QUANTIFYING SAFETY PERFORMANCE OF DRIVEWAYS ON STATE HIGHWAYS

Final Report

SPR 720

Oregon Department of Transportation

QUANTIFYING SAFETY PERFORMANCE OF DRIVEWAYS ON STATE HIGHWAYS

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16. Abstract

This report documents a research effort to quantify the safety performance of driveways in the State of Oregon. In particular, this research effort focuses on driveways located adjacent to principal arterial state highways with urban or rural designations. This report includes safety performance functions (SPFs) that can be used to evaluate the safety impacts of various access management and driveway-related configurations on Oregon arterial corridors. The project team developed these safety metrics using statistical models and methodologies similar to those outlined in the *Highway Safety Manual* (HSM) published in 2010 by the American Association of State Highway and Transportation Officials (AASHTO). Instead of using a base condition SPF that included only segment length and traffic volume and then would need companion CMFs to fully analyze a corridor, the project team developed full model SPFs that do not require any additional adjustments. The resulting models varied for urban versus rural conditions, but type of land use and traffic volume were two consistently significant variables observed for both models. A companion "smart spreadsheet" accompanies this report to assist readers with implementation of the procedure.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

QUANTIFYING SAFETY PERFORMANCE OF DRIVEWAYS ON STATE HIGHWAYS

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EXECUTIVE SUMMARY

This report documents a research effort to quantify the safety performance of driveways in the State of Oregon. In particular, this research effort focuses on driveways located adjacent to principal arterial state highways with urban or rural designations. The primary goal of this research is to provide the Oregon Department of Transportation (ODOT) with safety performance functions (SPFs) or that can be used to evaluate the safety impacts of various access management and driveway-related configurations. The project team developed these safety metrics using statistical models and methodologies similar to those outlined in the *Highway Safety Manual* (HSM) published in 2010 by the American Association of State Highway and Transportation Officials (AASHTO). Instead of using a base condition SPF that included only segment length and traffic volume and then would need companion CMFs to fully analyze a corridor, the project team developed full model SPFs that do not require any additional adjustments. The resulting models varied for urban versus rural conditions, but type of land use and traffic volume were two consistently significant variables observed for both models.

Chapter 1 introduces the project and reviews the specific objectives of this research effort. Chapter 2 of this report includes a literature review summarizing the many factors known to affect driveway safety. A review of available data suitable for the assessment of access management related historical crash and roadway data is included in Chapter 3. Chapter 4 then summarizes in detail the variety of data elements acquired and considered and the companion data collection methodology. The data analysis and resulting models are then depicted in Chapter 5. Finally, Chapter 6 reviews and summarizes the overall research effort.

1.0 INTRODUCTION

Within the State of Oregon and throughout the United States, thousands of unpermitted driveways currently exist. Many of these driveways were in place prior to permit regulations, while others have been installed without proper approval. In addition, permit applications are filed on a daily basis to install new driveways or relocate existing access points. Because of this overload, decision makers are in need of a standard method to guide the access management decision process. This process should include considerations of capacity, operations, right-of-way constraints, and safety. Making decisions based on the performance measures that are not safety related should be fairly straight forward as the process relies on standard analysis procedures and readily available information. However, safety-based decisions are much more difficult as the process of quantifying safety for predictive and analysis purposes continues to evolve. This research is intended to provide a standardized approach for making access management decisions based primarily on safety and associated operations.

The primary goal of this research is to provide the Oregon Department of Transportation (ODOT) with safety performance functions (SPFs) that can be used to evaluate the safety impacts of various access management driveway-related configurations. Using statistical analyses, the project team investigated the relationship between safety (based on crash frequency) and common driveway-related access management techniques. This research identifies the key factors that affect driveway safety for Oregon principal urban and rural arterial state highways.

This report provides information that will allow ODOT to use computational methods to quantify the predicted safety performance of Oregon corridors with various driveway densities and adjacent land uses. Chapter 2.0 of this report includes a literature review that summarizes the many factors known to affect driveway safety. A review of available data suitable for the assessment of access management related historical crash and roadway data is included in Chapter 3.0. Chapter 4.0 then summarizes in detail the variety of data elements acquired and considered and the companion data collection methodology. The data analysis and resulting models are then depicted in Chapter 5.0. Chapter 6.0 reviews and summarizes the overall research effort. The report concludes with the references cited in this document (see Chapter 7.0), a list of common acronyms used throughout this report and summary data tables (see Chapter 8.0).

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The goal of this literature review is to identify the critical issues related to crash risk at driveways and provide an overview of previous research efforts in this area. In addition to the results of earlier research studies, the techniques and tools used in various analyses are of particular interest. Better understanding of the pros and cons of different analysis methods, as well as the overall lessons learned in other research efforts, sets the stage for the model results developed with this research effort.

2.2 FACTORS AFFECTING SAFETY PERFORMANCE OF DRIVEWAYS

Previous research has shown that the number of crashes at driveways is disproportionately high compared to crash rates at other types of intersections; thus, driveway safety is of particular importance (*AASHTO 2004*). The safety of driveways is a complex issue that is affected by several factors and the impact of each factor is dependent on the unique nature of each location. Table 2.1 summarizes the seven main factors identified in the published literature that are thought to affect driveway safety and the notable findings in each category. An expanded version of Table 2.1, including the corresponding referenced publications, is included as Table in the Appendix.

Table 2.1: Summary of Factors Affecting Driveway Safety Performance

Factor	Findings
Driveway Spacing	An increased access frequency or density (access points per mile) is associated with an increase in crashes.
Proximity to and between Intersections	An increased spacing between access points and intersections is associated with a decrease in crashes. Spacing distance should include perception-reaction distance, weaving distance, transition distance, and downstream storage.
Signalized Intersection Spacing and Signal Coordination	An increase in the number of signals per segment is associated with an increase in crashes. Progression and coordination should be maintained for adequate gaps and good operations.
Driveway Design	Typically, driveways should always have simultaneous two-way operations or restricted one-way operations, but not alternating flow. Use clear and delineated striping or channelization to clearly define vehicle paths. Limit conflicts between different road users (vehicles, pedestrians, bicyclists).
Road Design Elements	Wider lanes, medians, and shoulders are associated with a reduction in crashes. Bike lanes increase sight distance and on-street parking decreases sight distance, both of which impact safety. Auxiliary lanes may decrease crashes but should only be considered when warranted.

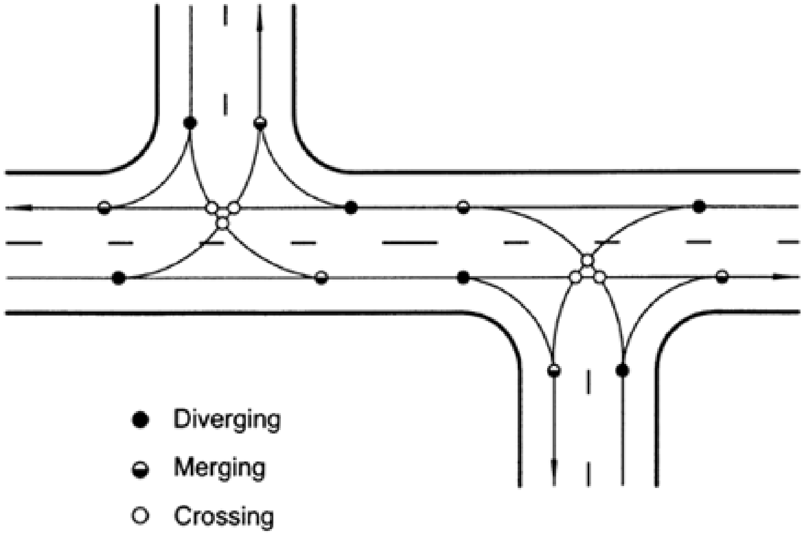
Land Use	A correlation between land use and number of crashes exists, but quantification of this correlation remains unclear. Actual geographic information systems (GIS) land use data may effectively be used instead of driveway frequency/type to enhance statistical models.
Median Configuration	Raised medians are typically safer than two-way left-turn lanes (TWLTLs), whereas, indirect left-turns are safer than direct left-turns. Longer distances between access points and downstream U-turn locations enhance safety.

As shown in Table 2.1, consideration of the seven main factors identified in the literature can significantly improve the safety and operations of access points for a highway segment. Crash rates associated with roadway segments characterized by full access control are between 50% and 75% less than for those segments without access control (*AASHTO 2004*).

The following report sections describe, in detail, the main factors affecting driveway safety and the major findings of previous research efforts associated with those factors.

2.2.1 Driveway Spacing

The majority of crashes at or near intersections are attributed to conflicts between vehicles. These include conflicts within the intersection (opposing turning movements) as well as at the end of a queue (the interaction of approaching vehicles with stopped vehicles). As the spacing of intersections or access points decreases, resulting in the more closely spaced access points, it is possible that the conflict areas of each individual intersection may interact with those of another. This additional conflict interaction poses an increased safety risk to all road users. This concept is presented graphically in Figure 2.1.



Source: Rodegerdts (2004)

Figure 2.1: Typical Vehicle Conflict Points Associated with Driveways

As shown in Figure 2.1, the number and type of conflict points associated with a given driveway or intersection is dependent on the permitted movements at each location. If adequate spacing between intersections is not provided, the individual conflict areas may overlap, introducing the potential for an increased number of conflict points. Previous research efforts have attempted to quantify this increased safety risk. Analysis results presented in the National Cooperative Highway Research Program (NCHRP) Report 420 (*Gluck, Levinson, and Stover 1999*) indicate that each additional access point (on a per-mile basis) is associated with a 4% increase in crash rates. This estimate is consistent with the results of other research efforts which estimate a 40% increase in crash rates at locations where access frequency had doubled (from 10 to 20 access points per mile) (*Papayannoulis et al. 1999*). Several additional researchers (*Brown and Tarko 1999; Mouskos et al. 1999; Eisele and Frawley 2005*) also reported a correlation between increased driveway density (frequency) and increased safety risk; however, these increases were not quantified.

2.2.2 Proximity to Intersections and Interchanges

As discussed in the previous section, the distance between access points can have a significant impact on safety operations. This is also true when considering the distance to adjacent intersections and interchanges.

