequencies. Therefore, estimation results for three separate run-off-roadway accident frequency models are presented (i.e., *Total* sections, *Urban* sections, and *Rural* sections). For accident frequency analysis, the 96.6 kilometers of northbound SR 3 were segmented into 120 equal-length sections of roadway (805 meters long), and the number of accidents per month were used as the dependent variable in model estimation. Negative binomial and zero-inflated negative binomial models of monthly accident frequency were then estimated. While the findings indicated that there were many differences between urban and rural roadway-section accident frequencies, there were also similarities among roadway locations.

The results indicated that run-off-roadway accident frequencies can be significantly reduced by

- increasing lane and shoulder widths;
- widening medians;
- expanding approaches to bridges;
- shielding, relocating, and removing roadside hazardous objects; and
- flattening side slopes and medians.

While these findings are intuitive, the statistical analysis not only identified roadside features that significantly influence accident frequency, but also estimated the magnitude of the influence. For example, using computed elasticities, it was found that a 10 percent increase in median width will result in a 2 percent reduction in accident frequency. This finding and numerous others can be used as a basis for guiding safety priority programming in the state.

ROADSIDE FEATURES AND THE SEVERITY OF RUN-OFF-ROADWAY ACCIDENTS

As with accident frequency, significant differences between urban and rural accident severities were found, and three separate run-off-roadway accident severity models are presented (i.e., *Total* sections, *Urban* sections, and *Rural* sections). The effects of roadside features on run-off-roadway accident severity were studied with a nested logit model. Roadside features that were found to significantly affect the severity of run-off-roadway accidents included the presence of bridges, cut-type slopes, ditches and culverts, fences, tree groups, sign supports, utility poles, isolated trees, and guardrails. As was the case for the frequency analysis, elasticity estimates allowed the effects of roadside features on accident severity to be quantified. For example, when a bridge is present, a run-off-roadway accident is about three times more likely to result in a disabling injury or fatality as when no bridge is present. This and other findings provide important quantitative direction for safety priority programming.

CONCLUSIONS

By accounting for relationships among roadway geometry, roadside characteristics, and run-off-roadway accident frequency and severity, this study provides a basis for identifying cost-effective ways to improve highway designs that will reduce the probability of vehicles leaving the roadway and the severity of accidents when they do. Among other things, the findings quantifiably underscore the importance of keeping vehicles on the roadway and, if this is not possible, improving the placement and design of roadside features to allow sufficient recovery area and to mitigate the severity of the accident. Specific estimates are provided of the magnitude that various safety improvements will have on the frequency and severity of run-off-roadway accidents. These estimates can be used as an important basis for guiding proactive priority programming for highway improvement projects in Washington State.

CHAPTER 1
INTRODUCTION

Roadside safety improvements have been one of Washington State Department of Transportation's (WSDOT) primary research areas. The latest statistics in Washington State indicate that about one-fourth of traffic accidents are associated with vehicles running off the road. For example, 9,903 out of the 44,523 vehicular accidents that occurred in 1994 were related to crashes with roadside fixed objects. The numbers were 10,158 out of 47,028 in 1995, and 11,903 out of 50,635 in 1996. Nationally, single vehicle run-off-roadway accidents result in a million highway crashes with roadside features every year. Such accidents account for one third of all highway fatalities, with an estimated societal cost of over $80 billion (NCHRP, 1997). These statistics on roadside-related vehicular accidents indicate the continued need for research to develop cost-effective countermeasures to reduce the frequency and severity of such accidents.

Rigorous statistical modeling approaches have provided important insights into the effects that roadway features have on the frequency and severity of vehicular accidents, but few have addressed roadside features, which influence run-off-roadway accident experiences. The roadside safety problem is complicated because there are so many variables and external influences, such as changing vehicle fleet, weather conditions, increasing traffic volumes, aggressive driver behavior, right-of-way constraints, infrastructure deterioration, and an aging driver population. This research provides insight regarding where geometry and roadside objects may or may not be more hazardous. The primary objective of this study was to undertake statistical modeling to predict accidents and to address problems at a given area through the use of existing information on roadway geometry and roadside features.

RESEARCH APPROACH

This chapter includes an analysis of the results of a survey sent to state transportation departments across the nation to determine the state-of-the-art and other standards used by other states to conduct and manage roadside inventories. Chapter 2 discusses the effects of roadway geometry and roadside features on run-off-roadway accident frequencies on State Route 3 in Washington State. Poisson regression, negative binomial regression, and zero-inflated regression models are estimated. An overall run-off-roadway accident frequency model for State Route 3 is estimated, followed by other models for accident location (urban or rural sections). Chapter 3 discusses the effects of roadway geometry and roadside features on run-off-roadway accident severity on State Route 3. A sequential estimation procedure was used to develop the nested logit model specified. Similarly, an overall run-off-roadway accident severity model for SR 3 is estimated, and then other models for accident location (urban or rural sections) follow. Chapter 4 completes the study with conclusions and recommendations for future work.

NATIONAL SURVEY OF HIGHWAY SAFETY PROGRAMMING

The WSDOT's method of priority programming for highway safety requires an analysis and inventory of the roadside features throughout a highway corridor. In an attempt to determine the state-of-the-art and other standards used by states to conduct and manage roadside inventories, and to estimate likely accident severities resulting from roadside features, a survey was sent to state traffic safety engineers across the United

States (including Alaska and Hawaii). Out of 51 surveys sent, 35 were returned (a response rate of 68.6 percent). The results of the survey are shown in Table 1, and a copy of the survey form is in Appendix A. Appendix B lists information on the survey contact person for each of the other states.

Seventy-three percent (26 of 35) of the responding states have methods for inventorying the roadside features throughout a highway corridor. Five of the states that responded use a global positioning system (GPS), eight states use video-logging systems, and five states use photo-logging. Alabama uses two road inventory systems, vehicle mounted GPS and video recording equipment. A computerized record is obtained and/or maintained on current roadway lengths, widths, specific events, boundaries, and roadside features. Twelve states use direct field inventory systems that incorporate laptops or roadway inventory sheets. However, their data are not duplicated or stored for distribution. Other methods for the remaining states include straight line diagrams, reference post systems, roadway information management systems (RIMS), and linear referencing systems that are relatively unique to their DOTs.

Of the states that responded, none employ methods for studying the probable severity of an accident on a given highway section. Only thirty-three percent (11 of 35) of the responding states have accident severity analysis methods. Alaska's DOT uses the highway safety improvement program (SIP) to address severe accident severity locations. Delaware's DOT uses the critical rate method to identify high accident locations, and this is similar to Florida and Indiana's analysis methods. However, their safety improvement methods are reactive, as improvement funds are allocated to locations where severe accidents have previously occurred. Because of the random nature of accidents, reactive methods do not necessarily take into account road design flaws that may exist. In contrast, proactive approaches would improve potentially problematic areas before severe accidents occurred. For example, Alabama has a program that computes the severity index of various roads, segments, and intersections on the basis of the number of accidents that have occurred throughout its highway network. Maryland's DOT uses a severity prediction method based on the features within a section, and Oregon provides reduction factors for specific substandard roadside features or road design flaws. Similarly, South Dakota's DOT uses a hazard elimination and safety (HES) program. It studies each location that has five or more accidents to determine the type of accident, accident rate, probable cause of accident, possible countermeasures, and estimated cost of improvements.

From the survey findings, it was possible to assess the advantages and disadvantages of other states' procedures. This assessment showed clearly that proactive approaches that account for the effects of roadside features on accidents are in their infancy. There is much need and room for improvement, and this research was intended to provide a methodological example of an advanced proactive approach for allocating safety funds.

Table 1. Results of the national DOT survey

States	Methods For Collecting Roadside Inventory						Accident Severity Analysis Methods
	Yes/ No	GPS	**Video Log**	Photo Log	Field Inventory	Other	
Alabama	Yes	√	√				Severity Index Program
Alaska	Yes				√		Highway Safety Improvement Program
Arizona	Yes			√			
Colorado	Yes				√		
Connecticut	Yes				√		
Delaware	Yes			√			Critical Rate Method
Florida	No						Eliminate the occurrence of crash
Georgia	Yes			√			
Hawaii	Yes			√	√	Straight Line Diagram	Traffic Accident Records System
Idaho	Yes		√				
Illinois	No						
Indiana	Yes		√			Reference Post System	Identification of Intersection with frequency of crashes
Kentucky	Yes				√		
Louisiana	Yes				√		
Maryland	Yes		√				Severity Prediction Method
Massachusetts	Yes				√		
Michigan	Yes			√			
Minnesota	No						
Mississippi	No						
Nebraska	Yes		√				
New Hampshire	Yes	√					
New Jersey	Yes		√				
New York	Yes				√		Roadside Obstacle Methodology
North Dakota	Yes				√	RIMS	
Ohio	No						
Oklahoma	Yes		√		√		
Oregon	Yes				√		Reduction Factor
Pennsylvania	Yes		√		√		
South Carolina	No						Severity Index
South Dakota	Yes	√					HES program
Texas	No						
Utah	Yes	√					
Washington	Yes	√				Linear Referencing System	
West Virginia	No						
Wisconsin	No						

CHAPTER 2
STATE ROUTE 3 RUN-OFF-ROADWAY ACCIDENT FREQUENCY

Roadside safety improvements have historically been allocated to locations where run-off-roadway accidents have previously occurred. This reactive method of improving areas means that safety practitioners must wait for a series of accidents to occur and may not necessarily take into account road design flaws that may exist. A proactive approach would improve potentially problematic areas before severe accidents and the damage associated with run-off-roadway accidents had occurred.

Because of the high cost of collecting roadside feature data, a methodology for accurately predicting run-off-roadway accidents has not been developed. The lack of data to support statistical modeling of run-off-roadway accidents led WSDOT to collect roadside feature data to identify potentially severe roadside conditions. These data were collected on 96.6 kilometers of the northbound direction of State Route 3 (SR 3) located 37 kilometers west of Seattle, Washington.

Using these data, a statistical model was developed to predict run-off-roadway accidents for SR 3 and to isolate the factors that contribute to run-off-roadway accident frequencies.

Below is a review of previous literature on accident frequencies. On the basis of previous efforts, some methodological directions for modeling run-off-roadway accident frequencies are described. Following this, the empirical setting and data of this study are detailed, then model estimation results and a summary of the findings are presented.

LITERATURE REVIEW

Numerous studies have been conducted to investigate the relationships between vehicle accidents and the geometric design of roadways. These studies have indicated that improvements to highway geometric design could significantly reduce the number of vehicular accidents. For example, Hamerslag, Roos, and Kwakernaak (1982) studied how the expected number of accidents depends on road and traffic characteristics. In other work (Okamoto and Koshi, 1989), linear regression has been used to model relationships between accident rates and the geometric design of roads. Miaou, Hu, Wright, Rathi, and Davis (1992) established empirical relationships among truck accidents and key highway geometric design components by using a Poisson regression approach. They found that annual average daily traffic per lane, horizontal curvature, and vertical grade were significantly correlated with truck accident rates. More comprehensive accident studies associated with roadway geometry have also been conducted. The effects of lane and shoulder widths (Zegeer *et al.*, 1981), paved shoulders (Ogden, 1997), traffic volume (Zhou and Sisiopiku, 1997), median width (Knuiman, Council and Reinfurt, 1993), and horizontal curves (Fink and Krammes, 1995, Council, 1998) on accident frequencies and rates were also investigated.

Even though previous work has provided insight into the impacts of geometric design on accident frequency, studies of factors that influence run-off-roadway accidents have been less successful. Furthermore, very little attention has been paid to the relationships between run-off-roadway accident frequency and roadside features. Recent national statistics indicate that about one-third of fatal traffic crashes are associated with vehicles running off the road (FHWA, 1998). These statistics on run-off-roadway vehicular accidents indicate the continued need for research to develop cost-effective ways to reduce run-off-roadway accident frequency.

To reduce the likelihood of accidents caused by roadside features, a number of general roadside safety studies have been conducted. Mak (1995) presented a general discussion on the safety effects of roadside design decisions, including the extent of the problem, safety improvement priorities, safety relationships, and cost-effectiveness analysis. To improve roadside safety, Ray, Carney and Opiela (1995) discussed general safety issues, such as better understanding of crash characteristics, accommodating a continually changing vehicle fleet, analyzing crash potentials, selecting effective safety treatments, and making use of new technologies.

Several run-off-roadway accident studies have examined particular roadside features, such as roadway guardrail systems (Gattis, Varghese and Toothaker, 1993, Michie and Bronstad, 1994, Reid *et al.,* 1997, Faller *et al.,* 1998) or the effects of luminaire poles on vehicle impacts (Kennedy, 1997). Other studies have examined accidents involving collisions with bridges (Turner, 1984), utility poles (Zegeer and Cynecki, 1982, Good, Fox and Joubert, 1987), side slopes and ditches (Viner, 1995a), sign supports (Mauer *et al.,* 1997), and roadway safety fences (Bateman *et al.,* 1998). A recent study by Ray (1999) examined the best available accident data to determine the most reasonable worst-case test impact conditions for side-impacts with fixed roadside objects such as utility poles, guardrail terminals, and luminaire poles. Wolford and Sicking (1997) quantified guardrail needs as a safety treatment option to shield traffic from roadside embankments and large roadside culverts. Zegeer and Council (1995) studied the relationships between accident experience and cross-sectional roadway elements on two-lane roads. They estimated the reduction in accident rates resulting from roadside improvements that included cutting trees near the roadway, relocating utility poles farther from the road, and using flatter side slopes.

However, the lack of roadside data for estimating rigorous statistical models has been a major obstacle of roadside safety research for many years, making it difficult to predict vehicular run-off-roadway accident frequency. Noteworthy efforts have been made even though data limitations have compromised research results. Hadi *et al.* (1995) used a negative binomial regression analysis to estimate the effects of cross-sectional design elements and found that increasing lane width, shoulder width, center shoulder width, and median width were significant in reducing accidents. Council and Stewart (1996) attempted to develop severity indexes for various fixed objects that are struck when vehicles leave the roadway. Miaou (1997) estimated some of the basic encroachment parameters such as AADT, lane width, horizontal curvature, and vertical grade without actually field-collecting data because the required cost of roadside data collection was prohibitively expensive. Miaou's study reinforced the need to statistically estimate a model of vehicle roadside encroachment frequencies.

In terms of methodological perspectives, many applications of accident frequency statistical modeling have been undertaken. Jovanis and Chang (1986), Joshua and Garber (1990), and Miaou and Lum (1993) demonstrated that conventional linear regression models are not appropriate for modeling vehicle accident events on roadways, and test statistics from these models are often erroneous. They concluded that Poisson and negative binomial regression models are a more appropriate tool in accident modeling. The inadequacy of linear regression models in uncovering the relationship between vehicular accidents and roadway characteristics has led to numerous Poisson and negative binomial regression model applications (Shankar, Mannering and Barfield, 1995, Poch and Mannering, 1996, Milton and Mannering, 1998).

Shankar, Mannering and Barfield (1995) used both the Poisson (when the data were not significantly overdispersed) and negative binomial regression models (when the data were overdispersed) to explore the frequency of rural freeway accidents with information on roadway geometry and weather-related environmental factors. Separate regressions of specific accident types, as well as overall accident frequency, were modeled. The estimation results showed that the negative binomial regression model was the appropriate model for all accident types, with the exception of those involving overturned vehicles. Poch and Mannering (1996) demonstrated that negative binomial regression (applied to intersection approach accidents) was the appropriate model for isolating the traffic and geometric elements that influence accident frequencies. Milton and Mannering (1998) also used the negative binomial regression model as a predictive tool to evaluate the relationship among highway geometry, traffic-related elements, and motor-vehicle accident frequencies.

Shankar, Milton and Mannering (1997) argued that traditional application of Poisson and negative binomial models did not address the possibility of zero-inflated counting processes. They distinguished the truly safe road section (zero accident state) from the unsafe section (non-zero accident state but with the possibility of having zero observed accidents) to show that a zero-inflated model structure is often appropriate for estimating the accident frequency of road sections (Mullahey 1986, Lambert 1992, Greene 1997). Zero-inflated probability processes, such as the zero-inflated Poisson

(ZIP) and zero-inflated negative binomial (ZINB) regression models, allow one to better isolate independent variables that determine the relative accident likelihoods of safe versus unsafe roadways. In other work, Miaou (1994) evaluated the statistical performance of three types of models (Poisson regression, negative binomial regression, and zero-inflated Poisson regression) in studying the relationship between truck accidents and the geometric design of road sections. Miaou recommended that the Poisson regression model is an appropriate model for developing the relationship when the mean and variance of the accident frequencies are approximately equal. If the overdispersion is found to be moderate or high, the use of both the negative binomial regression and zero-inflated Poisson regression were found to be more appropriate. However, on the whole, the zero-inflated Poisson regression model seems a justified model when accident data exhibit a high zero-frequency state.

In many applications, the zero outcome of the data is undoubtedly different from the non-zero ones (Greene, 1994, 1998). Ignoring the possibility of a zero outcome state leads to biased estimation of Poisson and negative binomial regression coefficients.

REVIEW OF ACCIDENT FREQUENCY ANALYSIS METHODOLOGY

To demonstrate the application of a Poisson regression in accident frequency analysis, consider a set of i road sections. Let n_{ij} , a random variable, be the number of run-off-roadway accidents during a one-month period, j,

$$P(N_{ij} = n_{ij}) = P(n_{ij}) = \frac{\exp(-\lambda_{ij})\lambda_{ij}^{n_{ij}}}{n_{ij}!} \tag{2.1}$$

where $P(n_{ij})$ is the probability of n run-off-roadway accidents occurring on a highway section i in month j, and

λ_{ij} is the expected value of n_{ij},

$$E(n_{ij}) = \lambda_{ij} = exp(\beta X_{ij}) \tag{2.2}$$

for a roadway section i in month j, β is a vector of unknown regression coefficients and can be estimated by standard maximum likelihood methods (Greene, 1997). X_{ij} describes roadway section geometric characteristics and other relevant roadside feature conditions for highway section i in month j.

A limitation of the Poisson distribution is that the variance and mean must be approximately equal (Maddala, 1977, Cox, 1983, Agresti, 1996). The possibility of overdispersion (having variance exceeding the mean, rather than equaling the mean as the Poisson requires) is always a concern in modeling accident frequency and may result in biased, inefficient coefficient estimates. The simple regression-based test by Cameron and Trivedi (1986, 1990) can be performed to detect overdispersion in the Poisson process. This regression-based test involves simple least-squares regression to test the significance of the overdispersion coefficient.

To relax the overdispersion constraint imposed by the Poisson model, a negative binomial distribution with a Gamma-distributed error term is commonly used (Miaou, 1994, Shankar *et al.,* 1995, Milton and Mannering, 1998, Carson, 1998). The negative binomial model is derived by rewriting equation 2.2 such that,

$$\lambda_{ij} = exp(\beta X_{ij} + \varepsilon_{ij}) \tag{2.3}$$

where $exp(\varepsilon_{ij})$ is a Gamma-distributed error term, and this addition allows the variance to exceed the mean as below:

$$Var[n_{ij}] = E[n_{ij}][1+\alpha E[n_{ij}]] = E[n_{ij}] + \alpha E[n_{ij}]^2 \tag{2.4}$$

The Poisson regression model is regarded as a limited model of the negative binomial regression model as α approaches zero, which means that the selection between these two models is dependent upon the value of α. The negative binomial distribution has the following formulation:

$$P(n_{ij}) = \frac{\Gamma((1/\alpha)+n_{ij})}{\Gamma(1/\alpha)n_{ij}!}\left(\frac{1/\alpha}{(1/\alpha)+\lambda_{ij}}\right)^{1/\alpha}\left(\frac{\lambda_{ij}}{(1/\alpha)+\lambda_{ij}}\right)^{n_{ij}} \tag{2.5}$$

Standard maximum likelihood methods can be used to estimate λ_i (Greene, 1997). Using equation 2.5, the likelihood function for the negative binomial regression model is,

$$L(\lambda_{ij}) = \prod_{i=1}^{N}\prod_{j=1}^{T} \frac{\Gamma((1/\alpha)+n_{ij})}{\Gamma(1/\alpha)n_{ij}!}\left[\frac{1/\alpha}{(1/\alpha)+\lambda_{ij}}\right]^{1/\alpha}\left[\frac{\lambda_{ij}}{(1/\alpha)+\lambda_{ij}}\right]^{n_{ij}} \tag{2.6}$$

where N is the total number of roadway sections, and

T is the last month of run-off-roadway accident data.

This maximum likelihood function is used to estimate the unknown parameters, β and $1/\alpha$.

To address the possibility of zero-inflated accident counting processes on roadway sections, the zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) regression models have been developed for handling zero-inflated count data. Both zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) assume that two different processes are at work for some zero accident count data. The zero-inflated Poisson (ZIP) assumes that the events, $Y = (Y_1, Y_2, \ldots\ldots, Y_n)'$ are independent and

$$Y_i = 0 \text{ with probability } p_i + (1 - p_i)e^{-\lambda} \tag{2.7}$$

$$Y_i = y \text{ with probability } (1 - p_i)e^{-\lambda i}\lambda_i^y/y!, \quad y = 1, 2, \ldots\ldots \tag{2.8}$$

where y is the number of run-off-roadway accidents, and the mean and variance of Y_i can be shown to be

$$E(Y_i) = (1 - p_i)\,\lambda_i^y \qquad (2.9)$$

$$Var(Y_i) = E[Y_i] + \frac{p_i}{1-p_i} E[Y_i]^2 \qquad (2.10)$$

The maximum likelihood estimates (MLEs) are used to estimate the coefficients of a zero-inflated Poisson (ZIP) regression model, and confidence intervals can be constructed by likelihood ratio tests.