Rakha et al. (*2008*) investigated the relationship between crash rates and the distance between a highway interchange and the nearest access point. Based on their analysis results, an access spacing increase from 300 feet to 600 feet could be expected to be associated with a crash rate reduction of 50% (*Rakha et al. 2008; Transportation Research Board 2003*). While the potential safety impacts were not quantified, Butorac and Wen (*2004*) concluded in NCHRP Synthesis 332 that the spacing between highway interchanges and access points is of high importance when implementing access management plans. NCHRP Report 420 (*Gluck, Levinson, and Stover 1999*) suggests that perception-reaction distance, weaving distance, transition distance, and storage requirements of the downstream access point be considered when determining the appropriate distance between access points and intersections or interchanges.

2.2.3 Signalized Intersection Spacing and Signal Coordination

As previously indicated, the distance between driveways and nearby intersections is an important factor when considering the safety of a given access point. This spacing is even more important when signalized intersections are present. Similar to the findings regarding unsignalized intersections, Stover (*1996*) reported that crash rates also increase as the number of signalized intersections per segment increase. Depending on the number of unsignalized access points along the same segment, increasing the signal density from two to four signals per mile can increase the average crash rate by up to 200% (*Transportation Research Board 2003*).

The safety of driveways is affected not only by the spacing of signalized intersections but also by the coordination of those signals. Proper signal coordination allows for adequate gaps in traffic in which left-turning vehicles can safely enter the roadway from an unsignalized intersection or driveway. If acceptable gaps are not present, impatient drivers may attempt to enter the roadway without adequate time or space to complete the movement, thereby increasing the potential for a crash.

Signal coordination along a roadway also significantly impacts the operations of a given segment. Optimal signal coordination is achieved when signal timings are properly established based on the roadway operating speeds, traffic volumes, and distance between signalized intersections. Because of this, any access point that is planned for signalization either in the short-term or long-term future should optimally be located such that progression and coordination can be maintained once signalization occurs. This will help to ensure that safety and operational goals are met for not only the driveway in question, but for other driveways along the corridor as well.

2.2.4 Driveway Design

To allow for the highest level of safety possible, all driveways should be designed according to the local, regional, and national standards that are applicable to each location. However, certain circumstances (e.g. unique sight distance issues) may require exceptions to these suggested design standards to ensure the safest operations possible. By maintaining a certain level of uniformity among all access points, driver expectations will be met, resulting in safer operations.

Gattis et al. (*2010*) present six major considerations for driveway design. These objectives include maintaining or improving the efficiency and safety of the intersecting roadway, providing a safe entrance and exit for all users, providing adequate sight distance for road and sidewalk users, incorporating the Americans with Disability Act (ADA) requirements into all design aspects, integrating any existing bicycle lanes and pedestrian paths, and supporting the requirements of public transportation when present.

Figure 2.2: Example of Clearly Defined Vehicle Paths

Other than a few rare exceptions, two-way driveways should always allow for simultaneous two-way operations and thus should provide separate entrance and exit lanes (*Stover and Koepke 2002*). Both one-way and two-way access points should not be excessively wide and lanes should be clearly defined (see Figure 2.2). Wide-open driveways that allow access to the full frontage of the lot should be prohibited as they negatively impact safety by introducing confusion and excess conflict points, particularly between vehicles and pedestrians or bicyclists (*Gattis et al. 2010*).

2.2.5 Road Design Elements

In addition to the driveway configuration, the design of the roadway can also affect the safety of a given access point. Elements such as sidewalks, bicycle lanes, auxiliary lanes, on-street parking, and shoulders are likely to have an impact on sight distance and driver behavior. Research conducted by Hadi et al. (*1995*) demonstrated that the widening of lanes, medians, and shoulders is associated with a reduction in crash rates. Other research efforts focused on the safety impacts based on stopping sight distance. It was suggested that bicycle lanes can increase sight distance and visibility for drivers, thereby improving driveway safety. In addition, the presence of on-street parking adjacent to driveways may decrease driveway safety by limiting visibility and sight distance (*Dixon, Van Schalkwyk, and Layton 2009*).

One of the major contributing factors to crashes at driveways is the speed differential between turning vehicles and through vehicles. When warranted and properly designed, auxiliary lanes are one of the most effective means of minimizing the speed differential (*Transportation Research Board 2003*). The presence of auxiliary lanes may, however, limit visibility and sight distance for all road users and should only be installed when warranted and applicable at a given location.

Castronovo, Dorothy, and Maleck (*1998*) investigated the effectiveness of boulevard (divided) roadways. They determined that boulevard roadways typically show a crash rate 50% less than roadways with TWLTLs. The authors also suggested that the optimal median width for safety performance is between 30 and 60 feet; however, the safety benefits must be balanced with geometric requirements, right-of-way limitations, and adjacent land use needs.

2.2.6 Land Use

Limited research has been conducted on the relationship between driveway safety and the land uses served by each driveway. Because most crash models include driveway density or driveway frequency, and both of these factors are dependent on land use type, the level and type of surrounding development is indirectly included in most safety analyses. Gattis, Balakumar, and Dunacan (*2005*) suggested that there is likely a correlation between land use and median type. This relationship may be due to the volume and type of traffic generated by certain land uses, local policies regulating median type for specific land uses, or other factors. Ivan, Wang, and Bernardo (*2000*) determined similar results for crashes associated with Connecticut two-lane highways. After accounting for time of day, they found that the number of driveways and traffic intensity had a significant effect on single- and multiple-vehicle crashes, although the effects were different for each crash type.

A more recent study by Bindra, Ivan, and Jonsson (*2009*) investigated the possibility of using actual land use data (retail versus non-retail in conjunction with population or number of employees) in prediction models in lieu of driveway intensity or frequency. They found that using this type of readily available land use data was not only more reliable and less labor intensive, but proved to be a much better predictor of segment-intersection crashes than typical driveway information.

2.2.7 Median Configuration

The published literature includes significant research regarding the safety of various median types and roadway configurations. It is well documented that the existence of a median, regardless of type, improves safety when contrasted with undivided roadways with similar volumes and driveway density. Typically, raised medians are safer than continuous TWLTLs; however, TWLTLs may be suitable for roadways with low-volumes and high driveway density (*Squires and Parsonson 1989; Margiotta and Chatterjee 1995*). Figure 2.3 depicts a typical TWLTL installation in an urban area.

Figure 2.3: Urban Five-Lane Roadway with TWLTL Median and Bicycle Lanes

More recent research by Gattis, Balakumar, and Dunacan (*2005*) investigated the safety of median treatments on high-speed (greater than 40 mph) rural and urban-fringe highways in Arkansas. The results of their analysis suggested a decrease in crash rates associated with increased median width and increased access spacing. The lowest crash rates were found to occur on roadways with wide shoulders and depressed medians, while the highest crash rates occurred on undivided roadways with curbs.

In addition to median type and width, restrictions on turning movements can also impact safety. A significant contributing factor of crashes at unsignalized intersections is the conflict between left-turning vehicles and opposing through vehicles or vehicles making conflicting turning movements. Restricting left-turns into or out of an access can improve safety by removing these types of conflicts. One alternative to allowing direct left-turns is the indirect left-turn, or Michigan U-turn. This configuration allows for only right-turns into and out of access points, and requires a U-turn at a downstream location. Many studies have shown that, in general, U-turns are safer than left-turns. This suggestion is supported by the smaller number of conflict points for each turning movement. Indirect left-turns have three conflict points, none of which are the crossing of vehicle paths, whereas direct left-turns have four conflict points, of which three are crossing (*Stover and Koepke 2002*). Figure 2.4 shows a comparison of conflict points for direct and indirect left-turns.

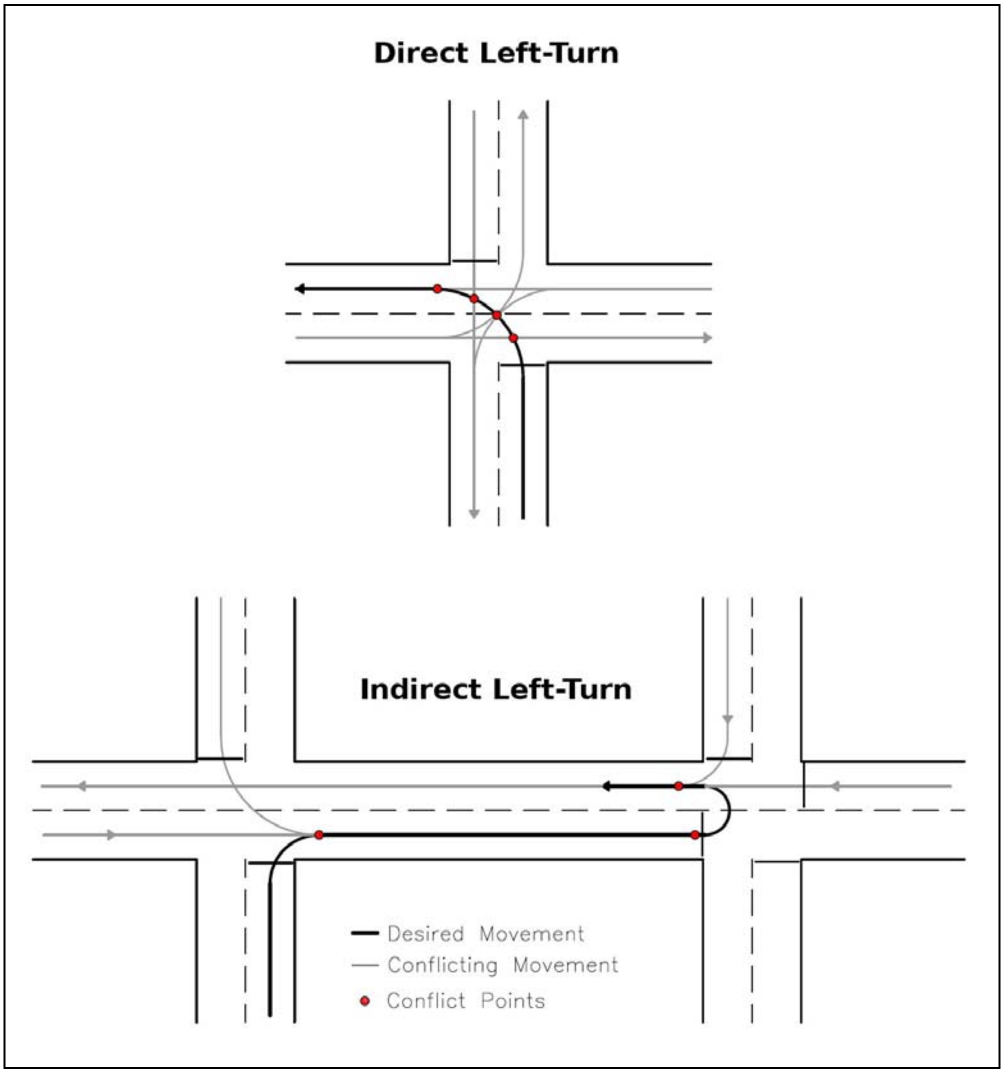


Figure 2.4: Comparison of Conflict Points for Direct and Indirect Left-Turns

Liu, Lu, and Chen (*2008*) report that increasing the distance between driveways and downstream U-turn locations can improve the safety performance of roadway segments. This separation distance should be longer when the downstream location is signalized, as queues can interfere with weaving maneuvers. Based on their analysis, Liu, Lu, and Chen suggested that a 10% increase in separation distance is associated with a 3.3% reduction in segment crash rates.

NCHRP Report 524 (*Potts et al. 2004*) compared crash rates for various study locations with differing median types. Due to low crash rates and the fact that crash reports did not differentiate between U-turns and left-turns, they could not complete a statistical regression analysis. They did conclude, however, that there is no evidence that U-turns negatively impact safety at unsignalized intersections and thus are not a cause for concern.

2.2.8 Safety Analysis Techniques

Until recently, the majority of all statistical safety analyses were completed using general linear regression models. It has been known for some time that the nature of crash data does not conform well to the basic assumptions of linear regression, particularly the normality and constant variance assumptions. Because of this, safety analyses have shifted to using linear models with either negative binomial or Poisson error structures. These types of models allow for a better fit when considering crash data and, as a result, provide more accurate estimation results. Negative binomial models are currently the accepted standard for developing crash prediction models. However, the selection of one type of model over another should be determined for each project individually and be based on the input data and desired results specific to that project.

Rakha et al. (*2008*) investigated the appropriateness of general linear regression as well as Poisson and negative binomial models in modeling crash rates for 186 study locations in Virginia. After completing in-depth analyses using each of the three models, including model validation, the researchers found that a modified Poisson regression model provided the best results. While the models developed in this study may not prove to be superior for other data sets, this research highlights the need for model evaluation on a case-by-case basis.

Another recent investigation into modeling techniques suggested that not only is the equal variance assumption suspect for crash data, but also the independence assumption. Kim et al. (*2007*) argue that crash data often express a hierarchical structure; that is multiple crash occurrences at a single location are not entirely independent of each other. By clustering crashes by location, the effects of site-related characteristics (such as pavement condition) can be neutralized and the effects of the factors of interest can be more accurately predicted.

2.3 RESEARCH IN PROGRESS

Several research efforts relating to access management and driveway safety are currently underway across the nation. These efforts are briefly discussed in the following sections.

2.3.1 Access Management Guidelines and Performance Measures

Kentucky, Alabama, and Kansas are currently working on or have just completed the development of access management guidelines similar to the national Development and Application of Access Management Guidelines project (NCHRP 03-99). The expected completion dates for the Kentucky and Alabama efforts are unknown. The Kansas expected completion date is fall 2012.

In addition, Oregon is nearing completion of a project to develop guidelines that demonstrate performance measures associated with access management. Virginia recently completed a similar project, and North Carolina is also in the process of developing methods for evaluating the effectiveness of access management strategies.

2.3.2 Roadway and Access Design

Several states are currently investigating the safety and operational impacts of various design strategies related to access management. A project in Idaho, completed in May 2011, evaluated the relationship between safety and shoulder width and lane width. Lastly, in 2009 Michigan recently completed an evaluation of the effects of right-turn-in / left-turn-out restrictions.

2.4 SUMMARY

Driveway safety is affected by a variety of factors and the impact of each factor is dependent on the unique nature of each location. The seven key factors, as presented in the literature, that affect driveway safety are: driveway spacing, proximity to intersections and interchanges, signalized intersection spacing and signal coordination, driveway design, road design elements, median configuration, and adjacent land use. As described in the previous sections, significant research has been completed in order to identify and understand these factors and improve the safety of current access management techniques. By studying the methods and results of previous research efforts, the project team plans to utilize proven methodologies and verified trends relating to driveway safety, thus completing this project in an efficient and effective manner.

3.0 REVIEW OF AVAILABLE DATA

ODOT maintains databases containing a significant amount of information related to state-maintained roadways across Oregon. Prior to developing a data collection plan for this effort, the research team investigated the types of data readily available through these ODOT resources. In addition, the research team completed detailed analyses in an effort to gain an understanding of the overall crash trends throughout Oregon. The team members performed this analysis through the use of GIS and advanced statistical software packages. Additional information regarding the data, analyses, and results is provided in the subsequent sections.

3.1 CRASH DATA

In order to thoroughly understand the crash trends in Oregon, all crashes should be associated with a specific location on the Oregon roadway network. ODOT provided the most recent state highway network data (*2008*) that were available at the beginning of this project and it contains information including route names, numbers, functional classification, etc., for every hundredth of a mile point in the State of Oregon. ODOT also provided crash data for the years 2000 through 2008 which included information directly related to each crash and all vehicles and participants involved. In addition to the highway and crash data, staff at ODOT and Portland State University provided various types of geographic information. This data was primarily in the form of GIS layers and included boundaries for cities, counties, census block groups, zoning, urban growth areas and climatic regions, among others. The research team also acquired GIS layers including the locations of all schools, hospitals, and liquor license locations in the State of Oregon.

Once the project team combined all the information, the resulting database included all state highway crashes extending from 2000 to 2008, their reported location on the highway network (to the nearest hundredth of a mile point), their proximity to schools, hospitals and liquor sales locations, and all available geographic information. Due to errors or omissions in the crash data and changes in the roadway network, approximately 5% of all crashes could not be tied to the state highway network.

In order to include only crashes applicable to this project, the research team then divided the previously described database into several subsets. Due to irregularities in the crash data during earlier years, the team elected to use the five years extending from 2004 through 2008 as the basis for all analyses. Next, it was necessary to isolate all known driveway-related crashes (where identified). Based on location information included in the crash data, the research team removed all crashes not occurring at a driveway. From 2004 to 2008, there were a total of 1,139 identified driveway-related crashes in the State of Oregon. It is feasible that some crashes associated with a driveway may not have been identified as a result of this procedure. Unfortunately at this time there is no clear way to locate such unidentified crashes. In subsequent chapters of this report as well as in Section 3.3 of this chapter, the uncertainty of using only crashes identified as driveway-related will be further reviewed.

During development of the project scope, the Technical Advisory Committee (TAC) agreed that focusing on major (principal) arterials would be appropriate for this effort. They also recommended that rural and urban highways be investigated separately. Therefore, the driveway crash database was further reduced to include only principal arterials, and separated into urban and rural areas. Between 2004 and 2008, there were a total of 866 driveway-related crashes on principal arterials, of which 244 occurred in rural areas and 622 occurred in urban areas.

The following sections describe statewide and regional trends identified in the Oregon crash data for years 2004 through 2008.

3.1.1 Oregon Driveway Crashes

The following sections are intended to give a broad overview of the driveway-related crash trends in Oregon between 2004 and 2008. Results presented in this section include all functional classifications including major arterials, minor arterials, and collectors. Where applicable, the results are divided into rural and urban subgroups.

3.1.1.1 Crash Type and Crash Severity

As indicated previously, there were a total of 1,139 known driveway-related crashes in Oregon from the beginning of 2004 until the end of 2008. These crashes included 692 that occurred in urban areas for a variety of road types and 447 that occurred in rural areas. Table 3.1 shows the breakdown of these crashes by crash severity.

Table 3.1: Oregon Driveway Crashes by Crash Severity (2004-2008)

Development	Fatal Injury	Non-Fatal Injury	PDO	Total
Urban	2 (1%)	322 (46%)	368 (53%)	692
Rural	9 (2%)	250 (56%)	188 (42%)	447
Total	11 (1%)	572 (50%)	556 (49%)	1,139

As shown in Table 3.1, of the 1,139 driveway-related crashes that occurred between 2004 and 2008, 50% were non-fatal injury crashes, 49% were property-damage only crashes, with only 1% fatal crashes.

Crash type can be a strong indicator of the level of crash severity. For both the urban and rural areas, the largest number of driveway-related crashes was angle crashes, followed by rear-end crashes, side-swipe crashes, and fixed-object crashes. Figure 3.1 depicts the breakdown of Oregon driveway-related crashes by crash type.