The zero-inflated negative binomial (ZINB) regression model follows a similar formulation and assumes that the events, $Y = (Y_1, Y_2, \ldots\ldots, Y_n)'$ are again independent and

$$Y_i = 0 \text{ with probability } p_i + (1 - p_i)\left[\frac{1/\alpha}{(1/\alpha)+\lambda_i}\right]^{1/\alpha} \qquad (2.11)$$

$$Y_i = k \text{ with probability } (1 - p_i)\left[\frac{\Gamma((1/\alpha)+k)\,u_i^{1/\alpha}(1-u_i)^k}{\Gamma(1/\alpha)k!}\right] \quad , k = 1, 2, \ldots\ldots \qquad (2.12)$$

Maximum likelihood methods are again used to estimate the coefficients of a zero-inflated negative binomial (ZINB) regression model.

The choice of an appropriate accident frequency model for road sections with zero-accident involvement is critical. However, one cannot directly test whether a zero-accident state and the non-zero accident state are totally different because the traditional Poisson or negative binomial model and the zero-inflated model are not nested. To test the appropriateness of using a zero-inflated model rather than traditional model, Vuong (1989) proposed a test statistic for non-nested models that is well suited for this setting when the distribution can be specified. Let $f_j(y_i/x_i)$ be the predicted probability that the random variable Y equals y_i under the assumption that the distribution is $f_j(y_i/x_i)$, for $j = 1$, 2, and let

$$m_i = \log\left(\frac{f_1(y_i|x_i)}{f_2(y_i|x_i)}\right) \tag{2.13}$$

where $f_1(y_i/x_i)$ is the probability density function of the zero-inflated model, and

$f_2(y_i/x_i)$ is the probability density function of the Poisson or negative binomial distribution.

Then Vuong's statistic for testing the non-nested hypothesis of zero-inflated model versus traditional model is (Greene, 1997, Shankar *et al.,* 1997),

$$v = \frac{\sqrt{n}\left[(1/n)\sum_{i=1}^{n} m_i\right]}{\sqrt{(1/n)\sum_{i=1}^{n}(m_i - \overline{m})^2}} = \frac{\sqrt{n}(\overline{m})}{S_m} \tag{2.14}$$

where $\overline{m}$ is the mean,

S_m is standard deviation, and

n is a sample size.

Vuong's value is asymptotically standard normally distributed, and if $|v|$ is less than 1.96 (the 95 percent confidence level for the *t*-test), the test does not indicate any other model. However, the zero-inflated regression model is favored if the v value is greater than 1.96, while a v value of less than –1.96 favors the Poisson or negative binomial regression model (Greene, 1997).

ACCIDENT FREQUENCY ANALYSIS

Empirical Setting

The study area consisted of 96.6 kilometers of State Route 3 (SR 3) located 37 kilometers west of Seattle. SR 3 is a principal arterial and has the majority of features that WSDOT has identified for the Road Object and Attribute Data (ROAD) inventory system. The reasons SR 3 was selected as the first roadside inventory site were that it has varying terrain, the surrounding environment is diverse, and it has both urban and rural sections. Figure 1 shows the region from Shelton to Port Gamble in western Washington along SR 3.

To investigate the relationship between run-off-roadway accidents, roadway geometry, and roadside features, databases from three sources were used. Accident characteristics were obtained using the WSDOT accident database MicroCARS. Only run-off-roadway accidents involving roadside features were used in this study. For run-off-roadway accident frequency analysis, accident data from January 1, 1994, to December 31, 1996, reported on SR 3 were used. Multi-vehicle crashes were excluded, and most of the data were from cases in which a vehicle struck only a single roadside object.

The Transportation Information and Planning Support (TRIPS) system of WSDOT includes geometric and traffic data that can be used to study run-off-roadway accident frequency. The TRIPS system includes roadway geometric data such as lane, shoulder, median, intersections, and vertical or horizontal alignment and also reports traffic data such as traffic volume, truck volume as a percentage of AADT, peak hour volume, and legal speed limit.

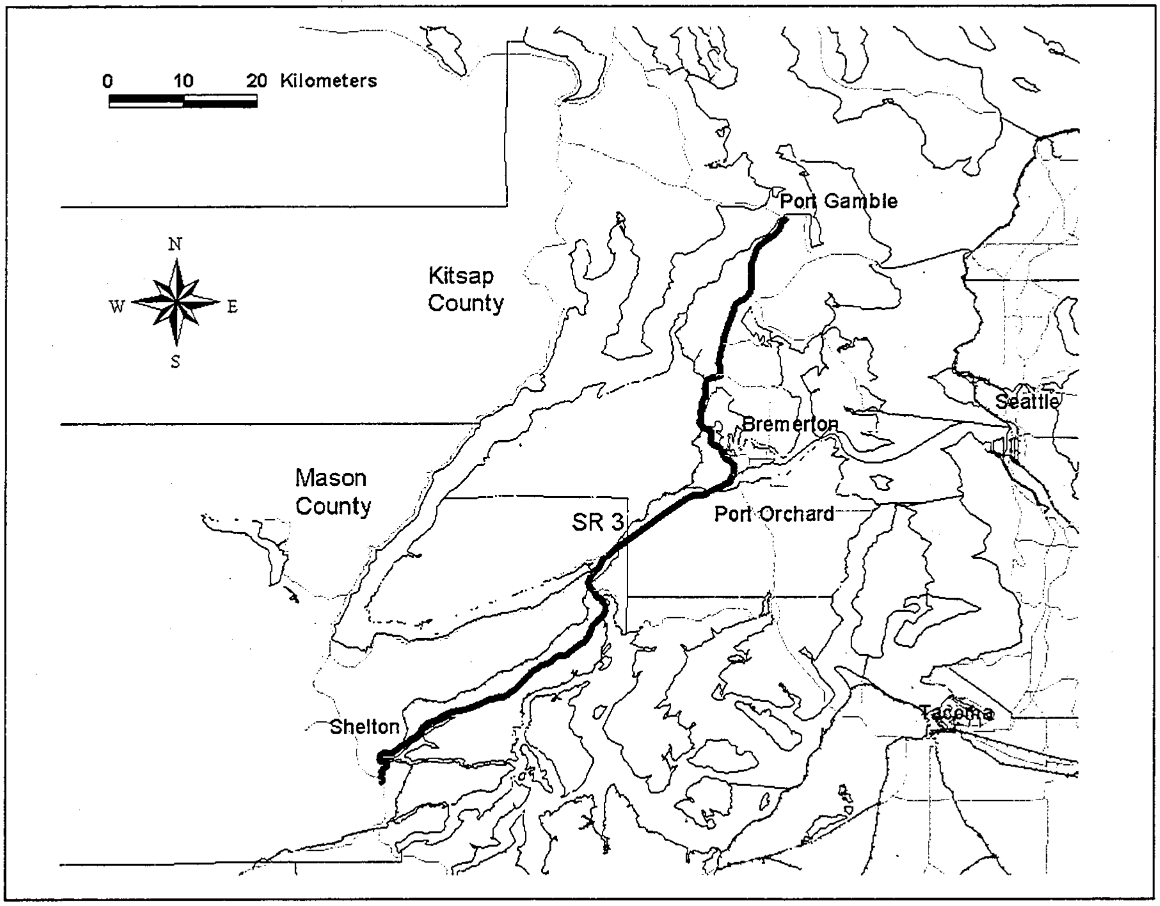

Figure 1. SR 3 Vicinity

For roadside features, the Roadway Object and Attribute Data (ROAD) inventory system was used. This inventory system focuses on the collection of specific roadside objects identified by the Federal Highway Administration (FHWA), the University of North Carolina Highway Safety Research Center, and WSDOT. Roadside data were collected with a global positioning system (GPS) over a period from May 1998 to September 1998. Accumulated route miles (ARM) were established with GPS and were assigned to each roadside feature that WSDOT collected. All attributes for the various features were entered into the roadside database while in the field, and queries of all location data were developed and validated in the Transportation Data Office (TDO) in WSDOT before the data were downloaded into the database.

In terms of roadside data collection, data were collected in the roadside zone area, which is the area between the outside shoulder edge and the right-of-way limits. WSDOT has established some guidelines for minimum distance inventoried in roadside zones. The guidelines are that if the speed limit is greater than 72.4 km/h, the minimum distance of the roadside zone is from the outside shoulder edge to 45.7 meters or to boundary objects (whichever is shorter); if the speed limit is less than 72.4 km/h, the minimum distance of the roadside zone is from the outside shoulder edge to 36.6 meters or to boundary objects. The actual widths inventoried for roadside zones depend a great deal on the conditions in the field. These include urban or rural location, degree of slope, and distance to boundary object such as continuous tree group, water, rock wall, building, and other obstructions through which a vehicle could not pass. Finally, some important data, such as bridge width, presence or absence of a median barrier or embankment, and ditch type or ditch width, were not contained in existing ROAD databases. Collection of such data is recommended for future data collection efforts.

To analyze the relationships between run-off-roadway accident frequency, roadway geometry, and roadside features, the three databases were integrated into one. The data were then segmented into 120 equal sections 805 meters long over the 96.6 kilometers of SR 3. Shankar, Mannering and Barfield (1995) addressed issues related to roadway section length determination. They found that the disadvantages of using fixed-length sections are far less severe than those of using homogeneous sections (an obvious alternative). The unequal lengths of homogeneous sections may exacerbate potential heteroskedasticity problems and result in a loss in model estimation efficiency. As a result of their findings, equal fixed-length sections were used.

Because of an absence of roadside data on the southbound direction of SR 3, only northbound run-off-roadway accident frequencies were considered. A total of 489 run-off-roadway accidents were reported on northbound SR 3 in 1994, 1995, and 1996. Figure 2 shows run-off-roadway accident frequencies by section during these three years. Sections are numbered sequentially from south to north in the study area. Among the 120 study sections, frequencies of run-off-roadway accidents were highest in section 70.

Crashes with roadside objects between January 1, 1994,and December 31, 1996, in this area are classified in Table 2 and Figure 3. The table lists crashes with various types of first-struck roadside objects. Guardrails, earth banks, ditches, and trees were the objects most often first-struck, accounting for over half of the first-struck crashes.

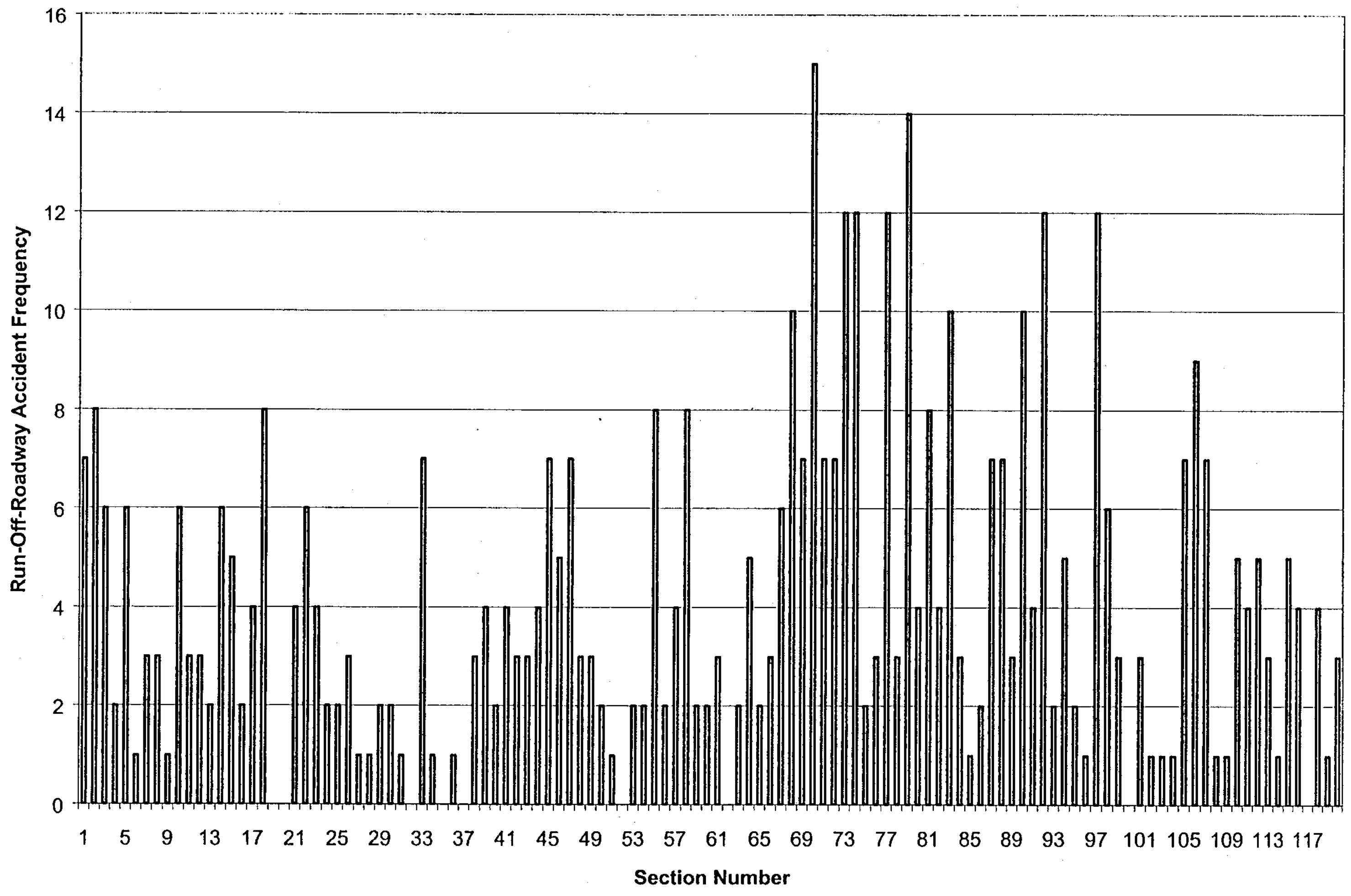

Figure 2. Run-Off-Roadway Accident Frequencies on State Route 3, 1994-1996.

Table 2. Crashes with roadside objects along SR 3 (% in parentheses)

Roadside Object	Number of crashes
Guardrail	57 (15.36)
Earth Bank	55 (14.82)
Ditch	42 (11.32)
Tree	42 (11.32)
Concrete Barrier	38 (10.24)
Over Embankment	31 (8.36)
Utility Pole	20 (5.39)
Wood Sign Support	19 (5.12)
Bridge Rail	17 (4.58)
Culvert	7 (1.89)
Boulder	6 (1.62)
Luminaire	6 (1.62)
Mailbox	5 (1.35)
Fence	5 (1.35)
Building	5 (1.35)
Other Object	4 (1.08)
Into River, Lake, Swamp	2 (0.54)
Rock Bank or ledge	2 (0.54)
Retaining Wall	2 (0.54)
Snow Bank	1 (0.27)
Fallen Tree or Rock	1 (0.27)
Temporary Traffic Sign	1 (0.27)
Traffic Signal Pole	1 (0.27)
Guide Post	1 (0.27)
Other objects which not stated	1 (0.27)

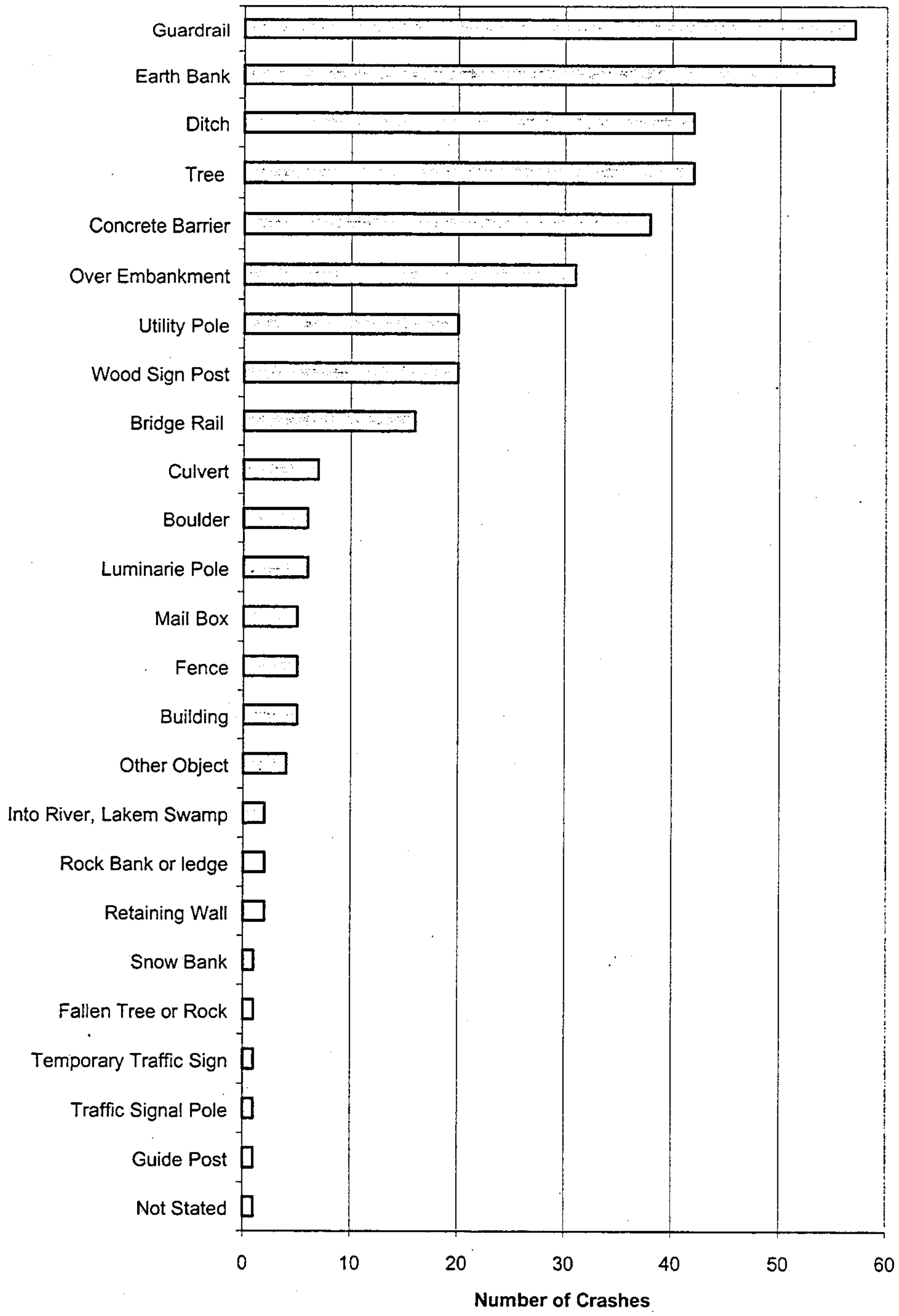

Figure 3. Objects Struck in Run-Off-Roadway Accidents

For the forthcoming model estimation, run-off-roadway accidents were sorted by year and month and integrated with roadway geometry and roadside feature data into one database. Data were classified into three types of run-off-roadway accident frequencies per month: all types, urban, and rural.

Table 3 shows the summary statistics of roadway geometry and roadside features used in this study. The mean frequency of *Total* section run-off-roadway accidents per month was 0.11, with an observed monthly minimum of zero and maximum of 9. The mean frequencies per month were virtually identical for urban and rural sections. Average general features consisted of two counties (*Kitsap* and *Mason*), a 3.8-meter median width, 3.64-meter lanes in the northbound direction with a 1.21-meter center shoulder width, a 1.79-meter shoulder width, and a 84.1-km/h legal speed limit. While there were many different distances from outside shoulder edge to roadside features, features most often closest to the roadway were, in order, guardrails, ditches, luminaire poles, sign supports, and fences. Objects farthest away from the roadway included utility poles, isolated trees, tree groups, miscellaneous fixed objects, and side slopes. Figure 4 shows the average distance from outside shoulder edge to roadside features. Data elements for run-off-roadway accident frequency are also shown in Appendix C.