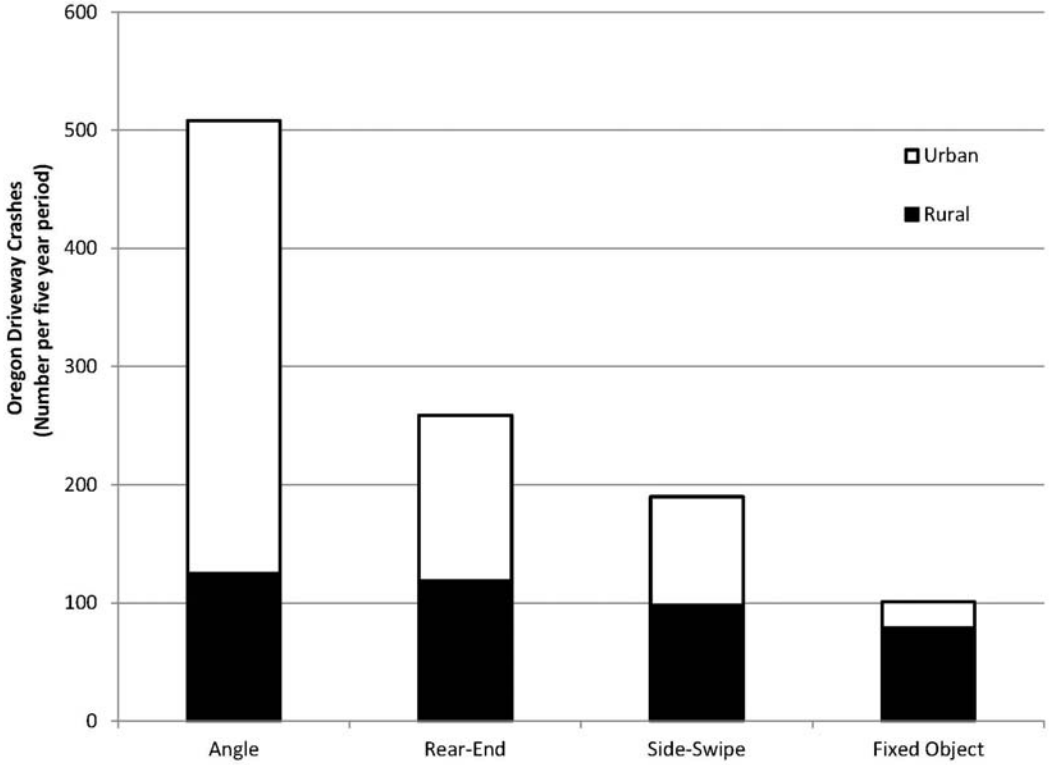


Figure 3.1: Oregon Driveway Crashes by Crash Type (Top 4 Crash Types, 2004-2008)

As shown in Figure 3.1, the ranking by frequency of crash types was similar for both urban and rural areas; however, the distribution of each of the four crash types was significantly different. In urban areas, angle crashes made up the vast majority of driveway-related crashes, and fixed-object crashes were relatively uncommon. In rural areas, driveway-related crashes were similarly distributed among the four crash types.

3.1.1.2 Temporal Distributions

Just as the total number of crashes can vary in different years, daily and monthly variations are also very prominent. Figure 3.2 depicts this daily variation for driveway crashes while the monthly variation is shown in Figure 3.3.

As shown on Figure 3.2, the days of the week with the highest number of driveway-related crashes varies for the urban and rural areas. In urban areas, driveway crashes occurred more frequently on Fridays and Tuesdays, followed by Mondays. Sundays were the day of the week with the lowest number of reported driveway crashes. In rural areas, driveway crashes occurred most frequently on Thursdays and Fridays, followed by Mondays. As was the case in urban areas, Sunday experienced the lowest number of driveway crashes for rural areas.

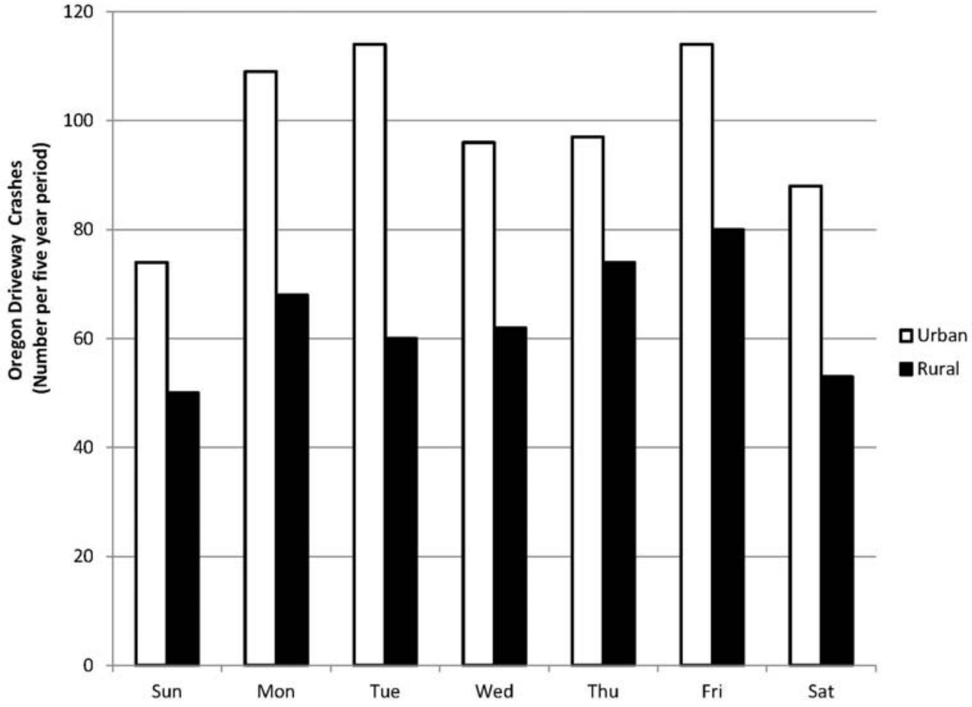


Figure 3.2: Oregon Driveway Crashes by Day of Week (2004-2008)

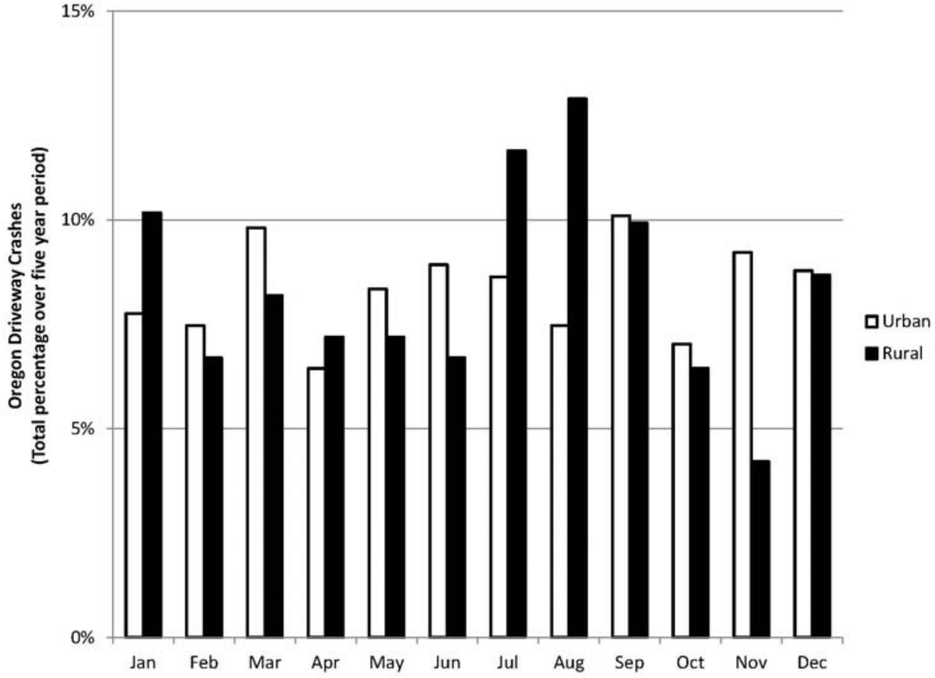


Figure 3.3: Oregon Driveway Crashes by Month (2004-2008)

Urban and rural areas also differed in their monthly variation of driveway-related crashes (see Figure 3.3). Rural area driveway crashes experienced a distinct peak in the summer months, as well as a smaller peak in the winter months. This trend appears to be consistent with the typical peaks for recreational activities and traffic volumes. Urban areas experienced less-dramatic variations of driveway-related crashes throughout the year, but peaks were still noticeable in March, September, November and December. The peak periods for both urban and rural areas are consistent with expected increases in vehicle travel such as spring break (March) and the holiday season (November and December).

3.1.1.3 Associated Roadway Characteristics

In both urban and rural areas, the majority of driveway-related crashes occurred on principal (major) arterials, followed by minor arterials and collectors. The large majority (56%) of urban driveway-related crashes occurred on 4-lane roadways, while approximately 30% occurred on 2-lane roadways. In rural areas, the trend was reversed, with 75% of driveway-related crashes occurring on 2-lane roadways and 18% on 4-lane roadways.

3.1.2 Oregon Driveway Crashes on Principal Arterials

As indicated previously, the project team and the TAC agreed that principal (major) arterials should be the focus of this research effort. This section describes the preliminary findings regarding driveway-related crash trends associated with principal arterials in the State of Oregon. Between 2004 and 2008, there were a total of 866 driveway-related crashes on principal arterials throughout the state. Of these, 622 of the crashes occurred in urban areas and 244 occurred in rural areas.

The project team has summarized the urban and rural crashes by county and location type to help better visualize where the highest proportion of driveway-related principal arterial crashes occurred. The results presented in Table 3.2 represent the five counties with the largest number of urban crashes and the five counties with the largest number of rural driveway-related crashes.

Table 3.3 presents the top five urban areas ranked by the number of driveway-related principal arterial crashes between 2004 and 2008. As expected for a frequency-based analysis, the Portland Metro area ranks first. Somewhat surprising was the high number of crashes in Medford and Albany, given their relative populations to lower-ranking urban areas like Salem-Keizer and Eugene-Springfield.

Table 3.2: Oregon Principal Arterial Driveway Crashes by County (Top Five Urban and Rural Counties, 2004-2008)

County	Number of Crashes (2004 - 2008)
Urban Areas	
Multnomah	87
Washington	73
Clackamas	49
Linn	48
Jackson	46
Rural Areas	
Lane	26
Clatsop	25
Columbia	22
Klamath	22
Deschutes	18

Table 3.3: Oregon Urban Principal Arterial Crashes by Urban Area (Top Five, 2004-2008)

Urban Area	Number of Crashes (2004 - 2008)
Portland	204
Medford	44
Albany	30
Eugene-Springfield	25
Salem-Keizer	23

3.1.2.1 Western Oregon versus Eastern Oregon

In addition to the breakdown by urban and rural areas, the research team also separated the data into two state regions – western and eastern – to better capture the unique characteristics of each region. The eastern category includes the Cascade region as well as the eastern part of Oregon. The graphical and tabular results presented in the following sections depict statewide trends for principal arterials. Where applicable, any significant regional differences are identified.

3.1.2.2 Crash Type and Severity

A summary of the severity of urban and rural driveway-related crashes on principal arterials in Oregon is shown in Table 3.4. As shown, the crash severity trends on principal arterials were similar to those shown in Table 3.1 for all functional classes. In general, approximately 1% of all driveway-related crashes were fatal, and the remaining crashes were relatively evenly split between property-damage-only (PDO) and non-fatal injury crashes. Urban areas statewide (and also for the eastern portion of Oregon) experienced a slightly higher percentage of PDO crashes than injury crashes, while rural areas showed a reverse trend. Though not directly depicted in Table 3.4, both urban and rural areas in western Oregon experienced a higher percentage of PDO crashes than injury crashes.

Table 3.4: Oregon Principal Arterial Driveway Crashes by Crash Severity

Development	Fatal Injury	Non-Fatal Injury	PDO	Total
Urban	2 (1%)	289 (46%)	331 (53%)	622
Rural	4 (2%)	124 (51%)	116 (47%)	244
Total	6 (1%)	413 (48%)	447 (51%)	866

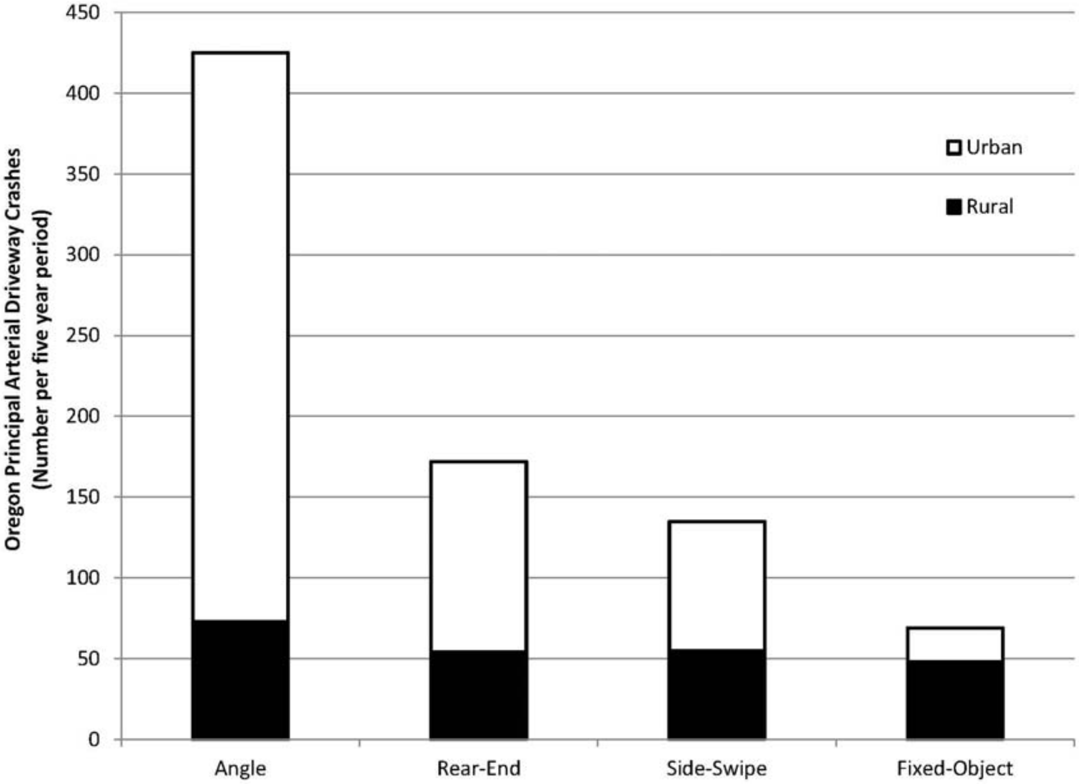


Figure 3.4: Oregon Principal Arterial Driveway Crashes by Crash Type
(Top Four Crash Types, 2004-2008)

Figure 3.4 shows the distribution of principal arterial driveway-related crashes by crash type. The principal arterial driveway crash type trends shown in Figure 3.4 are very similar to those shown for all functional classes in Figure 3.1. Across all functional classes and regions, urban areas were characterized by a significantly higher proportion of angle crashes than any other crash type. In rural areas, the distribution between crash types is much more even. Urban crash type trends were similar for the eastern and western regions of Oregon, but the western Oregon rural areas were characterized by a more significant proportion of angle crashes than those in the eastern Oregon rural areas.

3.1.2.3 Temporal Distributions

The daily and monthly variations in driveway-related crashes associated with Oregon principal arterials are shown in Figure 3.5 and Figure 3.6, respectively. The daily variations in driveway-related crashes for Oregon principal arterials are very similar to those observed for other roadway types (see Figure 3.2). In urban areas, the largest number of driveway-related crashes on arterial roads occurred on Tuesday followed closely by Friday and Monday. In rural areas, Thursday, Friday and Monday were the days with the most principal arterial driveway-related crashes. In both areas, the weekends were characterized by the lowest proportion of crashes. There were no significant differences between the eastern and western regions of Oregon.

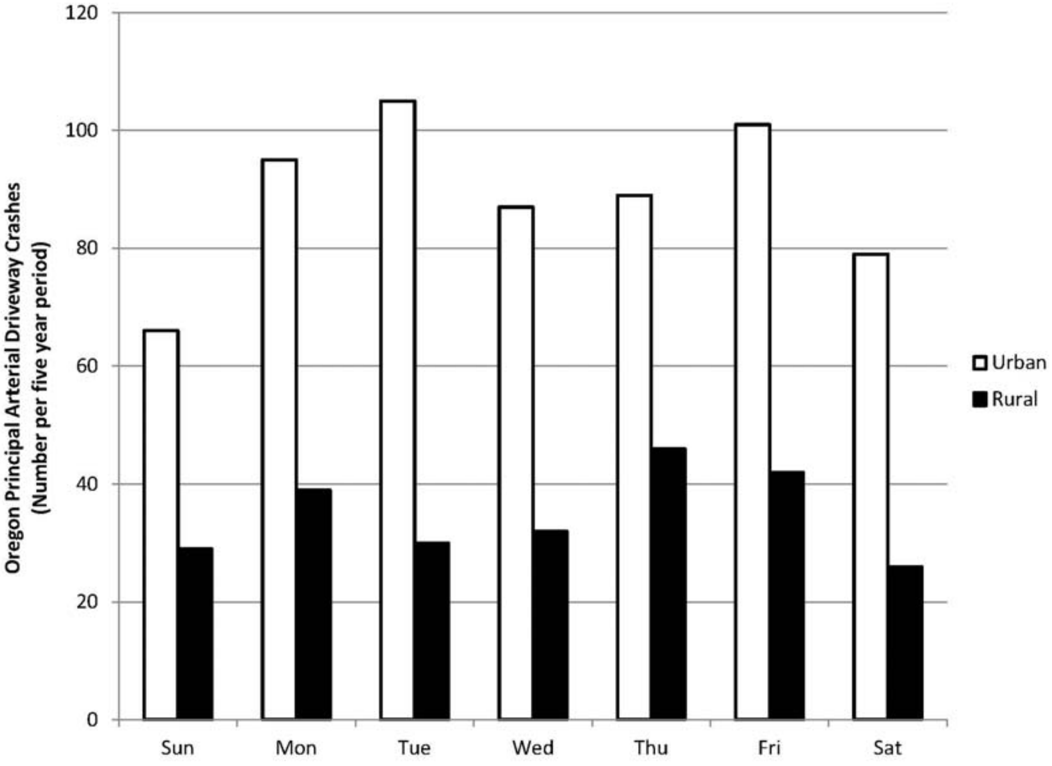


Figure 3.5: Oregon Principal Arterial Driveway-Related Crashes by Day of Week (2004-2008)

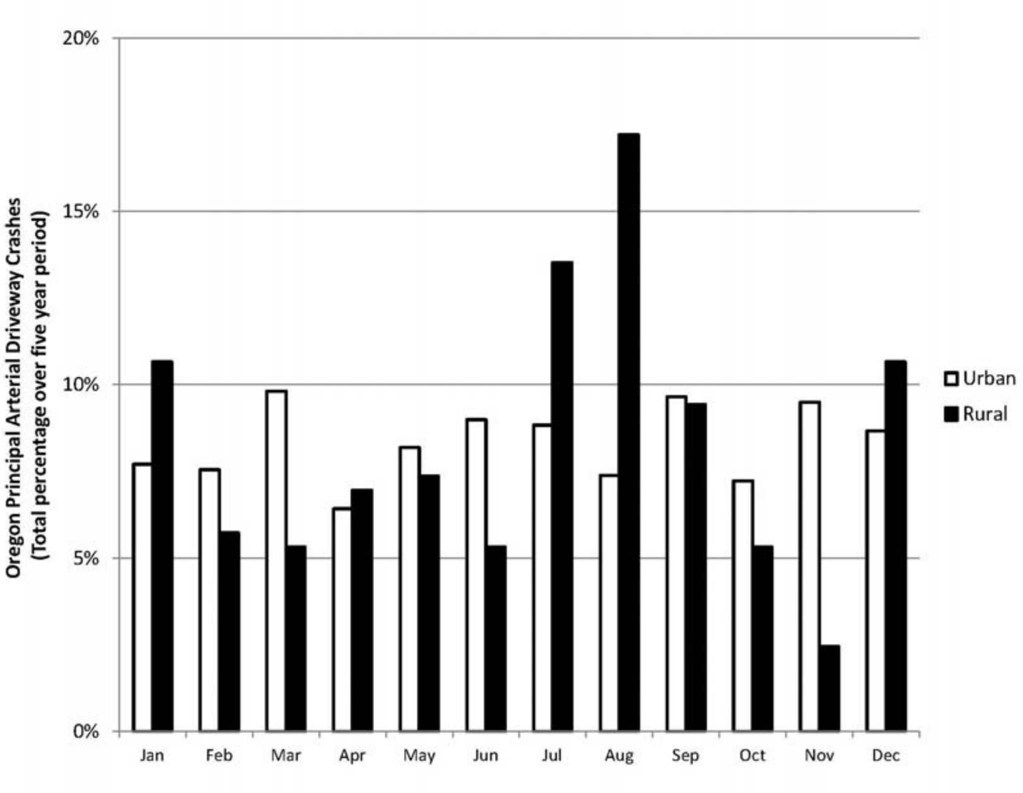


Figure 3.6: Oregon Principal Arterial Driveway-Related Crashes by Month (2004-2005)

As shown in Figure 3.6, the monthly variation in principal arterial driveway crashes was not significantly different than those shown in Figure 3.3 for all functional classifications. In rural areas, the summer and winter peaks were most significant, which corresponds with increased recreational travel. Urban areas showed less-extreme variations, but still include peaks in spring, late-summer, and winter. The overall trends were similar for both the eastern and western Oregon regions, with the eastern region showing slightly more variation.