Model Estimation

The effects of roadway geometry and roadside characteristics on run-off-roadway accident frequency were studied with a number of econometric models. Previous research has shown that conventional linear regression is not appropriate for estimating the relationships among run-off-roadway accident frequency, roadway geometry, and

Table 3. Summary statistics of roadway geometry and roadside features

Variable	Mean	Min.	Max.	Standard Deviation
Total section run-off-roadway accident frequency (per month)	0.11	0	9	0.37
Urban section run-off-roadway accident frequency (per month)	0.06	0	9	0.27
Rural section run-off-roadway accident frequency (per month)	0.06	0	6	0.25
PDO run-off-roadway accident frequency (per month)	0.07	0	8	0.28
Possible injury run-off-roadway accident frequency (per month)	0.02	0	5	0.14
Evident injury run-off-roadway accident frequency (per month)	0.02	0	2	0.15
Disabling injury or *fatality* run-off-roadway accident frequency (per month)	0.01	0	1	0.08
Lane width (in meters)	3.64	1.93	5.89	0.38
Shoulder width (in meters)	1.79	0.49	3.17	0.85
Center shoulder width (in meters)	1.21	0	3.05	0.56
Shoulder length (in meters)	1590	970	1610	80
Median width (in meters)	3.77	0	20.73	6.09
Legal speed limit (in km/h)	84.10	42.53	96.56	12.20
Number of vertical curves	2.61	0	9	2.16
Vertical curve length (in meters)	78.14	0	426.72	78.18
Vertical grade	0.80	0	3.04	0.72
Average annual daily traffic (AADT) per lane	2,194	988	6,522	998
Number of intersections	1.19	0	7	1.47
Guardrail length (in meters)	48.28	0	634.06	112.65
Distance from outside shoulder edge to guardrail (in meters)	0.67	0	5.05	1.11
Guardrail height (in meters)	0.20	0	1.52	0.33
Number of catch basins	0.93	0	15	2.76
Number of culverts	0.28	0	6	0.99
Ditch length (in meters)	80	0	1600	230
Distance from outside shoulder edge to ditch (in meters)	0.69	0	9.45	1.75
Ditch depth (in meters)	0.09	0	0.81	0.22
Fence length (in meters)	10	0	360	50
Distance from outside shoulder edge to fence (in meters)	1.06	0	14.07	2.83
Bridge length (in meters)	10	0	420	50
Slope length (in meters)	110	0	1050	230
Distance from outside shoulder edge to side slopes (in meters)	1.10	0	8.89	2.03
Number of miscellaneous fixed objects	0.7	0	9	1.68
Distance from outside shoulder edge to miscellaneous fixed object (in meters)	1.19	0	17.07	2.79
Number of utility poles	3.83	0	32	6.75
Distance from outside shoulder edge to utility pole (in meters)	1.92	0	11.79	2.91
Number of sign supports	1.9	0	24	4.22
Distance from outside shoulder edge to sign support (in meters)	0.97	0	12.44	2.05
Number of luminaire poles	0.76	0	30	3.27
Distance from outside shoulder edge to luminaire poles (in meters)	0.83	0	8.23	1.97
Number of tree groups	1.66	0	26	4.16
Distance from outside shoulder edge to tree group (in meters)	1.32	0	17.8	3.11
Number of isolated trees	0.55	0	9	1.57
Distance from outside shoulder edge to isolated tree (in meters)	1.54	0	18.39	3.83

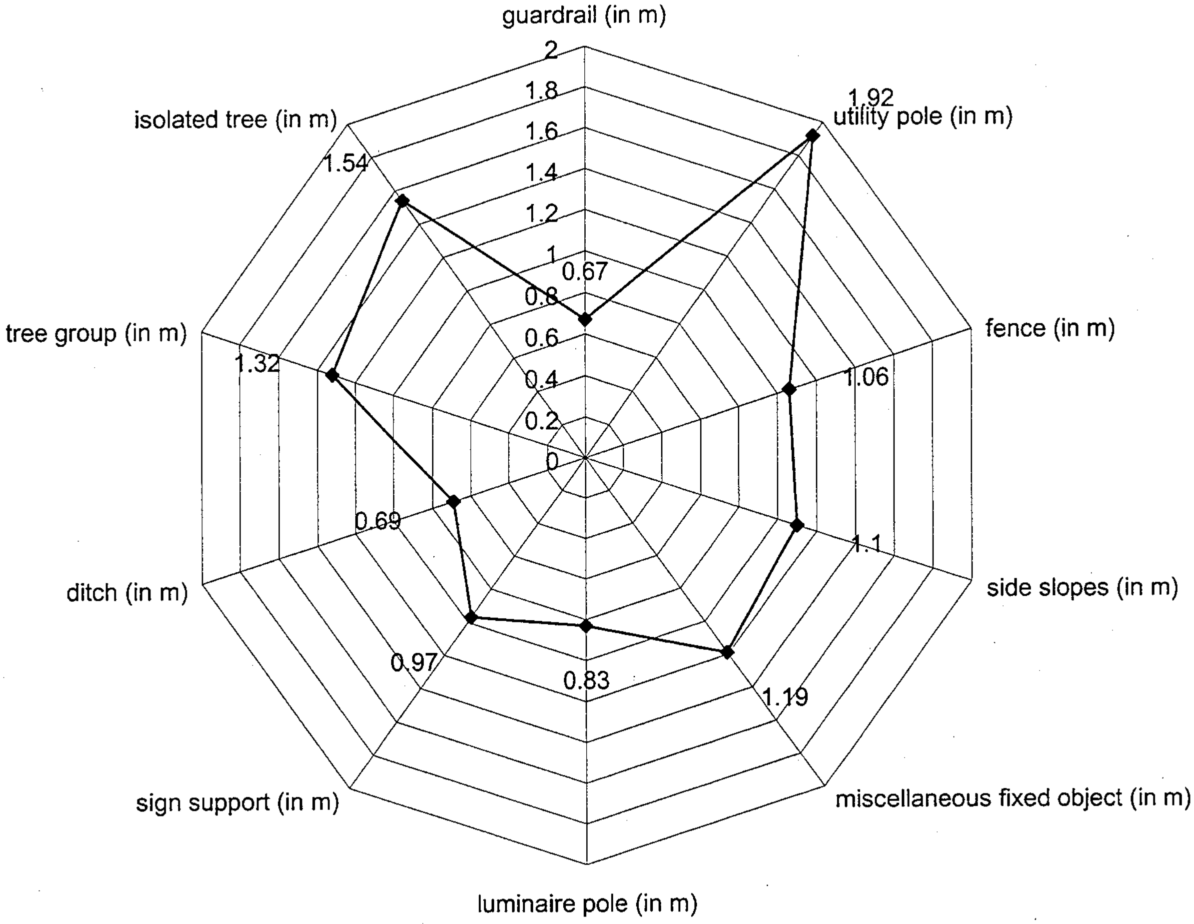

Figure 4. Average Distance from the Outside Shoulder Edge.

roadside features. Poisson or negative binomial regression (for overdispersed data) is a more proper analysis approach. However, when a preponderance of zeros exists in the accident frequency data, zero-inflated Poisson or zero-inflated negative binomial regression models are more suitable. For run-off-roadway accident frequency, for the three models that were estimated (total sections, urban sections, and rural sections), a decision rule was needed to select the appropriate model form (Shankar, Milton and Mannering, 1997, Carson 1998). The regression-based test for overdispersion by Cameron and Trivedi (1986, 1990) can determine the appropriateness of negative binomial regression models over Poisson regression models, and a Vuong's test statistic is suitable for testing the appropriateness between the zero-inflation model and the traditional Poisson or negative binomial regression.

This decision rule was adopted in selecting the proper econometric method for the seven run-off-roadway accident frequency models. First, an overall run-off-roadway accident frequency model for State Route 3 (SR 3) was selected. For *Total* section run-off-roadway accident frequency analysis along SR 3, the negative binomial regression model was appropriate. The overdispersion parameter α is statistically significant (*t*-statistic of 3.592), indicating the appropriateness of the negative binomial regression model rather than Poisson regression model to estimate model coefficients. This was validated when the zero-inflated negative binomial model specification failed to provide a statistically better fit (the Vuong statistic < 1.96, which corresponds to the 95 percent confidence limit of the *t*-test). Zero-inflation was not confirmed (the Vuong statistic of 0.3331), indicating the appropriateness of the negative binomial regression model over the zero-inflated negative binomial model. In the zero-inflated model, the overdispersion parameter α also turned out to be significant (t-statistic of 3.387). Accordingly, the negative binomial regression was appropriate. The model results for the negative binomial specification for *Total* section run-off-roadway accident frequency are given in Table 4. It shows that all variables were statistically significant and of plausible sign. These variables provide important insights into the tendency to increase or decrease *Total* section run-off-roadway accident frequency and are discussed below.

Variable : Summer month indicator

The summer month indicator shows that accident frequency for *Total* sections during the summer season was lower. This could be because daylight in summer months lasts longer than in winter months, and seasonal trends associated with summer—such as good visual effects and dry pavements—reduce the run-off-roadway accident frequency for *Total* sections.

Variable : Winter month indicator

The winter month indicator had a positive effect, thus tending to increase the likelihood of *Total* section run-off-roadway accident frequency. This finding represents the overall effects associated with rainfall or snowfall. Loss of visibility and loss of vehicle control as a result of foul weather during the winter season can increase run-off-roadway accident frequency for *Total* sections. Some highway maintenance includes a skid resistance system to prevent unusual accidents on the snowy and wet pavements caused by traditional cold weather.

Table 4. Negative Binomial Estimation Results (*Total* section run-off-roadway monthly accident frequency)

Variable	Estimated Coefficients	t-statistic
Constant	-1.699	-6.020
Temporal characteristics		
Summer month indicator (1 if June, July, August, or September, 0 otherwise)	-0.376	-1.874
Winter month indicator (1 if November, December or January, 0 otherwise)	0.280	1.680
Spatial characteristics		
Geographic indicator (1 if *Kitsap* County, 0 otherwise)	0.794	4.329
Traffic characteristics		
High traffic indicator (1 if AADT per lane is over 2,500 vehicles, 0 otherwise)	0.819	2.612
Roadway characteristics		
Center shoulder width (in meters)	-0.098	-2.631
Central angle of the horizontal curve in a section (in degrees)	0.0001	3.779
Number of lanes in a section	-0.291	-2.910
Number of vertical curves in a section	0.131	4.323
Number of vertical grade warning signs in a section	-0.092	-1.944
Shoulder width (in meters)	-0.118	-3.050
Roadside characteristics		
Bridge indicator (1 if the presence of bridges, 0 otherwise)	0.388	3.537
Distance from outside shoulder edge to miscellaneous fixed objects (in meters)	-0.017	-2.333
Fence length (in meters)	5.179	3.178
Number of tree groups in a section	0.030	1.944

Table 4. Negative Binomial Estimation Results (*Total* section run-off-roadway accident frequency) (Continued)

Variable	Estimated Coefficients	t-statistic
Dispersion parameter α	0.764	3.592
Restricted Log-likelihood	-1531.55	
Log-likelihood at Convergence	-1522.09	
Number of Observations	4,320	

Variable : Geographic indicator

Kitsap County had higher run-off-roadway accident frequencies. This could be because SR 3 in *Kitsap* County is almost completely in urbanized areas, and the high traffic densities typically observed in urban areas are likely to increase run-off-roadway accidents.

Variable : High traffic indicator

It is not surprising that, if average annual daily traffic per lane exceeds 2,500 vehicles per lane, *Total* section run-off-roadway accident occurrences increase because accident exposure increases with higher traffic volumes. However, research has shown that the correlation between traffic flow and accident probability generally follows a U-shape (McShane and Roess, 1990). Accordingly, accident probabilities are assumed to be highest with very low traffic volume, to decrease as traffic volumes increase, and then to increase again as traffic flow increases further. Evidence was found only for the increase in run-off-roadway accidents for higher volumes on SR 3.

Variable : Shoulder width, Center shoulder width

Increasing shoulder widths and center shoulder widths produced lower *Total* section run-off-roadway accident rates on SR 3. Broad shoulders are effective at decreasing accidents on highways because they allows drivers to bring out-of-control vehicles back under control.

Variable : Central angle of the horizontal curve in a section

As the central angle of the horizontal curve in a section increased, *Total* section run-off-roadway accident frequencies were likely to increase. An increase in the central angle reduces the visual impact of the curve, and this finding indicates that horizontal curves are more likely to be a special problem with tight and sharp topographical features, possibly because of the effects of making a difficult maneuver.

Variable : Number of lanes in a section

The number of lanes in a section is an intuitive variable with a statistically significant coefficient. An increased number of lanes provide a driver with less opportunity to leave the roadway whereas a smaller number of lanes can cause poor sight distance (because of a heavy truck, a slow vehicle, or left-turning vehicles at intersections) and provide less space for driver corrections. Some safety improvements that can reduce the likelihood of run-off-roadway accident rates in areas with few lanes include the use of the shoulder as a driving lane or providing turnout lanes to allow some vehicles to pass.

Variable : Number of vertical curves in a section

As the number of vertical curves in a section increased, so did the number of *Total* section run-off-roadway accidents. This finding suggests that vertical curves present drivers with a sight distance/speed modulation challenge that increases the likelihood of run-off-roadway accidents.

Variable : Number of vertical grade warning signs in a section

An increase in the number of vertical grade warning signs in a section decreased accident occurrence because of the warning to drivers.

Variable : Bridge indicator

The presence of bridges was associated with an increase in *Total* section run-off-roadway accident frequency. As expected, all else being the same, a higher number of bridges in a section resulted in a higher *Total* section run-off-roadway accident probability. In particular, bridges with narrow widths or with unprotected bridge ends were more likely to involve run-off-roadway accidents. According to Turner (1984), the most important features that affect the bridge accident rate are the bridge width, average daily traffic, and approach roadway width. His findings indicate that the number of run-off-roadway accidents on bridges decreases as the relative bridge width increases.

Variable : Distance from outside shoulder edge to miscellaneous fixed objects

As the distance from outside shoulder edge to miscellaneous fixed objects increased, the likelihood of *Total* section run-off-roadway accidents decreased. Miscellaneous fixed objects are devices such as mail boxes, signal boxes, antenna towers, phone booths, power meters, and large rocks found along a roadway. The average distance from outside shoulder edge to miscellaneous fixed objects was 1.19 meters. As the distance from outside shoulder edge to miscellaneous fixed objects increased, the probability of *Total* section run-off-roadway accidents decreased because the miscellaneous fixed objects were farther away than other roadside features.

Variable : Fence length

The majority of roadside variables in Table 4 are specified with a positive effect on *Total* section run-off-roadway accident frequency. Fences are used to minimize or prevent access to the area within WSDOT right-of-way that lies along a roadway. One would expect that as fence length increased, *Total* section run-off-roadway accident frequency would decrease. However, higher *Total* section run-off-roadway accident frequency was observed. This could be because longer fences do not give drivers precaution against running off the roadway or because fences have been installed at areas where observed run-off-roadway accident frequencies are high.

Variable : Number of tree groups in a section

As the number of tree groups near the roadway increased, the frequency of *Total* section run-off-roadway accidents also increased, possibly because of less space available to drivers for executing corrections. Trees are a more common roadside hazard than any other roadside features because they are narrow, rigid, and tall. To reduce the probability of impact with trees, roadside improvements include cutting or relocating the protruding trees.

Likelihood Ratio Test

To account for the differences in the values of parameters, or to statistically justify separate estimates of *Urban* and *Rural* section run-off-roadway accidents, the likelihood ratio (LR) test was performed. The estimation data were classified into two groups (*Urban* and *Rural* sections) and used to produce both *Urban* and *Rural* sections models. The estimation procedure was applied to both the *Urban* and *Rural* section data with *Total* sections variables. The likelihood ratio test statistic is given by

$$-2[L_T(\hat{\beta}) - L_U(\hat{\beta}^{T_U}) - L_R(\hat{\beta}^{T_R})] \tag{2.15}$$

where $L_T(\hat{\beta})$ is the log-likelihood at convergence of the model estimated on *Total* section,

$L_U(\hat{\beta}^{T_U})$ is the log-likelihood at convergence of the model estimated on the *Urban* section (T_U) subset of the data, and

$L_R(\hat{\beta}^{T_R})$ is the log-likelihood at convergence of the model estimated on the *Rural* section (T_R).

This test statistic was χ^2 distributed, with the degrees of freedom equal to the sum of the number of estimated coefficients in the *Urban* and *Rural* section models minus the number of coefficients in the *Total* section model.

Instead of determining the critical value from a table of the χ^2 distribution, *p*-values are presented. The *p*-value is the probability of obtaining a value of the test statistic greater than or equal to the observed value of the test statistic. For example, if the *p*-value for the test statistic is 0.025, then the null hypothesis can be rejected with over 95 percent confidence. The results of the test indicated a significant difference of frequency likelihoods between *Urban* section accidents and *Rural* section accidents (χ^2 = -2[-1522.088 - (-665.9059) - (-797.4040)] = 117.3802, degrees of freedom = 15, $P = 0$). The model comparisons proved to reject the null hypotheses with over 99 percent confidence. With this evidence we can conclude that there are statistically significant differences between *Urban* and *Rural* sections and suggest further exploration of the importance of and the reasons for these subsets.

Run-off-roadway Accident Frequency Models by Accident Location

The second and third models were estimated by accident location (whether urban or rural). For *Urban* section run-off-roadway accident frequency, the negative binomial regression model was most appropriate. The overdispersion parameter α was statistically significant (*t*-statistic of 2.680), indicating the appropriateness of the negative binomial regression model over the Poisson regression model. This was validated when the zero-inflated negative binomial model specification failed to provide a statistically better fit (the Vuong statistic < 1.96, which corresponded to the 95 percent confidence limit of the *t*-test). Zero-inflation was not confirmed (the Vuong statistic of -0.0003), indicating the appropriateness of the negative binomial regression model over the zero-inflated negative binomial model, and the overdispersion parameter α also turned out to be significant (*t*-statistic of 2.708). Accordingly, the negative binomial regression was most appropriate. The model results for the negative binomial specification for *Urban* section run-off-roadway accident frequency are given in Table 5. It shows that all variables were statistically significant and of plausible sign. These variables provide important insights into increases or decreases in *Urban* section run-off-roadway accident frequency and are discussed below.

Table 5. Negative Binomial Estimation Results (*Urban* section run-off-roadway monthly accident frequency)

Variable	Estimated Coefficients	t-statistic
Constant	-1.983	-2.641
Roadway characteristics		
Broad lane indicator (1 if lane width is greater than 3.69 meters, 0 otherwise)	1.684	3.984
Median width (in meters)	-0.017	-3.781
Roadside characteristics		
Bridge length (in meters)	4.610	2.145
Distance from outside shoulder edge to guardrail (in meters)	0.113	3.655
Fence length (in meters)	5.871	2.870
Number of isolated trees in a section	-0.093	-1.857
Number of miscellaneous fixed objects in a section	-0.094	-2.140
Number of sign supports in a section	-0.080	-3.515
Shoulder length (in meters)	-1.042	-1.461
Dispersion parameter α	0.661	2.680
Restricted Log-likelihood	-686.57	
Log-likelihood at Convergence	-681.53	
Number of Observations	1,584	

For *Rural* section run-off-roadway accident frequency, the zero-inflated negative binomial regression model was determined to be the most appropriate. The overdispersion parameter α was statistically significant (*t*-statistic of 2.694), indicating the appropriateness of the negative binomial regression model rather than Poisson regression model. This was validated when the zero-inflated negative binomial model specification failed to provide a statistically better fit (the Vuong statistic < 1.96, which corresponded to the 95 percent confidence limit of the *t*-test). Zero-inflation was confirmed (the Vuong statistic of 4.7311), indicating the appropriateness of the zero-inflated negative binomial regression model over the negative binomial model, and the overdispersion parameter α also was significant (*t*-statistic of 2.439). Accordingly, the zero-inflated negative binomial regression was determined to be the most appropriate model. The model results for the zero-inflated negative binomial specification for *Rural* section run-off-roadway accident frequency are presented in Table 6. The coefficients for both non-zero accident state and zero-accident state were found to be statistically significant and to have a plausible sign. These variables provide important insights into the tendency to increase or decrease *Rural* section run-off-roadway accident frequency and are discussed below.

Variable : Broad lane indicator

Broad lane indicator (lanes wider than 3.69 meters) was associated with a higher frequency of *Urban* section run-off-roadway accidents. A plausible explanation is that a broader lane could be expected to allow a higher traveling speed, creating a greater likelihood for run-off-roadways on *Urban* sections.

Table 6. Zero-Inflated Negative Binomial Estimation Results (*Rural* section run-off-roadway monthly accident frequency)

Variable	Estimated Coefficients	t-statistic
Non-zero accident state		
Constant	-5.322	-5.953
Temporal characteristics		
Year of occurrence indicator 2 (1 if 1995, 0 otherwise)	0.218	1.528
Roadway characteristics		
Legal speed limit (in km/h)	0.061	3.397
Median width (in meters)	-0.039	-5.861
Vertical curve length (in meters)	-0.002	-2.822
Roadside characteristics		
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise)	1.073	2.234
Distance from outside shoulder edge to luminaire poles (in meters)	-0.024	-1.569
Number of isolated trees in a section	0.106	1.674
Dispersion parameter α	1.377	2.439
Zero-accident state		
Constant	-48.593	-1.625
Roadway characteristics		
Legal speed limit (in km/h)	0.569	1.652
Shoulder width (in meters)	4.925	1.497
Vertical curve length (in meters)	-0.228	-1.660
Roadside characteristics		
Distance from outside shoulder edge to guardrail (in meters)	-0.827	-1.723

Table 6. Zero-Inflated Negative Binomial Estimation Results (*Rural* section run-off-roadway accident frequency) (Continued)

Variable	Estimated Coefficients	t-statistic
Restricted Log-likelihood	-904.72	
Log-likelihood at Convergence	-896.66	
Number of Observations	2,736	
Vuong Statistic	4.7311	

Variable : Median width

The statistical findings indicated that wider medians would reduce the likelihood of accidents on *Urban* sections and on *Rural* sections (non-zero state). Wider medians allow uncontrolled vehicles to recover without crossing over to the other side of the road and then onto the other side shoulder. Therefore, wider medians are considered very desirable in terms of reducing the likelihood of crashes.

Variable : Bridge length

As bridge length increased, so did the frequency of run-off-roadway *Urban* section accidents. A plausible explanation is that the probability of run-off-roadway accidents increases because the bridge has a relatively narrow width in relation to the roadway.

Variable : Distance from outside shoulder edge to guardrail

Guardrails have been the most widely used roadside barrier system in the United States and were also the leading fixed object hit in run-off-roadway accidents for our research area, accounting for about 15.3 percent of total accidents. As the distance from outside shoulder edge to the guardrail increased, the likelihood of run-off-roadway accidents on *Urban* sections increased, perhaps because of the additional recovery area. Similarly, *Rural* section (zero-state) run-off-roadway accident frequencies decreased as the distance from outside shoulder edge to guardrail increased.

Variable : Fence length

As with previous findings, increasing fence length was associated with a higher frequency of *Urban* section run-off-roadway accidents. This could be because even though a longer fence gives a sense of security to drivers, they can often overlook the function of the fence because the fence is farther away from the roadway than a guardrail, ditch, or luminaire pole. To alert inattentive drivers, it is effective to install shoulder rumble strips to alert drivers when they are running off the roadway. Also, fences may have been placed at locations that already had high run-off-roadway accident frequencies.

Variable : Number of isolated trees in a section

Along *Urban* sections on SR 3, a higher number of isolated trees in a section was associated with a lower frequency of run-off-roadway accidents. However, in *Rural* sections, a higher number of isolated trees was associated with higher frequencies of run-off-roadway accidents. As Table 2 indicated, the third object most commonly struck was trees, reflecting the large number of trees close to roadways. *Rural* section (non-zero state) run-off-roadway accident frequencies were substantially higher than that for *Urban* sections. This difference is primarily due to different tree densities on the two types of road sections. Higher tree densities on the *Rural* sections along SR 3 permit a higher likelihood of run-off-roadway collisions.

Variable : Number of miscellaneous fixed objects in a section

A higher number of miscellaneous fixed objects in a section was associated with lower *Urban* section run-off-roadway accident frequencies. This could be because drivers are more cautious when miscellaneous fixed objects such as mailboxes are prevalent along the roadway.

Variable : Number of sign supports in a section

A higher number of sign supports in a section had a negative effect on run-off-roadway accident frequency in *Urban* sections. Sign supports (sign bridges, cantilever signs, steel and wood sign posts) hold up signs adjacent to or over a roadway. The finding that such supports reduced accident frequency is likely due to people paying attention to the road signs.

Variable : Shoulder length

Increased shoulder length resulted in a lower likelihood of run-off-roadway accidents in *Urban* sections.

Variable : Year of occurrence indicator 2

Rural section run-off-roadway accident frequencies (non-zero state) were higher in 1995 along SR 3 than in other year data. This could be because seasonal variations and some unobserved effects were more severe in 1995 than in other years and/or severe windstorms plagued Washington in the winter of 1995.

Variable : Legal speed limit

The legal speed limit variable was found to positively affect *Rural* section run-off-roadway accident frequencies along SR 3 (both non-zero and zero state). Higher speed limits were generally associated with higher accident rates. The increase in the zero-state probability shows that high-speed limit sections were more likely to be safe but once in the non-zero accident state contributed to increased accident frequency.

Variable : Vertical curve length

Longer vertical curve length was found to negatively affect run-off-roadway accident frequency for *Rural* sections (non-zero state) and to also decrease the probability for *Rural* sections (zero-state). This indicates that long vertical curve lengths are likely to push the model into the non-zero accident state but to decrease the frequency.

Variable : Cut side slope indicator

Steeper and cut-typed side slopes were associated with higher *Rural* section run-off-roadway accident frequencies (non-zero state).

Variable : Distance from outside shoulder edge to luminaire poles

Luminaire poles aid the driver in viewing geometric conditions and distant hazards beyond the illumination range of vehicle headlights. Roadway lighting systems such as luminaire poles are more concentrated in urban areas with higher traffic densities than rural areas. The study showed that as the distance from outside shoulder edge to luminaire poles increased, *Rural* section run-off-roadway accident frequencies (non-zero state) decreased. This could be because the probability of a vehicle striking a luminaire pole is smaller with an increase in distance from the outside shoulder edge and the lower densities of luminaires in rural areas.

Variable : Shoulder width

It is not surprising that, as the shoulder width increased, so did the likelihood of the roadway section being in the zero-accident state in *Rural* sections. This positive effect shows that wider shoulders are associated with inherently safe sections of highway.

Elasticity Analysis

Elasticities were computed to determine the marginal effects of the independent variables in the three run-off-roadway accident frequency models. Elasticity of run-off-roadway frequency λ_{ij} is defined as,

$$E_{x_{ijk}}^{\lambda_{ij}} = \frac{\partial \lambda_{ij}}{\lambda_{ij}} \times \frac{x_{ijk}}{\partial x_{ijk}} \qquad (2.16)$$

where E represents the elasticity,

x_{ijk} is the value of the kth independent variable for section i in month j, and

λ_{ij} is the mean run-off-roadway accident frequency on roadway section i in month j.

Given equations 2.3 and 2.16, the following equation can be written,

$$E_{x_{ijk}}^{\lambda_{ij}} = \beta x_{ijk} \qquad (2.17)$$

where β is the coefficient corresponding to the kth independent variable for section i in month j.

However, the elasticity in equation 2.17 is only appropriate for continuous variables such as shoulder width, distance from outside shoulder edge to roadside features, or fence length. It is not valid for our non-continuous variables or indicator variables (i.e., dummy variables that take on values of zero or one). For indicator variables, a "pseudo-elasticity" can be computed to estimate an approximate elasticity of the variable. The pseudo-elasticity gives the incremental change in run-off-roadway frequency caused by changes in the indicator variables. The pseudo-elasticity is defined as,

$$E_{x_{ijk}}^{\lambda_{ij}} = \frac{\exp(\beta)-1}{\exp(\beta)} \tag{2.18}$$

The elasticities for each of the independent variables are shown in tables 7 to 9. Elasticity results show that one variable (legal speed limit in Table 9) was elastic and that most of the variables were inelastic (absolute value of less than 1). This means that, even though most of variables were statistically significant in our models, they may have had a lower effect on changes of the independent variables. However, tables 7 to 9 suggest some interesting interpretation. For example, in Table 7, a 1.0 percent increase in fence length caused a 0.04 percent increase in run-off-roadway accident frequency. Similarly, a 1.0 percent increase in the number of vertical curves in a section resulted in a 0.34 percent increase in run-off-roadway accident frequency. In contrast, a 1.0 percent decrease in the number of lanes in a section resulted in a 0.79 percent increase in run-off-roadway accident frequency. As an example of interpreting elasticity for indicator variables, our numerical computations showed that the average run-off-roadway frequency λ_{ij} for section i in month j can be said to increase 32.2 percent, if bridges are presented in the place of the run-off-roadway accidents.

Table 7. Elasticity estimates for *Total* section run-off-roadway monthly accident frequency.

Variable	Elasticity
Summer month indicator (1 if June, July, August, or September, 0 otherwise)	-0.457
Winter month indicator (1 if November, December or January, 0 otherwise)	0.244
Geographic indicator (1 if *Kitsap* County, 0 otherwise)	0.548
High traffic indicator (1 if AADT per lane is over 2,500 vehicles, 0 otherwise)	0.559
Center shoulder width (in meters)	-0.390
Center angle of the horizontal curve in a section (in degrees)	0.215
Number of lanes in a section	-0.789
Number of vertical curves in a section	0.343
Number of vertical grade warning signs in a section	-0.108
Shoulder width (in meters)	-0.693
Bridge indicator (1 if the presence of bridges, 0 otherwise)	0.322
Distance from outside shoulder edge to miscellaneous fixed objects (in meters)	-0.065
Fence length (in meters)	0.044
Number of tree groups in a section	0.050

Table 8. Elasticity estimates for *Urban* section run-off-roadway monthly accident frequency

Variable	Elasticity
Broad lane indicator (1 if lane width is greater than 3.69 meters, 0 otherwise)	0.814
Median width (in meters)	-0.207
Bridge length (in meters)	0.365
Distance from outside shoulder edge to guardrail (in meters)	0.249
Fence length (in meters)	0.001
Number of isolated trees in a section	-0.051
Number of miscellaneous fixed objects in a section	-0.065
Number of sign supports in a section	-0.152
Shoulder length (in meters)	-0.103

Table 9. Elasticity estimates for *Rural* section run-off-roadway monthly accident frequency

Non-zero accident state	
Variable	Elasticity
Legal speed limit (in km/h)	1.316
Median width (in meters)	-0.486
Vertical curve length (in meters)	-0.417
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise)	0.658
Distance from outside shoulder edge to luminaire poles (in meters)	-0.065
Number of isolated trees in a section	0.058
Zero-accident state	
Variable	Elasticity
Legal speed limit (in km/h)	0.297
Shoulder width (in meters)	0.290
Vertical curve length (in meters)	-0.585
Distance from outside shoulder edge to guardrail (in meters)	-0.182

SUMMARY OF FINDINGS

Three separate run-off-roadway accident frequency models were estimated to better account for differences attributable to roadway location (i.e., *Total* sections, *Urban* sections, and *Rural* sections). Table 10 comparatively summarizes the findings. The findings indicated that there were many differences and similarities among roadway locations.

The main research objectives of this chapter were to develop appropriate statistical modeling of a given area through the use of existing information on roadway geometric and roadside characteristics. The majority of previous studies have used Poisson regression, negative binomial regression, and zero-inflated regression techniques to derive the relationships among roadway geometry, roadside features, and accident frequency.

This investigation represented an attempt to define the relationships among roadway geometry, roadside characteristics, and run-off-roadway accident frequency. Several conclusions were drawn regarding the effect of roadway geometry and roadside features. Evidence from the results strongly indicated that run-off-roadway accident frequencies can be reduced by

- increasing lane and shoulder widths; widening medians;
- expanding the approaches to bridges;
- shielding, relocating, or removing roadside hazardous objects; and
- flattening side slopes and median.

Table 10. Summary of run-off-roadway accident frequency model results

Variable	Estimated Coefficients			
	Total	Urban	Rural	
	NB	NB	ZINB (Non-zero)	ZINB (Zero)
Constant	-1.699	-1.983	-5.322	-48.59
Temporal characteristics				
Summer month indicator (1 if June, July, August, or September, 0 otherwise)	-0.376			
Winter month indicator (1 if November, December or January, 0 otherwise)	0.280			
Year of occurrence indicator 2 (1 if 1995, 0 otherwise)			0.218	
Spatial characteristics				
Geographic indicator (1 if *Kitsap* County, 0 otherwise)	0.794			
Traffic characteristics				
High traffic indicator (1 if AADT per lane is over 2,500 vehicles, 0 otherwise)	0.819			
Roadway characteristics				
Broad lane indicator (1 if lane width is greater than 3.69 meters, 0 otherwise)		1.684		
Central angle of the horizontal curve in a section (in degrees)	0.0001			
Center shoulder width (in meters)	-0.098			
Legal speed limit			0.061	0.569
Median width (in meters)		-0.017	-0.039	
Number of lanes in a section	-0.291			
Number of vertical curves in a section	0.131			
Number of vertical grade warning signs in a section	-0.092			
Shoulder width (in meters)	-0.118			4.925
Vertical curve length (in meters)			-0.002	-0.228
Roadside characteristics				
Bridge indicator (1 if presence of bridges, 0 otherwise)	0.388			
Bridge length (in meters)		4.610		
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise)			1.073	

Table 10. Summary of run-off-roadway accident frequency model results (Continued)

Variable	Estimated Coefficients			
	Total	Urban	Rural	
	NB	NB	ZINB (Non-zero)	ZINB (Zero)
Distance from outside shoulder edge to guardrail (in meters)		0.113		-0.827
Distance from outside shoulder edge to luminaire poles (in meters)			-0.024	
Distance from outside shoulder edge to miscellaneous fixed objects (in meters)	-0.017			
Fence length (in meters)	5.179	5.871		
Number of isolated trees in a section		-0.093	0.106	
Number of miscellaneous fixed objects in a section		-0.094		
Number of sign supports in a section		-0.080		
Number of tree groups in a section	0.030			
Shoulder length (in meters)		-1.042		
Dispersion parameter α	0.764	0.661	1.377	

This study had the advantages of a larger roadside feature database than previous accident studies, and the roadside data were more current than the data in the older studies. However, because of the limited data, research could not explore the run-off-roadway accident frequencies of other functional classes (Interstate, principal arterial, minor arterial, and collector) or of different regional areas (eastern or western areas in Washington State). Additional research involving a larger roadside database is recommended. Such a study would require a large and extensive database because of the variability that could influence run-off-roadway accident frequency.

CHAPTER 3
STATE ROUTE 3 RUN-OFF-ROADWAY ACCIDENT SEVERITY

In terms of accident severity, this study attempted to extend the contributions of previous work by developing run-off-roadway accident severity models that can isolate risk factors, identify severe roadway geometric and roadside conditions, and ultimately lead to roadway improvements that will reduce the severity of crashes.

Below is a review of previous literature on accident severities. On the basis of previous efforts, some methodological directions for modeling run-off-roadway accident severities are described. Following this, the empirical setting and data of this study are detailed, then model estimation results and a summary of the findings are presented.

LITERATURE REVIEW

Numerous accident severity studies have attempted to determine the impacts of risk factors. In terms of empirical perspectives, many studies have focused on relationships between alcohol and crash risk (Mayhew *et al.*, 1986; Evans, 1990; Lloyd, 1992; Holubowycz *et al.*, 1994; Kim *et al.*, 1995). Evans (1986b) conducted a severity study to determine the effectiveness of seat belts in preventing fatalities. He found that safety belts are significantly effective at preventing risks to drivers and passengers. Several other studies investigated the effects of human factors on accident severity (Jonah, 1986; Mercer, 1987; Levy, 1990; Laberge-Nadeau *et al.*, 1992; Brorsson *et al.*, 1993). Among other things, they found that the driver's age was a significant factor, with young drivers at greater risk of being involved in a casualty accident than older drivers. Other accident studies looked at severity types such as fatalities (Shibata and Fukuda,

1994) or crashes involving certain types of vehicles such as heavy trucks and combination vehicles (Alassar, 1988; Chirachavala, 1985).

Even though previous studies have indicated that driver characteristics and vehicle features influence accident severity, quantitative studies among roadway design, roadside features, and accident severity have been rare. A study by Shankar, Mannering and Barfield (1996) employed a statistical model to provide a broad range of variables, including roadway geometry and weather-related conditions, as well as driver characteristics. Their estimation results provided valuable evidence on the effects that environmental conditions, highway design, accident type, driver characteristics, and vehicle attributes have on accident severity.

Several run-off-roadway accident studies have examined particular roadside features. Council and Stewart (1996) attempted to develop severity indexes for various fixed objects that are struck when vehicles leave the roadway. In other work, Viner (1995b) examined the risk of overturns in roadside crashes and found side slopes and ditches to be the dominant vehicle tripping mechanism involved in rollovers. To determine the effects of various traffic and roadway variables, Zegeer and Parker (1983) examined the severity of utility pole-related accidents and found that utility poles with wood supports were associated with significantly higher severities than utility poles with metal supports. More comprehensive accident severity studies associated with the economic measures were also conducted by Viner (1993). He found that the use of comprehensive costs could reduce distortions that may occur in analyses limited to fatal events. Overall, these past studies provided valuable insights, but very little attention has been paid to the relationships among roadway geometry, roadside features, and run-off roadway accident severity.

Methodologically, many alternatives have been used to analyze vehicular accident severity. Jones and Whitfield (1988) analyzed severity data with a logistic regression. Unconditional multiple logistic regression analysis was also performed by Shibata and Fukuda (1994). They explored the effects of driving without a license, alcohol use, speed, seat belts, and helmet use on accident severity. Another multivariate approach was employed by Lui *et al.* (1988). They modeled drivers' fatalities as a function of seat belts, principal impact point, and car weight with a conditional logistic regression. Evans (1986a) conducted a double pair comparison to investigate how occupant characteristics affect fatality risk in traffic accidents. In other work, Lassarre (1986) modeled accident time series to evaluate the effectiveness of nationwide countermeasures. O'Donnell and Connor (1996) identified risk factors that increase the probabilities of serious injury and fatalities with the ordered logit model and ordered probit models. The minimum permitted headway policy for automated highway systems (Glimm and Fenton, 1980) and discriminant analyses (Shao, 1987) on accident severity were other methodological options used.

Shankar and Mannering (1996) used a multinomial logit formulation to evaluate single-vehicle motorcycle accident severity, and Carson (1998) also applied a multinomial logit analysis to explore the relationships between ice accident severity and the presence of an ice-warning sign. There have been many recent applications of nested logit models to evaluate accident severity. For example, Shankar, Mannering and Barfield (1996) developed a probabilistic nested logit model using roadway geometry, environmental conditions, and human factors, and Chang and Mannering (1998) estimated a nested logit model to predict vehicle occupancies with standard accident data. Their estimation results showed that the nested logit model provides great potential for analyzing accident severity data. This is because there are shared unobservables among accident severity levels, and the nested logit model structure can account for such shared unobservables.

The intent of the work described in this chapter was to develop a methodological approach that could account for the relationships among roadway geometry, roadside features, driver characteristics, and run-off-roadway accident severity. The nested logit formulation employed by Shankar *et al.* (1996) and Chang and Mannering (1998) was used as the basis for this approach.

METHODOLOGY

To develop an appropriate model regarding the relationship between observable characteristics and run-off-roadway accident severity, an accident severity model with discrete data could be derived as long as each accident had a discrete outcome that would categorize the severity (Mannering, 1998). By assuming discrete outcome data, a conditional model of accident severity (i.e., conditioned on the fact that run-off-roadway accidents had occurred) could be developed. An appropriate method of modeling this is the multinomial logit (MNL) formulation previously applied to accident severity (Shankar and Mannering, 1996, Carson, 1998). They estimated the probability that vehicular accident n is severity i by determining the likelihood of discrete choices (several accident categories) occurring.

Given that each accident could be assigned one discrete outcome from a set of (1) property damage only, (2) possible injury involved, (3) evident injury involved, and (4) disabling injury or fatality involved, the multinomial logit (MNL) model could be derived to determine the probability of a run-off-roadway accident having a specific severity level by starting with the following probability statement:

$$P_n(i) = P\,(S_{in} \geq S_{In}) \qquad \forall\, I \neq i \tag{3.1}$$

where $P_n(i)$ is the probability that a discrete outcome i (accident severity category i) occurs in run-off-roadway accident n,

where P denotes probability and

S_{in} is a function provided by severity i to accident n.

This function is linearly formed such that,

$$S_{in} = \beta_i X_n + \varepsilon_{in} \tag{3.2}$$

where β_i is a vector of statistically estimable coefficients, and

X_n is a vector of measurable characteristics that determine severity (e.g., roadside characteristics, socioeconomic factor, vehicular type, roadway geometric factors, and so on), and

ε_{in} is an unobserved error term influencing run-off-roadway accident severity and is independent in each of the severity categories.

Given equations 3.1 and 3.2, the following equations can be written,

$$P_n(i) = P(\beta_i X_n + \varepsilon_{in} \geq \beta_I X_n + \varepsilon_{In}) \qquad \forall\, I \neq i \tag{3.3}$$

or

$$P_n(i) = P(\beta_i X_n - \beta_I X_n \geq \varepsilon_{In} - \varepsilon_{in}) \qquad \forall\, I \neq i \tag{3.4}$$

With equation 3.3, by assuming that the unobserved terms (ε_{in}'s) are generalized extreme value (GEV) distributed, a multinomial logit (MNL) model can be derived to estimate the probability of run-off-roadway accident severity (McFadden, 1981),

$$P_n(i) = [\sum_I exp[\beta_I X_n]]^{-1} exp[\beta_i X_n] \tag{3.5}$$

where all variables are as previously defined, and

the coefficient vector β_i is estimable by standard maximum likelihood techniques (Ben-Akiva and Lerman, 1985, Train, 1986).

The basic assumption in the derivation of the simple multinomial logit model is that unobserved terms (ε_{in}'s) are independent from one accident severity category to another. However, if some severity categories share unobserved terms and can thus be correlated, the multinomial logit model will lead to serious specification errors, and the model will be incorrectly estimated. If these shared unobservables are present in the model structure, the generalized extreme value (GEV) distribution can be applied to provide a more generalized form of the accident severity probabilities. This is referred to as a nested logit model, which groups alternatives with correlated error terms into a *nest* by estimating a model that includes only accidents with outcomes in the *nested* outcomes. The model has the following form (McFadden, 1981, Mannering, 1998),

$$P_n(i) = exp[\beta_i X_n + \Theta_i L_{in}] / \sum_I exp[\beta_i X_n + \Theta_i L_{in}] \tag{3.6}$$

$$P_n(k \mid i) = exp[\beta_{k \mid i} X_n] / \sum_K exp[\beta_{k \mid i} X_n] \tag{3.7}$$

$$L_{in} = ln\ [\sum_K exp(\beta_{k \mid i} X_n)] \tag{3.8}$$

where $P_n(i)$ is the unconditional probability of run-off-roadway accident n having severity i,

X_n is a vector of measurable characteristics that determine accident severity,

$P_n(k \mid i)$ is the probability of run-off-roadway accident n having severity k conditioned on the severity being in severity category i,

K 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 (log sum), and Θ_i is an estimable coefficient with a value between 0 and 1 to be consistent with the model derivation (McFadden, 1981).

The nested logit model structure will cancel out shared unobserved effects in each nest, thus preserving the assumption of independence of unobserved effects for model derivation.

ACCIDENT SEVERITY ANALYSIS

Empirical Setting

As with the run-off-roadway accident frequency data, in collecting data on the 96.6 kilometers of a State Route 3 (SR 3) located 37 kilometers west of Seattle, data were collected from three WSDOT sources. Accident data were obtained from the WSDOT MicroCARS accident database from January 1, 1994, to December 31, 1996, reported on SR 3, and most of the data were from cases in which a vehicle struck only a single roadside object. Accident data included information on time of accident, accident location, effects of weather on pavement conditions (e.g., icy, wet, dry), driver-related data, the number of vehicles involved in the accident, and vehicle-related data. The Transportation Information and Planning Support (TRIPS) system of WSDOT includes geometric factors involved in accidents and traffic data that can be used to study run-off-roadway accident severity. The TRIPS system includes roadway geometric data such as lane, shoulder, median, intersections, and vertical or horizontal alignment and also reports traffic data such as traffic volume, truck volume as a percentage of AADT, peak hour volume, and legal speed limit. Roadside feature data were collected over a period from May 1998 to September 1998 and were stored in the Roadway Object and Attribute Data (ROAD) inventory system. The ROAD system includes information on roadside features such as guardrails, catch basins, slopes, tree groups, isolated trees, culverts, sign poles, ditches, fences, utility poles, miscellaneous fixed objects, luminaires, intersections, and bridges when the run-off-roadway accidents happen. For the model estimation, the three databases were integrated into one on the basis of milepost (MP).