3.1.2.4 Roadway and Weather Characteristics

Across the State of Oregon, approximately 60% of the identified urban principal arterial driveway-related crashes occurred on four-lane highways, while just under 30% occurred on two-lane highways. In rural areas, this trend was reversed, with approximately 65% of crashes occurring on two-lane highways and nearly 30% occurring on four-lane highways.

Regardless of region or urban versus rural designation, the vast majority of principal arterial driveway-related crashes occurred on dry pavement and during daylight hours. For those crashes that did occur after dark, most urban crashes occurred at locations with street lights present, while the majority of rural crash locations did not have street lights.

Rural and urban principal arterial driveway-related crashes are summarized by associated traffic control device in Table 3.5. An unexpectedly large portion of driveway-related crashes were classified as having “unknown or not definite” traffic control in both urban and rural areas. It is currently unclear why this classification is so significantly over-represented; however, the distribution of known traffic control devices follows an expected pattern for both urban and rural areas. In rural areas, the majority of driveway-related crashes on principal arterials occur at locations with no traffic control, followed by stop-sign control and signal control. In urban areas, traffic signals are the most prevalent form of control, followed by no control and stop-sign control. There were no significant differences between the eastern and western regions of Oregon and the relationship between traffic control devices and crash history.

Table 3.5: Oregon Principal Arterial Driveway-Related Crashes by Traffic Control Device (2004-2008)

Traffic Control Device	Urban (%)	Rural (%)
Unknown or Not Definite	42	63
No Traffic Control Device	16	20
Stop Sign	15	9
Traffic Signal	20	3
No Passing Zone	0	2
Left-Turn Refuge (when involved)	5	2
Left-Turn Green Arrow or Lane Markings	1	1
One-Way Street	1	0

3.1.2.5 Driver Characteristics

Across the State of Oregon, more male drivers than female drivers were involved in driveway-related crashes on principal arterials during the period from 2004 to 2008. In urban areas, approximately 55% of the drivers involved in driveway-related of crashes were male leaving approximately 45% as female drivers. In rural areas, the difference was greater with approximately 60% male drivers.

Table 3.6 presents the percentage of drivers and their associated age groups for principal arterial driveway-related crashes for both urban and rural areas. In urban regions, drivers with ages ranging from 20 to 49 were involved in 51% of the studied crashes (see Table 3.6). In rural areas, fewer of the drivers in the 30 to 39 age group were involved in the driveway-related crashes. For comparison purposes, the rural drivers ages 30 to 39 who were involved in the study crashes represented the fifth largest category of drivers, while in urban areas this age group represented the second largest group of involved drivers.

Table 3.6: Oregon Principal Arterial Driveway-Related Crashes by Driver Age (2004-2008)

Driver Age	Urban (%)	Rural (%)
Unknown	7	4
< 20	9	10
20 - 29	20	16
30 - 39	16	12
40 - 49	15	17
50 - 59	14	15
60 - 69	9	13
70 - 79	7	7
> 79	4	5

3.1.2.6 Proximity to Hospitals, Schools, and Liquor Sales Establishments

In addition to investigating the general trends within the crash data, the project team assessed the relationship between crash characteristics and proximity to schools, hospitals, and liquor sales locations. Each of these land use types may have a unique influence on crash trends and characteristics. For all three land use types, crash trends did not differ significantly between the eastern and western regions of Oregon.

Hospitals

Figure 3.7 and Figure 3.8 depict the relationships between crash severity and proximity to hospitals for urban and rural regions respectively. For the purposes of these figures, crash severity is classified as either fatal, non-fatal injury, or property damage only crashes. The research team also used three categories to describe the proximity to hospitals: less than 25 miles away, less than 50 miles away, and greater than 50 miles away or unknown. The unknown values include those crashes that could not be linked to a specific location on the highway network. In general, proximity to emergency medical treatment improves the likelihood of survivability for severe crashes; however, the studied 2004 to 2008 crashes did not distinctly exhibit this trend.

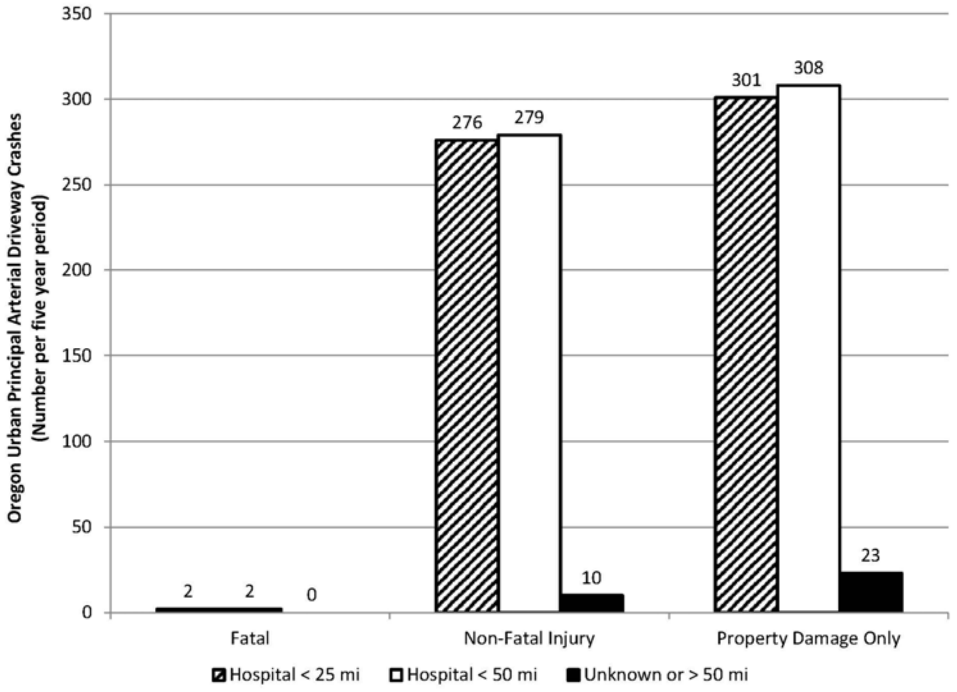


Figure 3.7: Oregon Urban Principal Arterial Driveway-Related Crashes by Proximity to Hospitals (2004-2008)

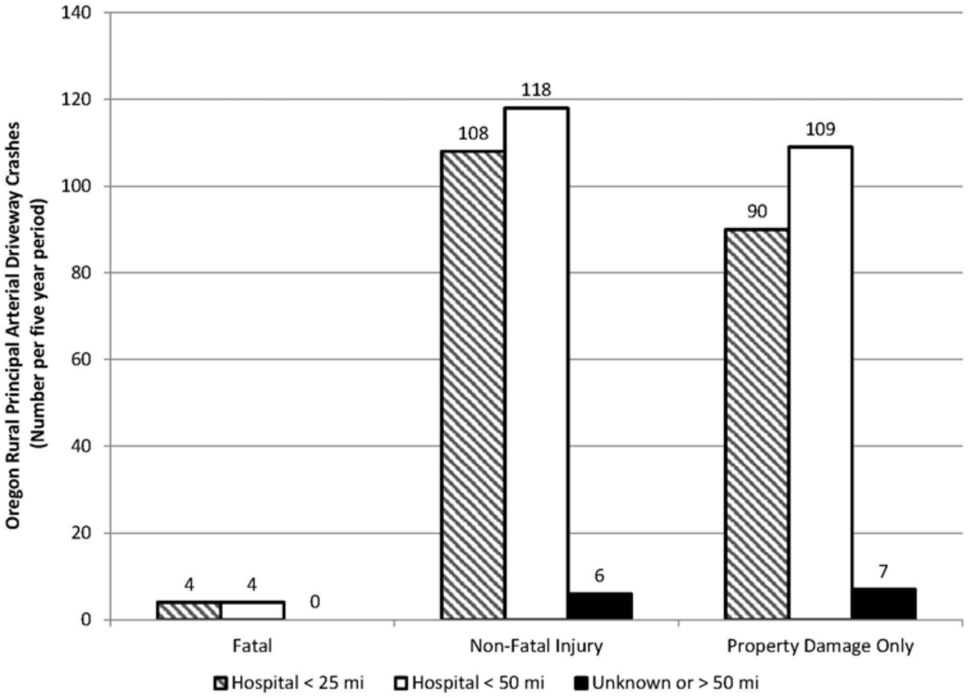


Figure 3.8: Oregon Rural Principal Arterial Driveway-Related Crashes by Proximity to Hospitals (2004-2008)

Schools

Due to the relative high percentage of inexperienced drivers and expected higher volumes of pedestrians near schools, the project team investigated the number of crashes and their proximity to schools. Figure 3.9 and Figure 3.10 show the percentage of driveway crashes within 2 miles, 1 mile, and 1,000 feet of a school for urban and rural areas, respectively.

There does not appear to be a direct relationship between the number of crashes and proximity to schools. In rural areas, approximately 50% of all crashes occurred within two miles of a school, while that number jumped to 94% for urban areas. The difference in values between urban and rural areas can likely be attributed to the higher density of schools in urban areas. In an urban area, for example, it is reasonable to expect that most crashes will occur within two miles of a school simply because there are a large number of schools present. For this reason, the proximity to a school may be coincidental rather than a contributing factor in the crashes.