As with the run-off-roadway accident frequency modeling, because of the absence of roadside feature data on the southbound direction of SR 3, only northbound run-off-roadway accident severities were considered. A total of 489 run-off-roadway accidents reported during this period were used in this severity study; 284 of those accidents resulted in property damage only. Of the remaining 205 run-off-roadway accidents, 82 were possible injury accidents, 94 were evident injury accidents, 25 resulted in disabling injuries, and 4 were fatality accidents. It is important to note that run-off-roadway accident severity was specified as one of four discrete categories. The number of run-off-roadway accidents in the fourth category was increased by combining disabling injuries and fatalities into a single severity category (29 disabling injury/fatality) when models were estimated. Data elements for run-off-roadway accident severity are shown in Appendix D.

Table 11 provides information on the run-off-roadway accident severity distribution of several variables. It shows that high frequency did not necessarily tend to produce more severe run-off-roadway accidents. For example, the total number of summer accidents was 117 and of winter was 225. However, for the winter season, only about 15.1 percent were evident injury and 3.1 percent were disabling injury/fatality accidents, whereas in summer 25.6 were evident injury and 8.5 percent were disabling injury/fatality. Alcohol-related driving or the presence of horizontal curves were also apt to produce more severe run-off-roadway accidents in spite of low accident frequency. On the other hand, for variables such as dry pavement or driver resident within 24 kilometers, a higher frequency did tend to produce more hazardous run-off-roadway accidents.

Table 12 shows that for fixed-object crashes, the obstacles associated with the highest percentage of injuries were, in order, guardrails or earth banks, ditches, trees, concrete barriers, embankments, utility poles, wood sign supports, bridge rails, and culverts. Obstacle types with the lowest percentage of injury included buildings, fences, mailboxes, luminaires, and boulders. Additional information on run-off-roadway accident severity distribution by roadside object struck is summarized in Table 12. It shows that some variables such as guardrails, earth banks, or ditches with a higher accident frequency tend to produce less severe run-off-roadway accidents. Other variables such as utility poles, bridge rails, or culverts with a lower accident frequency were involved in significantly hazardous run-off-roadway accidents. On the other hand, trees with a high accident frequency were also involved in more severe run-off-roadway accidents, and variables such as mailboxes or fences with a lower accident frequency showed less severe run-off-roadway accident results.

Table 11. Run-off-roadway accident severity distribution by several variables

Variables	Severity distribution				
	Property Damage only (58.1%)	Possible injury (16.8%)	Evident injury (19.2%)	Disabling injury (5.1%)	Fatality (0.8%)
Summer	58 (49.6%)	19 (16.2%)	30 (25.6%)	8 (6.8%)	2 (1.7%)
Winter	144 (64.0%)	40 (17.8%)	34 (15.1%)	7 (3.1%)	0 (0%)
Weekday	197 (59.5%)	54 (16.3%)	57 (17.2%)	20 (6.0%)	3 (0.9%)
Weekend	87 (55.1%)	28 (17.7%)	37 (23.4%)	5 (3.2%)	1 (0.6%)
Urban sections	139 (56.0%)	44 (17.7%)	48 (19.4%)	16 (6.5%)	1 (0.4%)
Rural sections	145 (60.2%)	38 (15.8%)	46 (19.1%)	9 (3.7%)	3 (1.2%)
Dry Pavement	123 (50.2%)	45 (18.4%)	57 (23.3%)	16 (6.5%)	4 (1.6%)
Wet Pavement	79 (61.7%)	16 (12.5%)	25 (19.5%)	8 (6.3%)	0 (0%)
Daylight	150 (58.1%)	49 (19.0%)	43 (16.7%)	13 (5.0%)	3 (1.2%)
Dark	126 (59.2%)	29 (13.6%)	46 (21.6%)	11 (5.2%)	1 (0.5%)
Resident within 24 kilometers	190 (54.1%)	62 (17.7%)	78 (22.2%)	18 (5.1%)	3 (0.9%)
Resident elsewhere	56 (57.1%)	19 (19.4%)	15 (15.3%)	7 (7.1%)	1 (1.0%)
Driving under influence	38 (36.9%)	21 (20.4%)	32 (31.1%)	10 (9.7%)	2 (1.9%)
Driving sober	192 (58.2%)	60 (18.2%)	62 (18.8%)	14 (4.2%)	2 (0.6%)
Horizontal curve section	70 (48.6%)	33 (22.9%)	31 (21.5%)	7 (4.9%)	3 (2.1%)
Straight section	214 (62.0%)	49 (14.2%)	63 (18.3%)	18 (5.2%)	1 (0.3%)

Table 12. Run-off-roadway accident severity distribution by roadside object struck

Variables	Severity distribution				
	Property Damage only (58.1%)	Possible injury (16.8%)	Evident injury (19.2%)	Disabling injury (5.1%)	Fatality (0.8%)
Guardrails	42 (73.7%)	8 (14.0%)	6 (10.5%)	1(1.8%)	0 (0%)
Earth bank	34 (61.8%)	10 (18.2%)	8 (14.5%)	3 (5.5%)	0 (0%)
Ditch	33 (78.6%)	3 (7.1%)	6 (14.3%)	0 (0%)	0 (0%)
Tree	14 (33.3%)	10 (23.8%)	9 (21.4%)	6 (14.3%)	1 (2.4%)
Concrete Barrier	25 (65.8%)	8 (21.1%)	8 (21.1%)	0 (0%)	0 (0%)
Over embankment	19 (61.3%)	4 (12.9%)	6 (19.4%)	2 (6.5%)	0 (0%)
Utility Pole	11 (55.0%)	4 (20.0%)	3 (15.0%)	1 (5.0%)	1 (5.0%)
Wood sign support	13 (68.4%)	1 (5.3%)	4 (21.1%)	1 (5.3%)	0 (0%)
Bridge rail	13 (76.5%)	1 (5.9%)	3 (17.6%)	2 (11.8%)	0 (0%)
Culvert	3 (42.9%)	2 (28.6%)	1 (14.3%)	0 (0%)	1 (14.3%)
Boulder	4 (66.7%)	1 (16.7%)	1 (16.7%)	0 (0%)	0 (0%)
Luminaires	1 (16.7%)	3 (50.0%)	2 (33.3%)	0 (0%)	0 (0%)
Mailbox	1 (20.0%)	3 (60.0%)	1 (20.0%)	0 (0%)	0 (0%)
Fence	3 (60.0%)	2 (40.0%)	0 (0%)	0 (0%)	0 (0%)
Building	3 (60.0%)	0 (0%)	2 (40.0%)	0 (0%)	0 (0%)

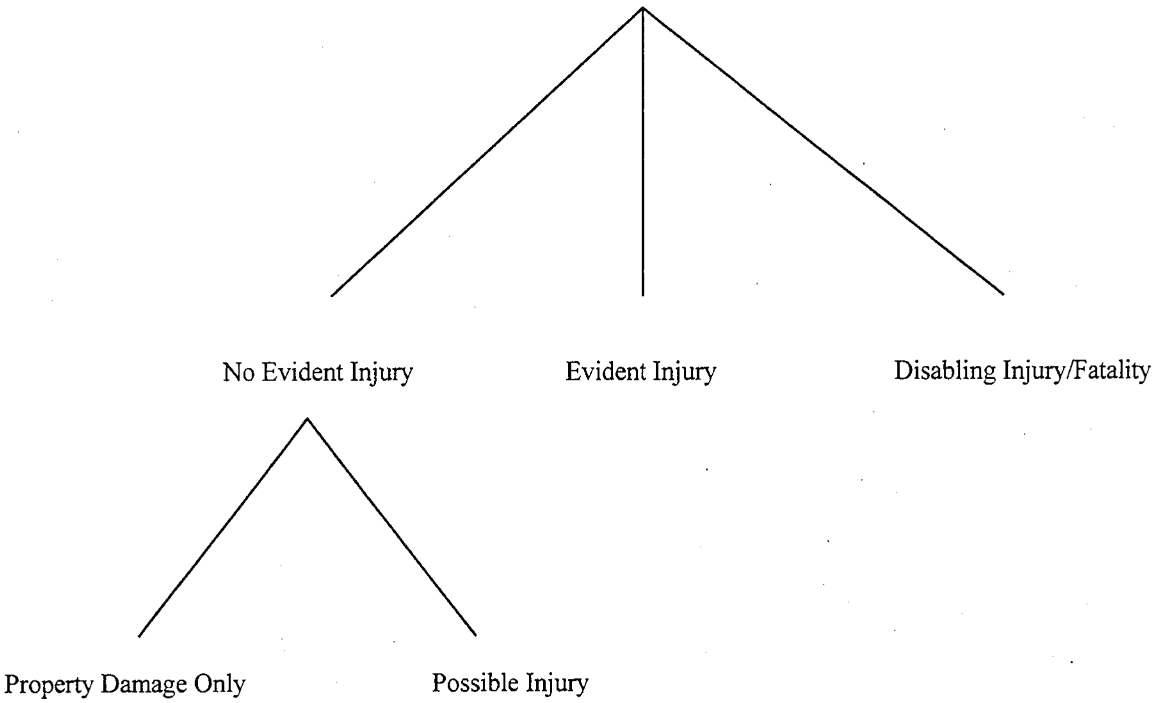

Figure 5. Nested Structure of Run-Off-Roadway Accident Severities

Model Estimation

The effects of roadway geometry and roadside characteristics on run-off-roadway accident severity were studied with a nested logit model. All possible nested structures were considered to capture the correlation among various severity levels. It is important to note that the property damage only and possible injury severity levels shared unobservables that would have led to serious model specification errors if a simple multinomial logit model had been used. To account for these shared unobservables, the nested logit structure in Figure 5 was used. For run-off-roadway accident severity, the three nested logit models (*Total* sections, *Urban* sections, *Rural* sections) were estimated with standard maximum likelihood methods. The sequential estimation procedure was used to estimate the model. First, the lower conditional level was estimated as a multinomial logit (MNL) model, and the estimated coefficients of each severity level was used to calculate the inclusive value (L_{in}). Finally, the upper level was estimated with a multinomial logit (MNL) model by including the inclusive value (L_{in}; logsum) as an independent variable.

First, *Total* section run-off-roadway accident severity models for State Route 3 (SR 3) were estimated, as in tables 13 and 14. Table 13 shows maximum likelihood estimation results for the lower level (property damage only (PDO) and possible injury), and Table 14 presents the estimation of the overall run-off-roadway accident severity model. The inclusive value coefficient is 0.293. This value is significantly different from zero and one, and suggests that shared unobservables were present among the lower levels. *Total* section run-off-roadway accident severity models resulted in good statistical fits by the log likelihood at convergence and ρ^2 values, and all variable coefficients were of plausible sign and statistically significant. A discussion of each variable shown in Table 13 follows.

Variable: Night time indicator

Finding: Increases the probability of possible injury relative to property damage only (PDO)

Loss of visibility and fatigue are likely contributing factors to the higher likelihood of possible injury relative to PDO at night. Improvement of luminous painted signing and delineation of the roadway aid drivers' ability during the night. Audible warning devices on the shoulder edge would also be effective at alerting drowsy drivers.

Variable: Winter month indicator

Finding: Increases the probability of possible injury relative to PDO

During the winter season, inclement weather conditions such as severe windstorms and snowfall can make driving more difficult because of the loss of visibility and other factors.

Variable: Year of occurrence indicator 2

Finding: Increases the probability of possible injury relative to PDO

The year of occurrence indicator showed that accidents in 1995 were more likely to involve an injury relative to property damage only. This could be because some unobserved effects and seasonal variations in 1995 were severe and made driving more hazardous.

Table 13. Estimation of property damage only and possible injury probabilities of *Total* run-off-roadway accident severity conditioned on no evident injury

Variable	Estimated Coefficients	t-statistic
Constant (specific to property damage only)	2.052	5.434
Temporal characteristics		
Night time indicator (1 if run-off-roadway accidents occurred at night time, 0 otherwise; specific to property damage only)	0.608	1.980
Winter month indicator (1 if November, December or January, 0 otherwise; specific to possible injury)	0.494	1.532
Year of occurrence indicator 2 (1 if 1995, 0 otherwise; specific to property damage only)	-0.378	-1.318
Environmental characteristics		
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to property damage only)	-0.764	-2.403
Driver characteristics		
Alcohol impaired driving indicator 1 (1 if driver had been drinking and ability impaired, 0 otherwise; specific to property damage only)	-1.040	-2.365
Contributing cause indicator 4 (1 if "inattention" was the primary contributing cause, 0 otherwise; specific to property damage only)	0.951	2.031
Old age driver indicator (1 if driver is at age of 60 or older, 0 otherwise; specific to possible injury)	0.653	1.497
Roadway characteristics		
Broad lane indicator (1 if lane width is greater than 3.69 meters, 0 otherwise; specific to property damage only)	0.748	1.324
Curve indicator (1 if run-off-roadway accidents occurred on a horizontal curve, 0 otherwise; specific to property damage only)	-0.648	-2.285
Roadside characteristics		
Bridge indicator (1 if the presence of bridges, 0 otherwise; specific to possible injury)	0.644	1.022

Table 13. Estimation of property damage and possible injury probabilities of *Total* run-off-roadway accident severity conditioned on no evident injury (Continued)

Variable	Estimated Coefficients	t-statistic
Catch basin indicator (1 if the presence of catch basins, 0 otherwise; specific to property damage only)	-1.087	-1.140
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise; specific to possible injury)	0.955	1.050
Guardrail indicator (1 if the presence of guardrails, 0 otherwise; specific to possible injury)	1.102	2.186
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to property damage only)	1.306	2.320
Restricted Log-likelihood	-253.69	
Log-likelihood at Convergence	-173.62	
Number of Observations	366	
ρ^2	0.32	

Table 14. Estimation of overall nested logit model of *Total* run-off-roadway accident severity probabilities

Variable	Estimated Coefficients	t-statistic
Constant (specific to evident injury)	-4.211	-3.233
Constant (specific to disabling injury/fatality)	-2.806	-3.455
Temporal characteristics		
Day time indicator (1 if run-off-roadway accidents occurred at day time, 0 otherwise; specific to no evident injury)	-0.766	-2.742
Peak hour indicator (1 if run-off-roadway accidents occurred in the peak hours, 0 otherwise; specific to no evident injury)	-0.709	-2.396
Weekday indicator (1 if run-off-roadway accidents occurred during weekday, 0 otherwise; specific to no evident injury)	0.328	1.271
Weekend indicator (1 if run-off-roadway accidents occurred during weekend, 0 otherwise; specific to disabling injury/fatality)	-0.844	-1.633
Environmental characteristics		
Clear/cloudy weather indicator (1 if run-off-roadway accidents occurred in the clear or cloudy weather condition, 0 otherwise; specific to no evident injury)	-0.790	-2.101
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to no evident injury)	-1.065	-2.904
Wet road surface indicator (1 if run-off-roadway accidents occurred on a wet road surface, 0 otherwise; specific to evident injury and disabling injury/fatality)	1.320	3.243
Driver characteristics		
Contributing cause indicator 1 (1 if "exceeded reasonably safe speed" was the primary contributing cause, 0 otherwise; specific to disabling injury/fatality)	-0.672	-1.394
Driver residence location indicator 1 (1 if run-off-roadway accidents occurred within 24 kilometers of residence, 0 otherwise; specific to evident injury)	2.596	2.513

Table 14. Estimation of overall nested logit model of *Total* run-off-roadway accident severity probabilities (Continued)

Variable	Estimated Coefficients	t-statistic
Driver residence location indicator 2 (1 if run-off-roadway accidents occurred more than 24 kilometers of residence, 0 otherwise; specific to evident injury and disabling injury/fatality)	-2.044	-1.922
Roadway characteristics		
High posted speed indicator (1 if the posted speed limit was 84 km/h or more, 0 otherwise; specific to evident injury and disabling injury/fatality)	0.336	1.364
Median indicator (1 if median is divided, 0 otherwise; specific to no evident injury)	0.468	1.308
Narrow shoulder indicator (1 if shoulder width is less than or equal to 1.98 meters, 0 otherwise; specific to no evident injury)	0.437	1.216
Roadside characteristics		
Bridge indicator (1 if the presence of bridges, 0 otherwise; specific to disabling injury/fatality)	1.166	1.690
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to no evident injury and evident injury)	-0.702	-1.216
Tree group indicator (1 if the presence of tree groups, 0 otherwise; specific to no evident injury)	-0.891	-2.553
Utility pole indicator (1 if the presence of utility poles, 0 otherwise; specific to disabling injury/fatality)	-1.200	-1.468
Inclusive value of property damage and possible injury (L_{in}, specific to no evident injury)	0.293	2.605
Restricted Log-likelihood	-537.22	
Log-likelihood at Convergence	-308.60	
Number of Observations	489	
ρ^2	0.43	

Variable: Dry road surface indicator

Finding: Increases the probability of possible injury relative to PDO

A plausible explanation is that people are more likely to drive faster on dry pavements, thus increasing the likelihood of possible injury relative to PDO.

Variable: Alcohol impaired driving indicator 1

Finding: Increases the probability of possible injury relative to PDO

Alcohol increased injury risk for run-off-roadway accidents. As shown in the vast literature on alcohol's effects on traffic accidents, if drivers have been drinking and are ability impaired, the likelihood of possible injury relative to PDO increases because of their decreased ability to control a vehicle.

Variable: Contributing cause indicator 4

Finding: Increases the probability of PDO relative to possible injury

If "inattention" was the primary contributing cause of a run-off-roadway accident, the accident tended to be less severe. When a driver is inattentive, driving speed is not likely to be high, resulting in less likelihood for severe accidents. Recent research suggests that rumble or chatter strips constructed on the shoulder at the lane edge may reduce run-off-roadway accident severity by alerting inattentive drivers about to run off the road (Gattis *et al.*, 1993).

Variable: Old age driver indicator

Finding: Increases the probability of possible injury relative to PDO

Even though older drivers tend to have more driving experience than younger drivers, their crash injury rates are higher, possibly because of reduced mobility and loss of judgment.

Variable: Broad lane indicator

Finding: Increases the probability of PDO relative to possible injury

In viewing the accident frequency modeling, the broad lane indicator was associated with a higher frequency of run-off-roadway accidents. However, the influence of broad lanes on run-off-roadway accident severity was likely to be slight. This could be because broad lanes provide extensive views to drivers.

Variable: Curve indicator

Finding: Increases the probability of possible injury relative to PDO

Most accident research has consistently found that accidents on horizontal curves are frequent and are more severe. This finding suggests that horizontal curves may present drivers with difficult maneuvers, possibly because of reduced sight and centripetal forces.

Variable: Bridge indicator

Finding: Increases the probability of possible injury relative to PDO

Bridges were associated with a higher probability of possible injury relative to PDO. Run-off-roadway bridge accidents may be very severe because an errant vehicle may go down an embankment and into the river or stream under the crossing. In addition, most old bridges are narrower than the roadway lane, and the approach to the bridge is also likely to be narrow and close.

Variable: Catch basin indicator

Finding: Increases the probability of possible injury relative to PDO

The function of a catch basin is to hold storm water runoff along a roadway. The finding indicates that the influence of catch basins on run-off-roadway accidents is likely to be severe. Catch basins usually have surface irregularities that significantly affect the likelihood of possible injury, and surface material differences between catch basins and the roadway may affect skidding.

Variable: Cut side slope indicator

Finding: Increases the probability of possible injury relative to PDO

This common finding shows that roadway sections with cut side slopes are more hazardous. Desirable roadside recovery areas are needed to provide a reasonable opportunity for drivers to regain a measure of control or to slow an errant vehicle.

Variable: Guardrail indicator

Finding: Increases the probability of possible injury relative to PDO

Guardrails were found to increase the probability of possible injury relative to PDO. Still, guardrails may be effective in reducing the likelihood of serious injury.

Variable: Intersection indicator

Finding: Increases the probability of PDO relative to possible injury

Intersections were associated with a lower probability of severe injury. This could be because the vehicle is stopped at a signal, or people drive at lower speeds to approach an intersection.

The overall nested logit model estimation of run-off-roadway accident severity probabilities for *Total* sections is shown in Table 14. The interpretation of estimated coefficients is provided below.

Variable: Day time indicator

Finding: Decreases the probability of no evident injury

The day time indicator showed that accidents were more likely to result in evident injury. The greater severity of day time accidents may be the result of driver behavior and possibly higher speeds.

Variable: Peak hour indicator

Finding: Decreases the probability of no evident injury and disabling injury/fatality

Run-off-roadway accidents that occurred during peak hours were less likely to produce either no evident injury or a disabling injury/fatality.

Variable: Weekday indicator

Finding: Increases the probability of no evident injury

This finding agreed with the earlier observation of the weekend indicator. This could relate to a reduction in speed, possibly due to routine traffic congestion.

Variable: Weekend indicator

Finding: Decreases the probability of disabling injury/fatality

The weekend indicator was associated with a lower probability of a disabling injury/fatality. This could relate to different driver behavior on weekends.

Variable: Clear/cloudy weather indicator

Finding: Decreases the probability of no evident injury

This finding indicated an increased likelihood of evident injury for accidents occurring in good weather conditions. As shown in a literature (Evans, 1990), many fatal crashes occur in the absence of any adverse atmospheric conditions. This variable also confirmed the finding of the dry road surface indicator.

Variable: Dry road surface indicator

Finding: Decreases the probability of no evident injury

This finding agreed with the observation of the lower nest. A plausible explanation is that if the surface of the roadway is dry, drivers may be overconfident in their abilities or ignore safety hazards.

Variable: Wet road surface indicator

Finding: Increases the probability of evident injury and disabling injury/fatality

The wet road surface indicator was associated with a higher probability of evident injury and disabling injury/fatality. Inclement weather conditions and slippery roadways are likely to lead to more severe crashes because drivers have more difficulty seeing distant hazards and have an increased reaction time.

Variable: Contributing cause indicator 1

Finding: Decreases the probability of disabling injury/fatality

This finding indicated that if the crash occurred because the driver exceeded a reasonably safe speed, the likelihood of a disabling injury/fatality would be lower. This could be because excessive speed is frequently assigned by troopers as a contributing factor in less severe accidents, and this assessment is subjective in nature.