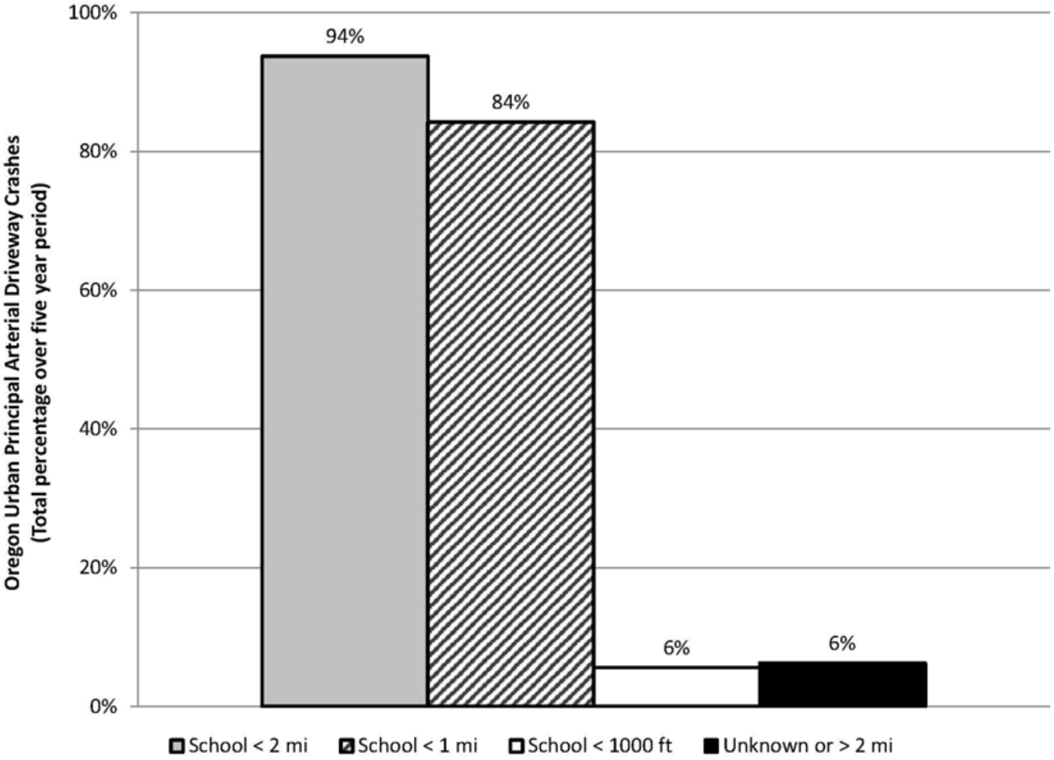


Figure 3.9: Oregon Urban Principal Arterial Driveway-Related Crashes by Proximity to Schools (2004-2008)

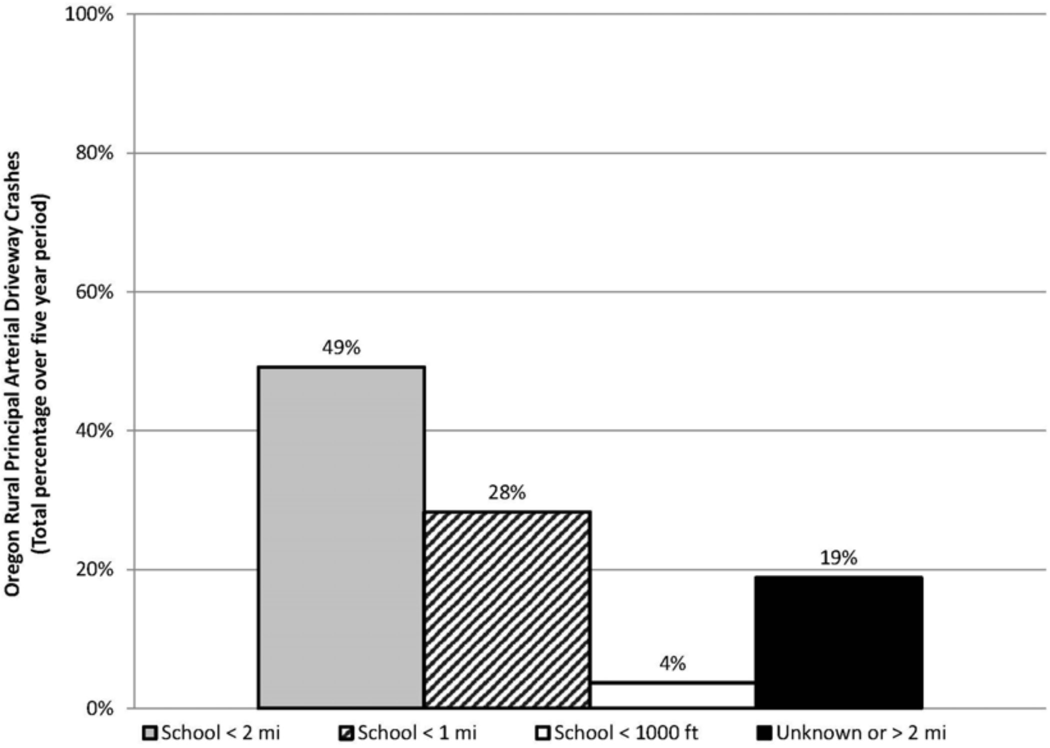


Figure 3.10: Oregon Rural Principal Arterial Driveway-Related Crashes by Proximity to Schools (2004-2008)

Liquor Sales Establishments and Commercial Development

Research has shown that a relationship exists between the number and type of crashes at a given location and the surrounding land use types (*Bindra et al. 2009*). In most cases, accurate land use data is not available for large areas; however, the presence of certain establishments can give an indication as to the type of land uses in the area. One example of this approach is using liquor sales establishment locations as an indicator of commercial land uses. Liquor sales locations refer to all establishments at which liquor is sold, including grocery stores, restaurants, and convenience stores. By identifying the location of all liquor sales establishments throughout the state, a certain level of commercial development can be assumed within a given proximity of those locations. Commercial development is typically associated with unique traffic patterns and pedestrian activity. Because of this, the project team investigated the relationship between driveway-related crashes and their proximity to liquor sales locations. These trends are shown in Figure 3.11 and Figure 3.12 for urban and rural areas, respectively. As shown in Figure 3.12, almost 80% of all rural driveway-related principal arterial crashes occurred within two miles of a liquor sales establishment. In urban areas (see Figure 3.11) 95% of the studied crashes occur within two miles of similar establishments. In fact, in urban areas nearly 80% of all driveway-related principal arterial crashes occurred within 1,000 feet of a liquor sales establishment. Similar to the trends observed for the school data, part of this trend may be due to the high density of liquor sales establishments in urban areas.

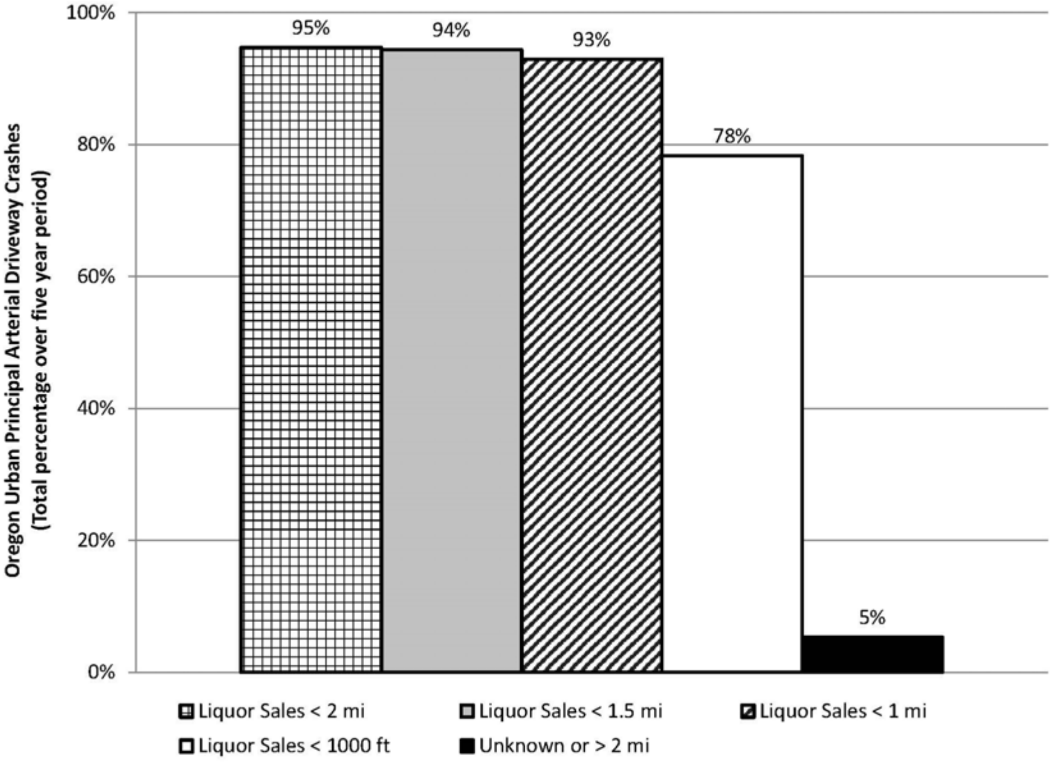


Figure 3.11: Oregon Urban Principal Arterial Driveway-Related Crashes by Proximity to Liquor Establishments (2004-2008)