Variable: Residence location indicator 1

Finding: Increases the probability of evident injury

The findings indicated that run-off-roadway accidents involving drivers living within 24 kilometers of the accident crash site were more likely to result in evident injury. A plausible explanation is that familiar surroundings may lead to overconfidence and aggressive driving.

Variable: Residence location indicator 2

Finding: Decreases the probability of evident injury and disabling injury/fatality

Run-off-roadway accidents involving drivers living more than 24 kilometers of the run-off-roadway accident crash site were less likely to result in evident injury and disabling injury/fatality. This variable further confirmed the finding of the residence location indicator 1. Drivers not familiar with roadway geometry or roadside features are more likely to be attentive, and this could be reflected in this variable.

Variable: High posted speed indicator

Finding: Increases the probability of evident injury and disabling injury/fatality

The findings indicated that run-off-roadway accidents involving higher posted speed limits at accident crash sites were more likely to result in evident injury and disabling injury/fatality.

Variable: Median indicator

Finding: Increases the probability of no evident injury

This finding indicated that if the median was divided, run-off-roadway accidents were more likely to result in no evident injury. This could be because a divided median allows an errant vehicle to recover without crossing over to the other side of the road.

Variable: Narrow shoulder indicator

Finding: Increases the probability of no evident injury

The narrow shoulder indicator (less than or equal to 1.98 meters) was associated with a lower probability of evident injury. This could relate to the increase in attention that such narrow shoulders may encourage.

Variable: Bridge indicator

Finding: Increases the probability of disabling injury/fatality

This variable confirmed the finding of the bridge indicator 1 of the lower nest. It seems plausible to presume that the presence of bridges makes a severe collision more probable.

Variable: Intersection indicator

Finding: Decreases the probability of no evident injury and evident injury

This finding indicated that intersections were associated with a lower probability of less severe accidents and a higher probability (by default) of a disabling injury/fatality.

Variable: Tree group indicator

Finding: Decreases the probability of no evident injury

The tree group indicator was associated with a higher probability of evident injury. Even though tree groups may serve a guidance function that helps reduce accident frequency, trees are still commonly struck objects and lead to serious injuries. It is desirable to remove hazardous tree groups, but if tree groups cannot be removed, the awareness of safety must be increased, and impact absorbing devices for trees should be installed.

Variable: Utility pole indicator

Finding: Decreases the probability of disabling injury/fatality

The presence of utility poles was associated with a lower probability of severe injury. This could be because the distance from the outside shoulder edge to utility poles is farthest away (average 1.92 meters), and increased recovery space is available for errant vehicles.

Likelihood Ratio Test

As with the run-off-roadway accident frequency models, to account for the differences in the values of parameters, or to statistically justify the separate estimation of *Urban* and *Rural* section run-off-roadway accidents, the likelihood ratio (LR) test was performed. The estimation data were classified into two groups (*Urban* and *Rural* sections) and estimated *Urban* and *Rural* sections models. The estimation procedure was applied to the *Urban* section data with *Total* sections variables, and to the *Rural* section data with *Total* sections variables. The likelihood ratio test statistic is given by

$$-2[L_T(\hat{\beta}) - L_U(\hat{\beta}^{T_U}) - L_R(\hat{\beta}^{T_R})] \qquad (3.9)$$

where $L_T(\hat{\beta})$ is the log-likelihood at convergence of the model estimated for *Total* section,

$L_U(\hat{\beta}^{T_U})$ is the log-likelihood at convergence of the model estimated for the *Urban* section (T_U) subset of the data, and

$L_R(\hat{\beta}^{T_R})$ is the log-likelihood at convergence of the model estimated for the *Rural* section (T_R).

This test statistic is χ^2 distributed, with the degrees of freedom equal to the sum of the number of estimated coefficients in the *Urban* and *Rural* section models minus the number of coefficients in the model estimated on *Total* section model.

Instead of determining the critical value from a table of the χ^2 distribution, *p*-values are presented. The *p*-value is the probability of obtaining a value of the test statistic greater than or equal to the observed value of the test statistic. For example, if the *p*-value for the test statistic is 0.025, then the null hypothesis can be rejected with 95 percent confidence. The results of the test indicated that a significant difference of severity likelihoods between *Urban* section frequency accidents and *Rural* section severity accidents ($\chi^2 = -2[-308.59632 - (-146.88858) - (-145.7071)] = 32.00128$, degrees of freedom = 20, $P = 0.0433$). The model comparisons rejected the null hypotheses with over 95 percent confidence. This evidence lead to the conclusion that there were statistically significant differences between the *Urban* and *Rural* sections, and the authors suggest further exploration of the importance of and the reasons for these differences between subsets.

Run-off-roadway Accident Severity Models by Accident Location

Both *Urban* and *Rural* section run-off-roadway accident severity models for SR 3 are estimated in Tables 15 to 18. Tables 15 and 17 show maximum likelihood estimation results for the lower level (property damage only and possible injury), and tables 16 and 18 present the estimation of overall *Urban* and *Rural* section run-off-roadway accident severity models, respectively. The inclusive value coefficients were 0.242 and 0.247. These values were significantly different from zero and one, and suggest that shared unobservables were present among the lower levels. Both *Urban* and *Rural* section run-off-roadway accident severity models resulted in good statistical fits by the log likelihood at convergence and ρ^2 values, and all variable coefficients were of plausible sign and statistically significant. In general, the findings of these models were consistent with the previous findings of the *Total* section run-off-roadway accident severity models, although some findings were slightly different. Therefore, the discussion below focuses on determinants with significantly different trends, as indicated in the newly estimated coefficients.

Variable: Year of occurrence indicator 1

Finding: Increases the probability of possible injury relative to PDO

This finding indicates that some unobserved effects (e.g., wet or icy pavements and seasonal variations) were more severe during 1994 than usual, thus creating a higher likelihood of possible injury on *Urban* sections.

Variable: Fence indicator

Finding: Increases the probability of possible injury relative to PDO

The presence of fences was more likely to result in possible injury relative to PDO. This could be because the fence itself produces a greater chance of injury. However, some caution should be exercised in interpreting this finding because fences may have been installed in areas where severe run-off-roadway accidents had occurred already.

Table 15. Estimation of property damage and possible injury probabilities of *Urban* section run-off-roadway accident severity conditioned on no evident injury

Variable	Estimated Coefficients	t-statistic
Constant (specific to property damage only)	2.722	4.282
Temporal characteristics		
Night time indicator (1 if run-off-roadway accidents occurred at night time, 0 otherwise; specific to property damage only)	0.809	1.507
Peak hour indicator (1 if run-off-roadway accidents occurred in the peak hours, 0 otherwise; specific to property damage only)	-0.483	-1.092
Winter month indicator (1 if November, December or January, 0 otherwise; specific to property damage only)	-0.731	-1.565
Year of occurrence indicator 1 (1 if 1994, 0 otherwise; specific to possible injury)	0.536	1.301
Environmental characteristics		
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to property damage only)	-0.922	-1.932
Driver characteristics		
Alcohol impaired driving indicator 1 (1 if driver had been drinking and ability impaired, 0 otherwise; specific to property damage only)	-1.456	-2.195
Roadway characteristics		
Curve indicator (1 if run-off-roadway accidents occurred on a horizontal curve, 0 otherwise; specific to property damage only)	-0.807	-1.840
Roadside characteristics		
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise; specific to possible injury)	1.707	1.383
Fence indicator (1 if the presence of fences, 0 otherwise; specific to possible injury)	1.210	1.682
Guardrail indicator (1 if the presence of guardrails, 0 otherwise; specific to possible injury)	0.934	1.440

Table 15. Estimation of property damage and possible injury probabilities of *Urban* section run-off-roadway accident severity conditioned on no evident injury (Continued)

Variable	Estimated Coefficients	t-statistic
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to possible injury)	-2.834	-1.834
Isolated tree indicator (1 if the presence of isolated trees, 0 otherwise; specific to property damage only)	-3.017	-2.278
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to possible injury)	-1.235	-1.159
Restricted Log-likelihood	-131.70	
Log-likelihood at Convergence	-87.20	
Number of Observations	190	
ρ^2	0.34	

Table 16. Estimation of overall nested logit model of *Urban* section run-off-roadway accident severity probabilities

Variable	Estimated Coefficients	t-statistic
Constant (specific to evident injury)	-3.994	-3.042
Constant (specific to disabling injury/fatality)	-3.997	-3.339
Temporal characteristics		
Day time indicator (1 if run-off-roadway accidents occurred at day time, 0 otherwise; specific to no evident injury)	-0.777	-2.075
Night time indicator (1 if run-off-roadway accidents occurred at night time, 0 otherwise; specific to no evident injury and evident injury)	1.727	1.506
Summer month indicator (1 if June, July, August or September, 0 otherwise; specific to evident injury and disabling injury/fatality)	0.629	1.632
Weekday indicator (1 if run-off-roadway accidents occurred during weekday, 0 otherwise; specific to no evident injury)	0.616	1.701
Weekend indicator (1 if run-off-roadway accidents occurred during weekend, 0 otherwise; specific to disabling injury/fatality)	-1.183	-1.358
Year of occurrence indicator 2 (1 if 1995, 0 otherwise; specific to no evident injury and disabling injury/fatality)	-0.482	-1.305
Environmental characteristics		
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to no evident injury)	-1.068	-2.005
Raining weather indicator (1 if run-off-roadway accidents occurred in the raining weather condition, 0 otherwise; specific to disabling injury/fatality)	1.120	1.141
Wet road surface indicator (1 if run-off-roadway accidents occurred on a wet road surface, 0 otherwise; specific to evident injury and disabling injury/fatality)	0.870	1.515
Driver characteristics		
Alcohol impaired driving indicator 2 (1 if driver had not been drinking, 0 otherwise; specific to no evident injury and evident injury)	1.389	1.500

Table 16. Estimation of overall nested logit model of *Urban* section run-off-roadway accident severity probabilities (Continued)

Variable	Estimated Coefficients	t-statistic
Contributing cause indicator 4 (1 if "inattention" was the primary contributing cause, 0 otherwise; specific to no evident injury and evident injury)	2.306	2.628
Old age driver indicator (1 if driver is at age of 60 or older, 0 otherwise; specific to no evident injury)	1.055	1.243
Residence location indicator 1 (1 if run-off-roadway accidents occurred within 24 kilometers of residence, 0 otherwise; specific to evident injury)	1.937	1.784
Residence location indicator 2 (1 if run-off-roadway accidents occurred more than 24 kilometers of residence, 0 otherwise; specific to evident injury and disabling injury/fatality)	-1.788	-1.555
Young age driver indicator (1 if driver is at age of 25 or younger, 0 otherwise; specific to evident injury and disabling injury/fatality)	0.366	1.006
Roadway characteristics		
Curve indicator (1 if run-off-roadway accidents occurred on a horizontal curve, 0 otherwise; specific to no evident injury and evident injury)	-1.116	-1.412
High posted speed indicator (1 if the posted speed limit was 84 km/h or more, 0 otherwise; specific to no evident injury)	-0.650	-1.764
Roadside characteristics		
Bridge indicator (1 if the presence of bridges, 0 otherwise; specific to disabling injury/fatality)	1.465	1.565
Ditch indicator (1 if the presence of ditches, 0 otherwise; specific to no evident injury)	0.964	1.217
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to no evident injury and disabling injury/fatality)	-1.093	-1.997
Tree group indicator (1 if the presence of tree groups, 0 otherwise; specific to disabling injury/fatality)	3.290	2.923

Table 16. Estimation of overall nested logit model of *Urban* section run-off-roadway accident severity probabilities (Continued)

Variable	Estimated Coefficients	t-statistic
Inclusive value of property damage and possible injury (L_{in}, specific to no evident injury)	0.242	2.345
Restricted Log-likelihood	-272.46	
Log-likelihood at Convergence	-134.11	
Number of Observations	248	
ρ^2	0.51	

Table 17. Estimation of property damage and possible injury probabilities of *Rural* section run-off-roadway accident severity conditioned on no evident injury

Variable	Estimated Coefficients	t-statistic
Constant (specific to property damage only)	3.230	3.868
Temporal characteristics		
Summer month indicator (1 if June, July, August or September, 0 otherwise; specific to possible injury)	1.160	2.440
Year of occurrence indicator 2 (1 if 1995, 0 otherwise; specific to property damage only)	-0.773	-1.837
Environmental characteristics		
Clear/cloudy weather indicator(1 if run-off-roadway accidents occurred in the clear or cloudy weather condition, 0 otherwise; specific to property damage only)	-1.123	-1.693
Wet road surface indicator (1 if run-off-roadway accidents occurred on a wet road surface, 0 otherwise; specific to possible injury)	1.057	1.663
Driver characteristics		
Alcohol impaired driving indicator 2 (1 if driver had not been drinking, 0 otherwise; specific to property damage only)	-0.625	-1.299
Contributing cause indicator 4 (1 if "inattention" is the primary contributing cause, 0 otherwise; specific to property damage only)	0.693	1.106
Young age driver indicator (1 if driver is at age of 25 or younger, 0 otherwise; specific to property damage only)	-1.167	-2.352
Roadway characteristics		
Curve indicator (1 if run-off-roadway accidents occurred on a horizontal curve, 0 otherwise; specific to property damage only)	-0.815	-1.907
Roadside characteristics		
Culvert indicator (1 if the presence of culverts, 0 otherwise; specific to property damage only)	-1.727	-1.373
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to property damage only)	1.242	1.732

Table 17. Estimation of property damage and possible injury probabilities of *Rural* section run-off-roadway accident severity conditioned on no evident injury (Continued)

Variable	Estimated Coefficients	t-statistic
Luminaire indicator (1 if the presence of luminaires, 0 otherwise; specific to property damage only)	-2.771	-1.438
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to possible injury)	-2.044	-1.857
Utility pole indicator (1 if the presence of utility poles, 0 otherwise; specific to possible injury)	2.179	2.030
Restricted Log-likelihood	-122.00	
Log-likelihood at Convergence	-77.92	
Number of Observations	176	
ρ^2	0.36	

Table 18. Estimation of overall nested logit model of *Rural* section run-off-roadway accident severity probabilities

Variable	Estimated Coefficients	t-statistic
Constant (specific to evident injury)	-2.084	-1.522
Constant (specific to disabling injury/fatality)	-2.144	-1.492
Temporal characteristics		
Day time indicator (1 if run-off-roadway accidents occurred at day time, 0 otherwise; specific to no evident injury)	-0.497	-1.275
Peak hour indicator (1 if run-off-roadway accidents occurred in the peak hours, 0 otherwise; specific to no evident injury)	-1.287	-3.065
Weekend indicator (1 if run-off-roadway accidents occurred during weekend, 0 otherwise; specific to disabling injury/fatality)	-1.280	-1.857
Year of occurrence indicator 1 (1 if 1994, 0 otherwise; specific to evident injury and disabling injury/fatality)	-0.510	-1.317
Environmental characteristics		
Clear/cloudy weather indicator (1 if run-off-roadway accidents occurred in the clear or cloudy weather condition, 0 otherwise; specific to no evident injury)	-1.086	-1.840
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to no evident injury)	-1.992	-3.542
Wet road surface indicator (1 if run-off-roadway accidents occurred on a wet road surface, 0 otherwise; specific to evident injury and disabling injury/fatality)	1.968	2.943
Driver characteristics		
Alcohol impaired driving indicator 1 (1 if driver had been drinking and ability impaired, 0 otherwise; specific to no evident injury and evident injury)	-1.231	-2.085
Contributing cause indicator 1 (1 if "exceeded reasonably safe speed" was the primary contributing cause, 0 otherwise; specific to evident injury)	0.895	2.159

Table 18. Estimation of overall nested logit model of *Rural* section run-off-roadway accident severity probabilities (Continued)

Variable	Estimated Coefficients	t-statistic
Roadway characteristics		
Asphalt indicator (1 if the surface of the shoulder is asphalt, 0 otherwise; specific to evident injury and disabling injury/fatality)	-1.795	-1.527
High posted speed indicator (1 if the posted speed limit was 84 km/h or more, 0 otherwise; specific to disabling injury/fatality)	0.805	1.375
Narrow shoulder indicator (1 if shoulder width is less than or equal to 1.98 meters, 0 otherwise; specific to no evident injury and evident injury)	1.055	1.715
Roadside characteristics		
Guardrail indicator (1 if the presence of guardrails, 0 otherwise; specific to disabling injury/fatality)	1.274	1.111
Miscellaneous fixed object indicator (1 if the presence of miscellaneous fixed objects, 0 otherwise; specific to no evident injury)	1.070	1.281
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to evident injury and disabling injury/fatality)	-1.188	-1.719
Tree group indicator (1 if the presence of tree groups, 0 otherwise; specific to no evident injury)	-1.434	-2.796
Utility pole indicator (1 if the presence of utility poles, 0 otherwise; specific to evident injury and disabling injury/fatality)	-1.093	-1.452
Inclusive value of property damage and possible injury (L_{in}, specific to no evident injury)	0.247	2.102
Restricted Log-likelihood	-264.77	
Log-likelihood at Convergence	-153.13	
Number of Observations	241	
ρ^2	0.42	

Variable: Isolated tree indicator

Finding: Decreases the probability of PDO relative to possible injury

The presence of isolated trees was associated with a lower probability of property damage only in urban areas, indicating that collisions with trees are likely to result in injury accidents.

Variable: Sign support indicator

Finding: Decreases the probability of possible injury relative to PDO

The presence of sign supports was less likely to result in possible injury. It seems plausible that increased attentiveness to road signs likely reduces run-off-roadway accident severities for *Urban* sections.

Variable: Summer month indicator

Finding: Increases the probability of evident injury and disabling injury/fatality

This indicator showed that accidents are more severe in *Urban* sections in the summer. During the summer, the effects of good weather and dry pavement conditions may allow vehicles to drive faster and alter driver behavior, thus creating an increased risk of being injured or killed in run-off-roadway accidents.

Variable: Raining weather indicator

Finding: Increases the probability of disabling injury/fatality

Run-off-roadway accidents resulting from loss of control and loss of visibility were more likely to be severe in rainy weather. It seems plausible that, during a rainfall, drivers do not pay attention to the roadside surroundings because much of their attention is directed toward headways to maintain appropriate reaction times. This may explain severe crash rates for *Urban* sections in rainy weather.

Variable: Alcohol impaired driving indicator 2

Finding: Increases the probability of no evident injury and evident injury

This common finding indicated that, if a driver had not been drinking, a run-off-roadway accident would be less likely to be a disabling injury/fatality.

Variable: Old age driver indicator

Finding: Increases the probability of no evident injury

Unlike the finding shown in Table 13, the old age driver indicator was associated with a lower probability of severe run-off-roadway accidents for *Urban* sections.

Variable: Young age driver indicator

Finding: Increases the probability of evident injury and disabling injury/fatality

As shown in much of the extant accident research, this variable indicated that young age drivers were more likely to be involved in severe injury accidents on *Urban* sections. This could relate to a lack of driving experience, inability to change steering control, and the intrinsic nature of youths to take more risks.

Variable: Ditch indicator

Finding: Increases the probability of no evident injury

Run-off-roadway accidents involving ditches were less likely to be severe in *Urban* sections. In viewing Table 2, even though ditches appear to be the third leading cause of fixed-objects crashes, they are not associated with a higher probability of severe injury. This could be because of fewer ditches on *Urban* sections than on *Rural* sections.

Variable: Culvert indicator

Finding: Decreases the probability of PDO relative to possible injury

The culvert indicator was associated with a higher probability of possible injury relative to PDO in *Rural* sections. Even though culvert end structures are generally located outside the designated roadside recovery area, slant roadsides around the culverts may not allow errant vehicles to be brought under control.

Variable: Luminaire indicator

Finding: Decreases the probability of PDO relative to possible injury

The luminaire indicator was also associated with a higher probability of possible injury relative to PDO in *Rural* sections. This could be because luminaires have been installed at areas with an already higher observed run-off-roadway accident severity, so we would expect a greater likelihood of possible injury accidents relative to PDO.

Variable: Asphalt indicator

Finding: Decreases the probability of evident injury and disabling injury/fatality

The finding indicated that, if the shoulder surface type was not gravel or curbed but asphalt, run-off-roadway accidents were less likely to be severe in *Rural* sections. This variable further confirms the finding offered by Ogden (1997), which indicated that shoulder paving is associated with a statistically significant reduction in the severity of accidents.

Variable: Miscellaneous fixed object indicator

Finding: Increases the probability of no evident injury

Miscellaneous fixed objects are devices such as mail boxes, signal boxes, antenna towers, phone booths, power meters and large rocks that are found along a roadway. The finding indicated that the presence of miscellaneous fixed objects was more likely to result in no evident injury accidents. This could be because miscellaneous fixed objects are farther away from the roadway (average distance from shoulder edge is 1.19 meters), and their size does not result in severe accidents.

Elasticity Analysis

As with the accident frequency models, elasticities were estimated to examine the marginal effects of the variables in the lower and upper nests of three models. Elasticity is defined as

$$E_{x_n}^{P_n(i)} = \frac{\partial P_n(i)}{\partial x_n} \times \frac{x_n}{P_n(i)} \qquad (3.10)$$

where E is the direct elasticity,

x_n is the value of the variables being considered to have effects on the run-off-roadway accident severity i, and

$P_n(i)$ is the probability of a run-off-roadway accident n being of severity i.

Given equations 3.5 and 3.10, the following can be written,

$$E_{x_n}^{P_n(i)} = [1 - \sum_{I=I_n} P_n(i)]\beta_i x_n \qquad (3.11)$$

where I_n is the set of severity levels that have variable x_n in the severity function (i.e., S_{in} in equation 3.2), and

β_i is the estimated coefficient corresponding to the variable.

However, the elasticity in equation 3.11 is only appropriate for continuous variables such as traffic volume, age, or speed. It is not valid for the non-continuous indicator variables (i.e., those dummy variables that take on values of zero or one). For indicator variables, a "pseudo-elasticity" was used to estimate an approximate elasticity of the variables. The pseudo-elasticity is defined as,

$$E_{x_n}^{P_n(i)} = \frac{\exp[\Delta(\beta_i X_n)]\sum_{I}\exp(\beta_i x_n)}{\exp[\Delta(\beta_i X_n)]\sum_{I=I_n}\exp(\beta_i X_n) + \sum_{I\neq I_n}\exp(\beta_i X_n)} - 1 \qquad (3.12)$$

The elasticities for each independent variable in the lower nest are shown in tables 19 to 21. Interpretation is straightforward. For example, the elasticity of the intersection indicator shown in Table 19 is 0.220 for possible injury. This means that, given a vehicle is involved in a no evident injury run-off-roadway accident (property damage only and possible injury), the driver is 22.0 percent more likely to have a possible injury if the run-off-roadway accident site has an intersection. Other examples include cut slope or fence indicator variables in Table 20, with an absolute value of elasticity greater than 1, they are considered "elastic." Their elasticities are 2.263 and 1.399 for possible injury, respectively. This means that, given a vehicle involved in an *Urban* section, no evident injury run-off-roadway accident, there is a 226.3 percent or 139.9 percent increase in the probability of possible injury if the run-off-roadway accident site presents a cut slope or a fence, respectively. The results in tables 19 to 21 show that only the guardrail, cut slope, fence, or utility pole indicators were found to be elastic. This underscores the importance of these four variables in estimating run-off-roadway accident severity.

Table 19. Elasticity estimates for *Total* section run-off-roadway accident severity

Variable	Elasticity
Elasticity estimates for variables conditioned on no evident injury	
Night time indicator (specific to property damage only)	0.120
Dry road surface indicator (specific to property damage only)	-0.192
Alcohol impaired driving indicator 1 (specific to property damage only)	-0.269
Contributing cause indicator 4 (specific to property damage only)	0.174
Old driver indicator (specific to possible injury)	0.609
Broad lane indicator (specific to property damage only)	0.144
Curve indicator (specific to property damage only)	-0.161
Bridge indicator (specific to possible injury)	0.601
Catch basin indicator (specific to property damage only)	-0.282
Cut side slope indicator (specific to possible injury)	0.961
Guardrail indicator (specific to possible injury)	1.148
Intersection indicator (specific to property damage only)	0.220
Elasticity estimates for variables of overall nested logit model	
Day time indicator (specific to no evident injury)	-0.243
Peak hour indicator (specific to no evident injury)	-0.194
Weekday indicator (specific to no evident injury)	0.106
Weekend indicator (specific to disabling injury/fatality)	-0.556
Dry road surface indicator (specific to no evident injury)	-0.331
Wet road surface indicator (specific to evident injury and disabling injury/fatality)	1.244
Contributing cause indicator 1 (specific to disabling injury/fatality)	-0.475
Residence location indicator 1 (specific to evident injury)	4.234
Residence location indicator 2 (specific to evident injury and disabling injury/fatality)	-0.800
High posted speed indicator (specific to evident injury and disabling injury/fatality)	0.247
Median indicator (specific to no evident injury)	0.150
Narrow shoulder indicator (specific to no evident injury)	0.140
Bridge indicator (specific to disabling injury/fatality)	1.886
Intersection indicator (specific to no evident injury and evident injury)	-0.005
Tree group indicator (specific to no evident injury)	-0.280
Utility pole indicator (specific to disabling injury/fatality)	-0.686

Table 20. Elasticity estimates for *Urban* section run-off-roadway accident severity

Elasticity estimates for variables conditioned on no evident injury	
Variable	Elasticity
Night time indicator (specific to property damage only)	0.147
Peak hour indicator (specific to property damage only)	-0.107
Dry road surface indicator (specific to property damage only)	-0.213
Alcohol impaired driving indicator 1 (specific to property damage only)	-0.346
Curve indicator (specific to property damage only)	-0.185
Cut side slope indicator (specific to possible injury)	2.263
Fence indicator (specific to possible injury)	1.399
Guardrail indicator (specific to possible injury)	0.995
Intersection indicator (specific to possible injury)	-0.921
Isolated tree indicator (specific to property damage only)	-0.685
Sign support indicator (specific to possible injury)	-0.649
Elasticity estimates for variables of overall nested logit model	
Day time indicator (specific to no evident injury)	-0.206
Night time indicator (specific to no evident injury and evident injury)	0.003
Weekday indicator (specific to no evident injury)	0.152
Weekend indicator (specific to disabling injury/fatality)	-0.686
Dry road surface indicator (specific to no evident injury)	-0.283
Wet road surface indicator (specific to evident injury and disabling injury/fatality)	0.836
Alcohol impaired driving indicator 2 (specific to no evident injury and evident injury)	0.003
Contributing cause indicator 4 (specific to no evident injury and evident injury)	0.004
Old age driver indicator (specific to no evident injury)	0.247
Residence location indicator 1 (specific to evident injury)	2.715
Residence location indicator 2 (specific to evident injury and disabling injury/fatality)	-0.770
Young age driver indicator (specific to evident injury and disabling injury/fatality)	0.303
Curve indicator (specific to no evident injury and evident injury)	-0.004
High posted speed indicator (specific to no evident injury)	-0.173
Bridge indicator (specific to disabling injury/fatality)	3.071
Ditch indicator (specific to no evident injury)	0.228
Sign support indicator (specific to no evident injury and disabling injury/fatality)	-0.267
Tree group indicator (specific to disabling injury/fatality)	20.196

Table 21. Elasticity estimates for *Rural* section run-off-roadway accident severity

Elasticity estimates for variables conditioned on no evident injury	
Variable	Elasticity
Wet road surface indicator (specific to possible injury)	1.130
Alcohol impaired driving indicator 2 (specific to property damage only)	-0.148
Contributing cause indicator 4 (specific to property damage only)	0.138
Young age indicator (specific to property damage only)	0.215
Curve indicator (specific to property damage only)	-0.197
Culvert indicator (specific to property damage only)	-0.434
Intersection indicator (specific to property damage only)	0.226
Luminaire indicator (specific to property damage only)	-0.675
Sign support indicator (specific to possible injury)	-0.829
Utility pole indicator (specific to possible injury)	3.017
Elasticity estimates for variables of overall nested logit model	
Day time indicator (specific to no evident injury)	-0.170
Peak hour indicator (specific to no evident injury)	-0.330
Weekend indicator (specific to disabling injury/fatality)	-0.693
Dry road surface indicator (specific to no evident injury)	-0.599
Wet road surface indicator (specific to evident injury and disabling injury/fatality)	1.911
Alcohol impaired driving indicator 1 (specific to no evident injury and evident injury)	-0.176
Contributing cause indicator 1 (specific to evident injury)	0.893
Asphalt indicator (specific to evident injury and disabling injury/fatality)	-0.740
High posted speed indicator (specific to disabling injury/fatality)	0.999
Narrow shoulder indicator (specific to no evident injury and evident injury)	0.009
Guardrail indicator (specific to disabling injury/fatality)	1.922
Miscellaneous fixed object indicator (specific to no evident injury)	0.362
Sign support indicator (specific to evident injury and disabling injury/fatality)	-0.573
Tree group indicator (specific to no evident injury)	-0.459
Utility pole indicator (specific to evident injury and disabling injury/fatality)	-0.541

Table 22. Summary of property damage only and possible injury probabilities of run-off-roadway accident severity conditioned on no evident injury

Variable	Estimated Coefficients		
	Total	Urban	Rural
Constant (specific to property damage only)	2.052	2.722	3.230
Temporal characteristics			
Night time indicator (1 if run-off-roadway accidents occurred at night time, 0 otherwise; specific to property damage only)	0.608	0.809	
Peak hour indicator (1 if run-off-roadway accidents occurred in the peak hours, 0 otherwise; specific to property damage only)		-0.483	
Summer month indicator (1 if June, July, August or September, 0 otherwise; specific to possible injury)			1.160
Winter month indicator (1 if November, December or January, 0 otherwise; specific to property damage only)		-0.731	
Winter month indicator (1 if November, December or January, 0 otherwise; specific to possible injury)	0.494		
Year of occurrence indicator 1 (1 if 1994, 0 otherwise; specific to possible injury)		0.536	
Year of occurrence indicator 2 (1 if 1995, 0 otherwise; specific to property damage only)	-0.378		-0.773
Environmental characteristics			
Clear/cloudy weather indicator (1 if run-off-roadway accidents occurred in the clear or cloudy weather condition, 0 otherwise; specific to property damage only)			-1.123
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to property damage only)	-0.764	-0.922	
Wet road surface indicator (1 if run-off-roadway accidents occurred on a wet road surface, 0 otherwise; specific to possible injury)			1.057
Driver characteristics			
Alcohol impaired driving indicator 1 (1 if driver had been drinking and ability impaired, 0 otherwise; specific to property damage only)	-1.040	-1.456	
Alcohol impaired driving indicator 2 (1 if driver had not been drinking, 0 otherwise; specific to property damage only)			-0.625
Contributing cause indicator 4 (1 if "inattention" was the primary contributing cause, 0 otherwise; specific to property damage only)	0.951		0.693
Old age driver indicator (1 if driver is at age of 60 or older, 0 otherwise; specific to possible injury)	0.653		

Table 22. Summary of property damage only and possible injury probabilities of run-off-roadway accident severity conditioned on no evident injury (Continued)

Variable	Estimated Coefficients		
	Total	Urban	Rural
Young age driver indicator (1 if driver is at age of 25 or younger, 0 otherwise; specific to property damage only)			-1.167
Roadway characteristics			
Broad lane indicator (1 if lane width is greater than 3.69 meters, 0 otherwise; specific to property damage only)	0.748		
Curve indicator (1 if run-off-roadway accidents occurred on a horizontal curve, 0 otherwise; specific to property damage only)	-0.648	-0.807	-0.815
Roadside characteristics			
Bridge indicator (1 if the presence of bridges, 0 otherwise; specific to possible injury)	0.644		
Catch basin indicator (1 if the presence of catch basins, 0 otherwise; specific to property damage only)	-1.087		
Culvert indicator (1 if the presence of culverts, 0 otherwise; specific to property damage only)			-1.727
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise; specific to possible injury)	0.955	1.707	
Fence indicator (1 if the presence of fences, 0 otherwise; specific to possible injury)		1.210	
Guardrail indicator (1 if the presence of guardrails, 0 otherwise; specific to possible injury)	1.102	0.934	
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to property damage only)	1.306		1.242
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to possible injury)		-2.834	
Isolated tree indicator (1 if the presence of isolated trees, 0 otherwise; specific to property damage only)		-3.017	
Luminaire indicator (1 if the presence of luminaires, 0 otherwise; specific to property damage only)			-2.771
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to possible injury)		-1.235	-2.044
Utility pole indicator (1 if the presence of utility poles, 0 otherwise; specific to possible injury)			2.179

Table 23. Summary of overall nested logit model results of run-off-roadway accident severity

Variable	Estimated Coefficients		
	Total	Urban	Rural
Constant (specific to evident injury)	-4.211	-3.994	-2.084
Constant (specific to disabling injury/fatality)	-2.806	-3.997	-2.144
Temporal characteristics			
Day time indicator (1 if run-off-roadway accidents occurred at day time, 0 otherwise; specific to no evident injury)	-0.766	-0.777	-0.497
Night time indicator (1 if run-off-roadway accidents occurred at night time, 0 otherwise; specific to no evident injury and evident injury)		1.727	
Peak hour indicator (1 if run-off-roadway accidents occurred in the peak hours, 0 otherwise; specific to no evident injury)	-0.709		-1.287
Summer month indicator (1 if June, July, August or September, 0 otherwise; specific to evident injury and disabling injury/fatality)		0.629	
Weekday indicator (1 if run-off-roadway accidents occurred during weekday, 0 otherwise; specific to no evident injury)	0.328	0.616	
Weekend indicator (1 if run-off-roadway accidents occurred during weekend, 0 otherwise; specific to disabling injury/fatality)	-0.844	-1.183	-1.280
Year of occurrence indicator 1 (1 if 1994, 0 otherwise; specific to evident injury and disabling injury/fatality)			-0.510
Year of occurrence indicator 2 (1 if 1995, 0 otherwise; specific to no evident injury and disabling injury/fatality)		-0.482	
Environmental characteristics			
Clear/cloudy weather indicator (1 if run-off-roadway accidents occurred in the clear or cloudy weather condition, 0 otherwise; specific to no evident injury)	-0.790		-1.086
Dry road surface indicator (1 if run-off-roadway accidents occurred on a dry road surface, 0 otherwise; specific to no evident injury)	-1.065	-1.068	-1.992
Raining weather indicator (1 if run-off-roadway accidents occurred in the raining weather condition, 0 otherwise; specific to disabling injury/fatality)		1.120	
Wet road surface indicator (1 if run-off-roadway accidents occurred on a wet road surface, 0 otherwise; specific to evident injury and disabling injury/fatality)	1.320	0.870	1.968
Driver characteristics			
Alcohol impaired driving indicator 1 (1 if driver had been drinking and ability impaired, 0 otherwise; specific to no evident injury and evident injury)			-1.231

Table 23. Summary of overall nested logit model results of run-off-roadway accident severity (Continued)

Variable	Estimated Coefficients		
	Total	Urban	Rural
Alcohol impaired driving indicator 2 (1 if driver had not been drinking, 0 otherwise; specific to no evident injury and evident injury)		1.389	
Contributing cause indicator 1 (1 if "exceeded reasonably safe speed" was the primary contributing cause, 0 otherwise; specific to evident injury)			0.895
Contributing cause indicator 1 (1 if "exceeded reasonably safe speed" was the primary contributing cause, 0 otherwise; specific to disabling injury/fatality)	-0.672		
Contributing cause indicator 4 (1 if "inattention" was the primary contributing cause, 0 otherwise; specific to no evident injury and evident injury)		2.306	
Old age driver indicator (1 if driver is at age of 60 or older, 0 otherwise; specific to no evident injury)		1.055	
Residence location indicator 1 (1 if run-off-roadway accidents occurred within 24 kilometers of residence, 0 otherwise; specific to evident injury)	2.596	1.937	
Residence location indicator 2 (1 if run-off-roadway accidents occurred more than 24 kilometers of residence, 0 otherwise; specific to evident injury and disabling injury/fatality)	-2.044	-1.788	
Young age driver indicator (1 if driver is at age of 25 or younger, 0 otherwise; specific to evident injury and disabling injury/fatality)		0.366	
Roadway characteristics			
Asphalt indicator (1 if the surface of the shoulder is asphalt, 0 otherwise; specific to evident injury and disabling injury/fatality)			-1.795
Curve indicator (1 if run-off-roadway accidents occurred on a horizontal curve, 0 otherwise; specific to no evident injury and evident injury)		-1.116	
High posted speed indicator (1 if the posted speed limit was 84 km/h or more, 0 otherwise; specific to no evident injury)		-0.650	
High posted speed indicator (1 if the posted speed limit was 84 km/h or more, 0 otherwise; specific to evident injury and disabling injury/fatality)	0.336		
High posted speed indicator (1 if the posted speed limit was 84 km/h or more, 0 otherwise; specific to disabling injury/fatality)			0.805

Table 23. Summary of overall nested logit model results of run-off-roadway accident severity (Continued)

Variable	Estimated Coefficients		
	Total	Urban	Rural
Median indicator (1 if median is divided, 0 otherwise; specific to no evident injury)	0.468		
Narrow shoulder indicator (1 if shoulder width is less than or equal to 1.98 meters, 0 otherwise; specific to no evident injury)	0.437		
Narrow shoulder indicator (1 if shoulder width is less than or equal to 1.98 meters, 0 otherwise; specific to no evident injury and evident injury)			1.055
Roadside characteristics			
Bridge indicator (1 if the presence of bridges, 0 otherwise; specific to disabling injury/fatality)	1.166	1.465	
Ditch indicator (1 if the presence of ditches, 0 otherwise; specific to no evident injury)		0.964	
Guardrail indicator (1 if the presence of guardrails, 0 otherwise; specific to disabling injury/fatality)			1.274
Intersection indicator (1 if the presence of intersections, 0 otherwise; specific to no evident injury and evident injury)	-0.702		
Miscellaneous fixed object indicator (1 if the presence of miscellaneous fixed objects, 0 otherwise; specific to no evident injury)			1.070
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to no evident injury and disabling injury/fatality)		-1.093	
Sign support indicator (1 if the presence of sign supports, 0 otherwise; specific to evident injury and disabling injury/fatality)			-1.188
Tree group indicator (1 if the presence of tree groups, 0 otherwise; specific to no evident injury)	-0.891		-1.434
Tree group indicator (1 if the presence of tree groups, 0 otherwise; specific to disabling injury/fatality)		3.290	
Utility pole indicator (1 if the presence of utility poles, 0 otherwise; specific to evident injury and disabling injury/fatality)			-1.093
Utility pole indicator (1 if the presence of utility poles, 0 otherwise; specific to disabling injury/fatality)	-1.200		
Inclusive value of property damage and possible injury (L_{in}, specific to no evident injury)	0.293	0.242	0.247

As with the lower nest, the elasticities for each of the independent variables in the upper nest are shown in tables 19 to 21. They provide some interesting insights. For example, the elasticity of the high posted speed indicator shown in Table 19 is 0.247 for both evident injury and disabling injury/fatality. This means that, when a vehicle is involved in a run-off-roadway accident, the driver is 24.7 percent more likely to have both evident injury and disabling injury/fatality if the run-off-roadway accident site has a posted speed limit of 84 km/h or more. Other examples include the bridge or tree group indicator variables with an absolute value of elasticity greater than 1.0 in Table 20. Their elasticities are 3.071 and 20.20 for disabling injury/fatality, respectively. This means that when a vehicle is involved in an *Urban* section run-off-roadway accident, there is a 307.1 percent or 2,020 percent increase in the probability of a disabling injury if the run-off-roadway accident site has a bridge or a tree group, respectively. The results in tables 19 to 21 show that the wet road surface, residence location 1, bridge, tree group, and guardrail indicators also had absolute values of elasticity greater than 1.0. These findings underscore the importance of these five variables in estimating run-off-roadway accident severity and of accounting for environmental and driver characteristics as well as roadside feature characteristics.

SUMMARY OF FINDINGS

Three separate run-off-roadway accident severity models were estimated to better account for differences attributable to roadway location (i.e., *Total* sections, *Urban* sections, and *Rural* sections). Tables 22 and 23 comparatively summarize the findings. The findings indicated that there were many differences and similarities among roadway locations.

The effects of roadway geometric and roadside characteristics on run-off-roadway accident severity were studied with a nested logit model. The authors concluded that a nested logit model was the best structure in that it accounted for shared unobservables between property damage only and possible injury accidents. The models (*Total* sections, *Urban* sections, *Rural* sections) gave plausible estimates for the coefficients of the variables, and were roughly consistent with one another and with other models.

On the basis of the findings of this run-off-roadway accident study, it can be concluded that all temporal, environmental, driver-related, roadway, and roadside characteristics should be considered to address the roadside safety problem.

Above all things, even though the roadside recovery space cannot be expanded because of right-of-way limitations, it is strongly needed to prevent crashes from occurring and to reduce the severity of crashes.

Other findings indicated that the driver's inability—such as inattention, exceeding the speed limit, being alcohol impaired, a lack of driving experience, and ignorance of safety hazards—can have a significant effect on the likelihood of severe injury in run-off-roadway accidents.

CHAPTER 4
CONCLUSIONS AND RECOMMENDATIONS

This study provides empirical and methodological analysis of run-off-roadway accident frequency and severity. By accounting for relationships among roadway geometry, roadside characteristics, and run-off-roadway accident frequency and severity, this research analysis provides some direction needed to identify cost-effective countermeasures that will improve highway designs and decrease the probability of vehicles leaving the roadway and the severity of accidents when they do. Above all, it is important to keep vehicles on the roadway, but if a run-off-roadway accident cannot be avoided, there is a need to mitigate the consequences after the vehicle has left the roadway through improved designs of the roadway and roadside.

The results show that run-off-roadway accident frequencies and severities can be reduced by

- widening lanes, medians, bridges, or shoulders;
- relocating roadside fixed objects farther from the roadway; and
- flattening side slopes and the median.

Also, sufficient maintenance of the roadway and roadside is required. Tables 24 and 25 summarize the findings of the roadside feature variables.

Furthermore, this research provides an aid to highway design engineers in determining safe and cost-effective recovery areas. Expansion of the roadside recovery space is strongly needed to prevent crashes from occurring and to reduce the severity of crashes. The removal of unnecessary fixed objects along the roadside should be achieved through a comprehensive field survey and study of traffic operations requirements. This effort can contribute greatly to the safety of the roadway. It is better to remove a hazardous object completely from the roadside rather than relocate it farther from the roadway. However, relocation is preferable to shielding. Therefore, roadside features should only be used where needed and should be installed to function effectively.

With respect to future research, a notable limitation of the models is apparent: the need for additional roadside feature data for empirical analysis. Although the models are intuitively valid, they only explain the likelihood of run-off-roadway accidents on the northbound direction of SR 3. Because of limited data, research could not explore run-off-roadway accident frequencies and severities of other functional classes (Interstate, principal arterial, minor arterial and collector), nor for different regional areas (eastern or western Washington). The cost for roadside field data collection makes it difficult to develop the quantifiable models for the relationship between roadside-struck objects and run-off-roadway accidents, and there is still much work to be done as the quantity and quality of data sources continue to improve.

Table 24. Summary of findings of roadside feature variables of run-off-roadway accident frequency

Variable (*Urban* sections)	Frequency finding*
Bridge length (in meters)	+
Distance from outside shoulder edge to guardrail (in meters)	+
Fence length (in meters)	+
Number of isolated trees in a section	–
Number of miscellaneous fixed objects in a section	–
Number of sign supports in a section	–
Shoulder length (in meters)	–
Variable (*Rural* sections)	**Frequency finding***
Cut side slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise)	+
Distance from outside shoulder edge to guardrail (in meters)	+
Distance from outside shoulder edge to luminaire poles (in meters)	–
Number of isolated trees in a section	+

* "+" indicates variable increases accident frequency,
"-" indicates the variable decreases accident frequency

Table 25. Summary of findings of roadside feature variables of run-off-roadway accident severity

Variable (*Urban* sections)	Severity finding*				
	Lower nest		Upper nest		
	PDO	Possible injury	No evident injury	Evident injury	Disabling injury/ Fatality
Presence of bridges					√
Presence of cut-typed side slopes		√			
Presence of ditches			√		
Presence of fences		√			
Presence of guardrails		√			
Presence of intersections	√				
Presence of isolated trees		√			
Presence of sign supports	√			√	
Presence of tree groups					√

Variable (*Rural* sections)	Severity finding*				
	Lower nest		Upper nest		
	PDO	Possible injury	No evident injury	Evident injury	Disabling injury/ Fatality
Presence of culverts		√			
Presence of guardrails					√
Presence of intersections	√				
Presence of luminaires		√			
Presence of miscellaneous fixed objects			√		
Presence of sign supports	√		√		
Presence of tree groups				√	√
Presence of utility poles		√	√		

* "√ " indicates an increase in the probability of the severity outcome.

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APPENDIX A

NATIONAL DEPARTMENT OF TRANSPORTATION SURVEY

Washington State
Department of
Transportation

University of
Washington

TRAC
Washington State
Transportation
Center

The Washington State Department of Transportation (WSDOT), Washington State Transportation Center (TRAC) and the University of Washington are conducting research that will develop a standard method to collect roadside information and an estimate of likely accident severity resulting from roadside features. The WSDOT's method of priority programming for highway safety requires an analysis of the roadside features and inventories throughout highway corridors. In an attempt to determine the state of the art, the attached survey is being sent to DOTs across the nation. **We would appreciate your sending us related information, publications and brochures about your State's procedures and methods along with this survey.** Thank you, your participation is appreciated.

1. What State are you in? ______________________

2. Does your department have any methods for collecting an inventory of the roadside features throughout highway corridors?
   ☐ Yes ☐ No

3. Please specify which if any methods your department uses to collect an inventory of the roadside features throughout highway corridors.
   ____
   ____

4. Does your department employ methods for studying the probable severity of an accident, given that an accident occurs on a highway section?
   ☐ Yes ☐ No

5. Please specify which if any accident severity analysis methods your department uses to identify accident severity causality.
   ____
   ____

6. Contact person in your State for further information:

   Name:________________________ E-mail:__________________________
   Phone: _______________________ Fax: __________________________

When completed please use envelope provided and drop in any US mailbox. If you have questions, please contact Jinsun Lee (jinsun@u.washington.edu). Thank you.

APPENDIX B

NATIONAL DOT SURVEY CONTACT LIST

National DOT Survey Contact List

State	CONTACT NAME	Phone Number	Fax Number
Alabama	Waymon Benifield Bureau of Multimodal Transportation Alabama DOT 1409 Coliseum Boulevard, G-101 Montgomery, AL 36130-3050	(334) 242-6128	(334) 262-7658
Alaska	Kurt Smith State Traffic Engineer Alaska DOT&PF Headquarters office 3123 Channel Drive Juneau, AK 99801	(907) 465-6963	(907) 465-6992
Arizona	Bob Pike Arizona DOT 1841 W. Buchanan Phoenix, AZ 85007-3335	(602) 255-8228	(602) 255-7766
Arkansas	Mike Selig Traffic Safety Section Arkansas State Highway and Transportation Department Little Rock, AR 72203-2261	(501) 569-2000	(501) 569-2400
California	**Greg Tom** Caltrans Division of Traffic Operation P.O. Box 942874 Sacramento, CA 95814	(916) 654-5898	(916) 654-5266
Colorado	Jake Kononov Safety Programs Engineer Colorado DOT 4201 E. Arkansas Ave. Denver, CO 80222	(303) 757-9039	(303) 757-9459
Connecticut	John Vivari Division of Traffic Engineering Connecticut DOT P.O. Box 317546 Newington, CT 06131-7546	(860) 594-2712	**(860) 594-3376**
Delaware	Bruce E. Littleton **Delaware DOT** **P.O. Box 778** Dover, DE 19903	(302) 739-4361	(302) 739-3306
Florida	Pat Brady, P.E. State Safety Office 605 Suwannee Street Tallahassee, FL 32399	(850) 488-3546	(850) 922-2935
Georgia	M.G. Waters III, P.E. State Traffic Operations Engineer Georgia DOT # 2 Capital Square, S.W. Atlanta, GA 30334-1002	(404) 635-8038	(404) 635-8037
Hawaii	Jan Higaki Hawaii DOT 869 Punchbowl Street Honolulu, HI 96813	(808) 587-2180	(808) 587-2339

National DOT Survey Contact List (Continued)

State	Contact Name	Phone Number	Fax Number
Idaho	JoAnn Moore **Idaho Transportation Department** P.O. Box 7129, 3311 W. State Street Boise, ID 83707-1129	(208) 334-8101	(208) 334-4430
Illinois	Eugene D. Brenning P.E. Illinois DOT Division of Traffic Safety 3215 Executive Park Dr. Springfield, IL 62794	(217) 785-2364	(217) 782-9159
Indiana	John L. Nagle Chief, Roadway Management Indiana DOT 100 N. Senate Ave., Rm N808 IGCN Indianapolis, IN 46204	(317) 232-5464	(317) 232-5478
Kentucky	KEN AGENT Kentucky Transportation Center 176 CE/Transportation Bldg. University of Kentucky Lexington, KY 40506-0281	(502) 564-7183	(502) 564-3532
Louisiana	Daniel J. Magri P.O. Box 94245 Baton Rouge, LA 70804	(225) 358-9117	(225) 358-9151
Maine	Gerry Audibert Safety Management Coordinator Maine DOT 16 State House Station 35 Child Street Augusta, ME 04333-0016	(207) 287-3775	(207) 623-2526
Maryland	Thomas Hicks Director of Office of Traffic and Safety 7491 Connelley Drive Hanover, MD 21076	(410) 787-5815	(410) 787-4082
Massachusetts	Charles Sterling Massachusetts Highway Department 10 Park Plaza Boston, MA 02118-3973	(617) 973-7360	**(617) 973-8035**
Michigan	Dale Lighthizer Engineer of Traffic & Safety Michigan DOT P.O. Box 30050 Lansing, MI 48909	(517) 373-2334	(517) 373-2330
Minnesota	Loren Hill, P.E. State Traffic Safety Engineer Office of Traffic Engineering Minnesota DOT 1500 W County Road B2 Roseville, MN 55113	(651) 582-1044	(651) 582-1033
New Hampshire	**Steven Dubos** New Hampshire DOT P.O. Box 483 Concord, NH 0302-0483	(603) 271-3344	(603) 271-8093

National DOT Survey Contact List (Continued)

State	Contact Name	Phone Number	Fax Number
New Jersey	Steve Warren Bureau of Traffic Engineering & Safety Programs New Jersey DOT 1035 Parkway Avenue PO Box 600 Trenton, NJ 08625	(609) 530-3879	(609) 530-5253
New York	**Barbara R.W. O'Rourke** New York State DOT State Office Building Campus, Building 5 Albany, NY 12232	(518) 457-1910	(518) 457-1780
North Dakota	Robert Olzweski North Dakota DOT 608 East Boulevard Ave. Bismarck, ND 58506-0700	(701) 328-3479	(701) 328-1404
Ohio	Shirley Shokouhi Ohio DOT 25 S. Front Columbus, OH 43215	(614) 644-8181	(614) 644-8199
Oklahoma	Ken Hess 200 N.E. 21st Street Oklahoma City, OK 73105	(405) 521-4160	**(405) 521-2865**
Oregon	Steve Reed Oregon DOT 355 Capitol St. NE Salem, OR 97310	(503) 986-3608	(503) 986-4063
Pennsylvania	Devang Patel Bureau of Highway Safety and Traffic Engineering P.O. Box 2047 **Harrisburg, PA 17105-2047**	(717) 787-6853	(717) 787-9507
South Carolina	Dipak M. Patel South Carolina DOT P.O. Box 191 Columbia, SC 29202	(803) 737-1736	(803) 737-0271
Utah	Mack Christensen 4501 so 2700 west Salt lake City, UT 84114-3200	(801) 965-4264	(801) 965-3845
Washington	John C. Milton Washington State DOT P.O. Box 47320 Olympia, WA 98504-7370	(360) 705-7299	(360) 705-6518
West Virginia	**Ray Lewis** West Virginia Division of Highways, Building 5 1900 Kanawha Boulevard East Charleston, WV 25305	(304) 558-8912	(304) 558-1209
Wisconsin	Dick Lange Safety Analysis Engineer P.O. Box 7910 Madison, WI 53707-7910	(608) 266-1620	(608) 261-6295

APPENDIX C

DATA ELEMENTS FOR RUN-OFF-ROADWAY ACCIDENT FREQUENCY

Data Elements for run-off-roadway accident frequency

Variables	Definition (in a section)
Winter month indicator	Indicator variable (if November, December or January)
Summer month indicator	Indicator variable (if June, July, August, or September)
Year of occurrence indicator 1	Indicator variable (if 1994)
Year of occurrence indicator 2	Indicator variable (if 1995)
Year of occurrence indicator 3	Indicator variable (if 1996)
Accident database	
Total section frequency	Number of *Total* section run-off-roadway accidents
Urban section frequency	Number of *Urban* section run-off-roadway accidents
Rural section frequency	Number of *Rural* section run-off-roadway accidents
PDO frequency	Number of *PDO* run-off-roadway accidents
Possible injury frequency	Number of *Possible* injury run-off-roadway accidents
Evident injury frequency	Number of *Evident* injury run-off-roadway accidents
Disabling injury/*Fatality* frequency	Number of *Disabling* injury/*Fatality* run-off-roadway accidents
Kitsap County indicator	Indicator variable of the *Kitsap* county jurisdiction
Mason County indicator	Indicator variable of the *Mason* county jurisdiction
Urban location indicator	Indicator variable used to identify the urban region location
Rural location indicator	Indicator variable used to identify the rural region location
Roadway geometric database	
Lanes	Number of lanes in the direction of increasing mileposts
Lane width	Average width per lane of the roadway
Broad lane indicator	Indicator variable (if lane width is greater than 3.69 meters)
Narrow lane indicator	Indicator variable (if lane width is less than or equal to 3.69 meters)
Center shoulder width	Average center shoulder with of an increasing direction
Shoulder width	Average shoulder width of increasing direction
Median width	Average distance from inside shoulder edge to inside shoulder edge on a divided highway (median width includes inside shoulder)
Speed	Average posted speed limit (km/h)
High speed indicator	Indicator variable (if average posted speed limit is greater than or equal to 84 km/h)
Low speed indicator	Indicator variable (if average posted speed limit is less than 84 km/h)
Vertical curve	Number of vertical alignment curves of the roadway
High vertical curve indicator	Indicator variable (if number of vertical alignment curves are greater than 4)
Low vertical curve indicator	Indicator variable (if number of vertical alignment curves are less than or equal to 4)
Vertical curve length	Average vertical alignment curve length of the roadway
Vertical grade ahead sign	Number of vertical grade signs
Vertical grade ahead	Vertical grade
Curve length	Average horizontal alignment curve length of the roadway
Central angle	Central angle of the horizontal curve
Radius	Horizontal curve radius
AADT	Average Annual Daily Traffic (AADT) per lane average
High traffic indicator	Indicator variable (if AADT per lane is over 2,500 vehicles)
Truck volume	Total truck volumes as a percentage of AADT
Peak hour volume	Peak hour volume as a percentage of AADT
Roadway geometric database	
Intersection	Number of intersections
High intersection indicator	Indicator variable (if number of intersections are greater than 4)
Low intersection indicator	Indicator variable (if number of intersections are less than or equal to 4)

Data Elements for run-off-roadway accident frequency (Continued)

Roadside feature database	
Shoulder length	Shoulder length of increasing direction
Guardrail length	Total length of guardrail to prevent vehicles from leaving a roadway
Long guardrail indicator	Indicator variable (if guardrail length is greater than 96.5 meters)
Short guardrail indicator	Indicator variable (if guardrail length is less than or equal to 96.5 meters)
Guardrail distance	Average distance from outside shoulder edge to guardrail
Guardrail height	Average height of guardrail
Catch basins	Total number of catch basins used to hold storm water runoff along a roadway
Culvert	Total number of culverts (conduit for water beneath or alongside a roadway)
Ditch length	Total length of furrows, channels, trenches, swales that occur along a roadway
Long ditch indicator	Indicator variable (if ditch length is greater than 161 meters)
Short ditch indicator	Indicator variable (if ditch length is less than or equal to 161 meters)
Ditch distance	Average distance from outside shoulder edge to ditch
Ditch depth	Average depth of ditch
Fence length	Total length of fence used to minimize or prevent access to the area within WSDOT right-of-way that lies along a roadway
Fence distance	Average distance from outside shoulder edge to fence
Chain type indicator	Indicator variables (if the fence type is chain)
Hog type indicator	Indicator variables (if the fence type is hog)
Wood type indicator	Indicator variables (if the fence type is wood)
Unknown type indicator	Indicator variables (if the fence type is unknown)
Bridge length	Total length from the beginning of the bridge to end
Bridge indicator	Indicator variable (if the presence of bridges)
Overhead bridge indicator	Indicator variable (if the presence of overhead bridges)
Side slope length	Total side slope length from the beginning of the slope to end
Long side slope indicator	Indicator variable (if the length of side slope is greater than 210 meters)
Short side slope indicator	Indicator variable (if the length of side slope is less than or equal to 210 meters)
Side slope distance	Average distance from outside shoulder edge to beginning of the side slope
Cut side slope indicator	Indicator variable (if the presence of cut-typed side slopes)
Fill side slope indicator	Indicator variable (if the presence of fill-typed side slopes)
Miscellaneous fixed objects	Total number of miscellaneous fixed objects
Miscellaneous fixed objects distance	Average distance from outside shoulder edge to beginning of the miscellaneous fixed objects
Utility pole	Total number of utility poles (support used to hold up any utility fixture)
Utility pole distance	Average distance from outside shoulder edge to beginning of the utility pole
High utility pole indicator	Indicator variable (if the number of utility poles are greater than 10)
Low utility pole indicator	Indicator variable (if the number of utility poles are less than or equal to 10)
Sign support	Total number of sign supports (used to hold up any sign)
Sign support distance	Average distance from outside shoulder edge to beginning of the sign support
Luminaire	Total number of luminaire poles (light fixture supported by a pole)
High luminaire indicator	Indicator variable (if the number of luminaire poles are greater than 4)
Low luminaire indicator	Indicator variable (if the number of luminaire poles are less than or equal to 4)
Luminaire distance	Average distance from outside shoulder edge to beginning of the luminaire poles

Data Elements for run-off-roadway accident frequency (Continued)

Roadside feature database	
Tree group	Total number of any flora group with a trunk thickness of 3″ or greater occurring in the median area or in the maximum clear zone area adjacent to a roadway
Tree group distance	Average distance from outside shoulder edge to beginning of the tree groups whether mixed or uniform
Isolated trees	Total number of any isolated flora with a trunk thickness of 3″ diameter or greater occurring in the median area or in the maximum clear zone area adjacent to a roadway
Isolated trees distance	Average distance from outside shoulder edge to beginning of the isolated trees

APPENDIX D

DATA ELEMENTS FOR RUN-OFF-ROADWAY ACCIDENT SEVERITY

Data Elements for run-off-roadway accident severity

Accident database	
Variables	Definition
Year of occurrence indicator 1	Indicator variable (if run-off-roadway accidents occurred in the 1994)
Year of occurrence indicator 2	Indicator variable (if run-off-roadway accidents occurred in the 1995)
Year of occurrence indicator 3	Indicator variable (if run-off-roadway accidents occurred in the 1996)
Winter month indicator	Indicator variable (if run-off-roadway accidents occurred in November, December or January)
Summer month indicator	Indicator variable (if run-off-roadway accidents occurred in June, July, August, or September)
Weekday indicator	Indicator variable (if run-off-roadway accidents occurred on Monday, Tuesday, Wednesday, Thursday, or Friday)
Weekend indicator	Indicator variable (if run-off-roadway accidents occurred during Saturday or Sunday)
Peak hour indicator	Indicator variable (if run-off-roadway accidents occurred during the morning(6 to 9 am) or afternoon (3 to 6 pm) rush hours)
Night time indicator	Indicator variable (if run-off-roadway accidents occurred at night time)
Day time indicator	Indicator variable (if run-off-roadway accidents occurred at day time)
Dry road surface indicator	Indicator variable (if run-off-roadway accidents occurred on a dry road surface)
Wet road surface indicator	Indicator variable (if run-off-roadway accidents occurred on a wet road surface)
Snow road surface indicator	Indicator variable (if run-off-roadway accidents occurred on a snow road surface)
Ice road surface indicator	Indicator variable (if run-off-roadway accidents occurred on an icy road surface)
Clear/cloudy weather indicator	Indicator variable (if run-off-roadway accidents occurred in the clear or cloudy weather condition)
Raining weather indicator	Indicator variable (if run-off-roadway accidents occurred in the raining weather condition)
Snowing weather indicator	Indicator variable (if run-off-roadway accidents occurred in the snowing weather condition)
Foggy weather indicator	Indicator variable (if run-off-roadway accidents occurred in the foggy weather condition)
Residence location indicator 1	Indicator variable (if run-off-roadway accidents occurred within 24 kilometers of residence)
Residence location indicator 2	Indicator variable (if run-off-roadway accidents occurred more than 24 kilometers of residence)
Contributing cause indicator 1	Indicator variable (if "exceeded reasonably safe speed" was primary cause of the run-off-roadway accidents)
Contributing cause indicator 2	Indicator variable (if "following too closely" was primary cause of the run-off-roadway accidents)
Contributing cause indicator 3	Indicator variable (if "operating defective equipment" was primary cause of the run-off-roadway accidents)
Contributing cause indicator 4	Indicator variable (if "inattention" was primary cause of the run-off-roadway accidents)
Contributing cause indicator 5	Indicator variable (if "exceeded state speed limit" was primary cause of the run-off-roadway accidents)
Vehicle type indicator 1	Indicator variable (if vehicle involved in the run-off-roadway accidents was a passenger car)
Vehicle type indicator 2	Indicator variable (if vehicle involved in the run-off-roadway accidents was a small truck, pickup or panel delivery under 10,000 lbs.)
Alcohol impaired driving indicator 1	Indicator variable (if driver had been drinking and ability impaired)

Data Elements for run-off-roadway accident severity (Continued)

Accident database	
Alcohol impaired driving indicator 2	Indicator variable (if driver had not been drinking)
Young age driver indicator	Indicator variable (if driver is at age of 25 or younger)
Old age driver indicator	Indicator variable (if driver is at age of 60 or older)
Roadway geometric database	
Broad lane indicator	Indicator variable (if lane width is greater than 3.69 meters)
Narrow lane indicator	Indicator variable (if lane width is less than or equal to 3.69 meters)
Center asphalt indicator	Indicator variable (if the surface of the center shoulder is asphalt)
Center curb indicator	Indicator variable (if the presence of curb on any center shoulder)
Center soil indicator	Indicator variable (if the surface of the center shoulder is soil)
Broad center shoulder indicator	Indicator variable (if center shoulder width is greater than 1.07 meters)
Narrow center shoulder indicator	Indicator variable (if center shoulder width is less than or equal to 1.07 meters)
Asphalt indicator	Indicator variable (if the surface of the shoulder is asphalt)
Curb indicator	Indicator variable (if the presence of curb on any shoulder)
Soil indicator	Indicator variable (if the surface of the shoulder is soil)
Gravel indicator	Indicator variable (if the surface of the shoulder is gravel)
Broad shoulder indicator	Indicator variable (if shoulder width is greater than 1.98 meters)
Narrow shoulder indicator	Indicator variable (if shoulder width is less than or equal to 1.98 meters)
Median indicator 1	Indicator variable (if median is divided)
Median indicator 2	Indicator variable (if median is undivided)
High speed indicator	Indicator variable (if the posted speed limit is 84 km/h or more)
Low speed indicator	Indicator variable (if average posted speed limit is less than or equal to 84 km/h)
Curve indicator	Indicator variable (if run-off-roadway accidents occurred on a horizontal curve)
Straight indicator	Indicator variable (if run-off-roadway accidents occurred on a straight section)
Roadside feature database	
Guardrail indicator	Indicator variable (if the presence of the guardrails)
Catch basins indicator	Indicator variable (if the presence of the catch basins)
Culvert indicator	Indicator variable (if the presence of the culverts)
Sign support indicator	Indicator variable (if the presence of the sign supports)
Isolated trees indicator	Indicator variable (if the presence of the isolated trees)
Tree group indicator	Indicator variable (if the presence of the tree groups)
Ditch indicator	Indicator variable (if the presence of the ditches)
Fence indicator	Indicator variable (if the presence of the fences)
Cut side slope indicator	Indicator variable (if the presence of cut-typed side slopes)
Fill side slope indicator	Indicator variable (if the presence of fill-typed side slopes)
Miscellaneous fixed objects indicator	Indicator variable (if the presence of the miscellaneous fixed objects)
Utility pole indicator	Indicator variable (if the presence of the utility poles)
Luminaire indicator	Indicator variable (if the presence of luminaire poles)
Intersection indicator	Indicator variable (if the presence of intersections)
Bridge indicator	Indicator variable (if the presence of the bridges)