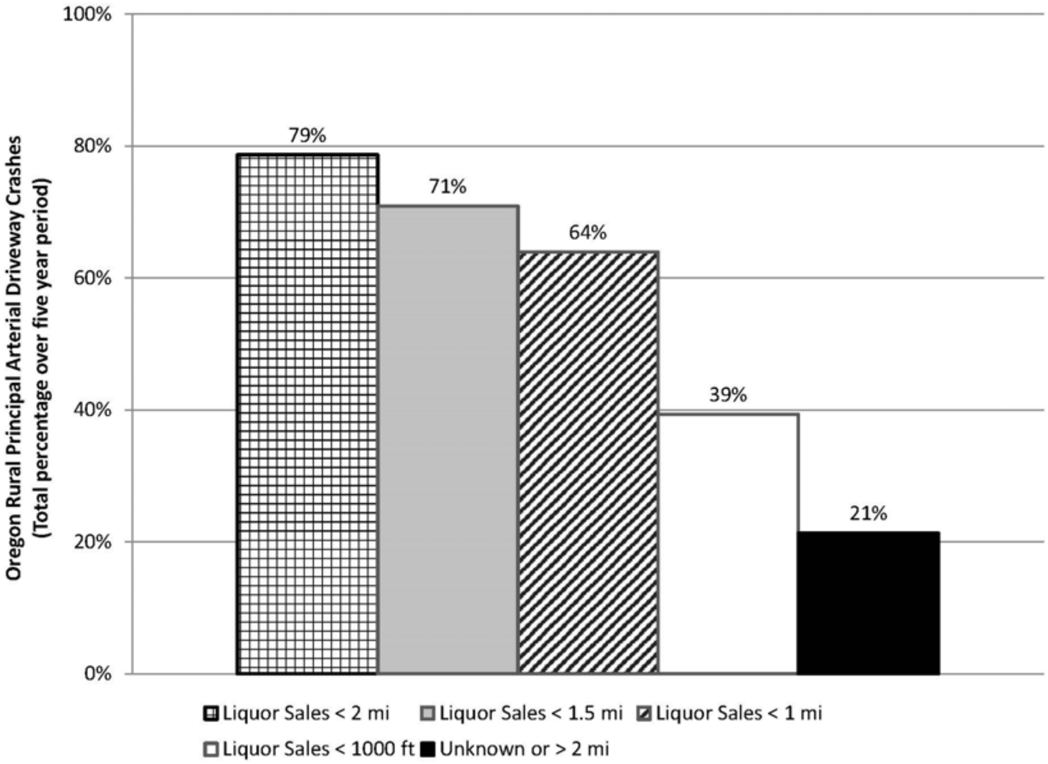
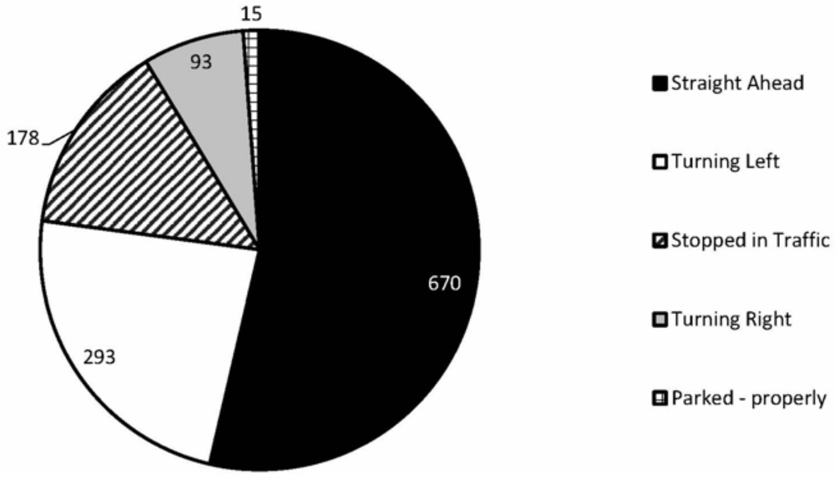


Figure 3.12: Oregon Rural Principal Arterial Driveway-Related Crashes by Proximity to Liquor Establishments (2004-2008)

3.1.2.7 Vehicle Movements

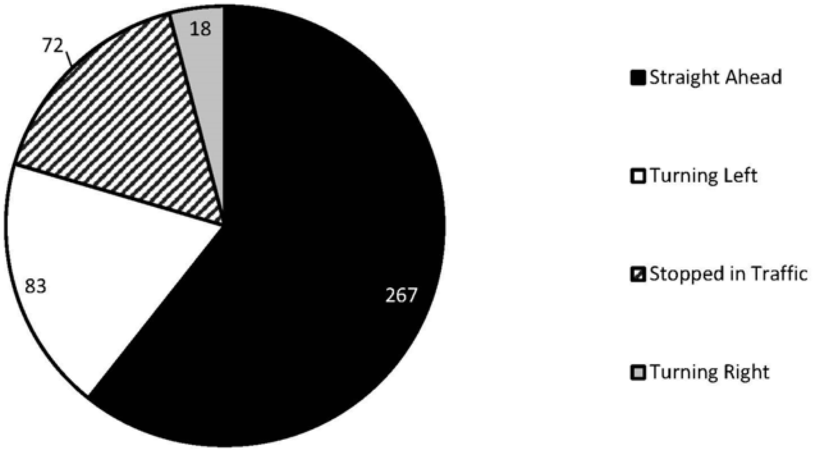
In an effort to better understand the nature of driveway-related principal arterial crashes in Oregon, the project team investigated various crash characteristics based on primary vehicle movements. The major vehicle movements associated with driveway-related crashes in Oregon are shown on Figure 3.13 and Figure 3.14 for urban and rural areas, respectively. The majority of vehicles involved in driveway-related crashes on principal arterials were traveling straight ahead, followed by left-turning vehicles, stopped vehicles, and right-turning vehicles.

In rural areas, the majority of crashes (regardless of vehicle movement) occurred between 4:00 p.m. and 6:00 p.m. In urban areas, there was no clear peak period, with vehicle movement peak periods scattered throughout the afternoon between noon and 6:00 p.m.



Note: Only movements associated with 10 or more crashes included

Figure 3.13: Vehicles Involved in Oregon Urban Principal Arterial Driveway-Related Crashes by Vehicle Movement



Note: Only movements associated with 10 or more crashes included

Figure 3.14: Vehicles Involved in Oregon Rural Principal Arterial Driveway-Related Crashes by Vehicle Movement

For stopped-vehicles involved in driveway-related crashes, the number of stopped-left and stopped-straight-or-right vehicles differed significantly for urban versus rural areas. In urban areas, approximately 30% of stopped vehicles involved in crashes were waiting to turn left and 60% were waiting to continue straight or turn right. In rural areas, however, approximately 50% of stopped vehicles were waiting to turn left and 50% were waiting to turn right or continue straight. The higher percentage of left-turning vehicles involved in driveway-related crashes in rural areas may be contributed to by the relatively infrequent presence of exclusive left-turn lanes, requiring left-turning vehicles to stop in through-lanes to wait for acceptable gaps. In urban areas, exclusive turn lanes are much more prevalent, resulting in fewer potential conflicts for left-turning vehicles.

The project team further evaluated the distribution of entering and exiting vehicles at driveways. In urban areas, left-turning and right-turning vehicles were associated with more crashes when exiting a driveway than when entering. In rural areas, this trend is reversed with a higher percentage of crashes associated with entering vehicles.

Overall, rural crashes involving left-turning, straight, and stopped vehicles have a higher severity than crashes involving the same movements in urban areas. One possible contributing factor may be that rural roads often have higher posted speeds than on urban roads, thus resulting in higher severity when a crash occurs. Other contributing factors may include differences in geometric design, lighting, or sight distance.

3.2 DRIVEWAY AND ROAD DATA

Prior to developing the data collection plan, the project team completed a thorough review of all driveway and roadway data currently available through ODOT. Currently, there is no comprehensive database that includes information relating to all driveways on the state highway network. The acquisition of this data was the primary focus of the data collection effort, as described in Chapter 4.0.

As indicated previously, roadway data is available for the state highway network system. This information includes route names, numbers, functional classification, and general physical road characteristics. Since maintenance of a road characteristic database requires significant effort, it is likely that some inaccurate data may be included in the database. As a result, the project team attempted to verify all associated roadway information for the study sample as part of the data collection process through the use of aerial photography analysis to ensure the quality and accuracy of the analysis data.

3.3 SUMMARY

Inspection of historic Oregon crash data associated with driveways includes a wide variety of crash type, temporal, facility type and configuration, driver, land use, and location trends.

In many cases, trends of crashes identified as driveway-related tend to align with known land development patterns. This observation suggests that crash data assessment may require additional consideration. Presumably, if a crash is indicated as driveway-related then it is reasonable to assume this to be true; however, in some cases a mid-block crash could occur that is associated with a driveway but not indicated as driveway-related. One example would be a sideswipe crash that occurs because a driver took evasive actions due to unexpected driveway conflicts. As a result, Chapter 4.0 reviews the data collection process and the expanded target crashes that will include all non-intersection crashes. The research team recognizes that all segment crashes are not associated with driveways, but the resulting models will better represent the overall predicted segment crashes including those at driveways. Relative crash predictions for different driveway variables can then help to represent the direct influence of the driveways on the overall road segment safety performance.

4.0 DATA COLLECTION PLAN

Based on the findings presented in the Chapter 2.0 literature review and the crash trends presented in Chapter 3.0, the project team developed a data collection plan. The goal of the data collection plan was to acquire a statistically significant sample to allow the evaluation and ultimate development of safety performance functions for predicting the number of driveway crashes for Oregon principal arterial state highways. The project team collected data relating to the seven key factors affecting driveway safety as identified in Chapter 2.0. This data collection effort, therefore, included the collection of (1) driveway spacing, (2) driveway proximity to intersections and interchanges, (3) signalized intersection spacing and signal coordination, (4) driveway design, (5) road design elements, (6) land use, and (7) median configuration. The following sections describe the data collection effort in detail.

4.1 SAMPLE SIZE AND ASSOCIATED DATA VARIABLES

As a starting point for developing a statistically significant sample, the project team first identified all of the known Oregon principal arterials located on the state highway system. From this collection of arterials, they separated the corridors into categories based on rural versus urban locations. Urban and rural designations were based on the state roadway and functional classification database. Because these designations do not always represent actual conditions, the project team used a GIS database and aerial photography to verify the urban and rural classification for each study segment. Additionally, the project team felt that selecting a precise location of an urban-rural distinction was inaccurate and would not adequately capture the roadway conditions in those areas. In order to account for this, the team utilized a GIS map of urban growth boundaries (UGB) to identify the transition zone between urban and rural areas. The research team flagged a one-mile buffer around the UGB as a transition zone and then removed those sections from the pool of potential study sites. The remaining database of clearly defined urban and rural roadways served as the starting point for the data collection process.

Initially, the project team intended to divide these urban and rural categories of roads into smaller homogeneous segments and use this data set as the basis for selecting the random sample of road segments to further use for this analysis. This process utilized Google Earth as a tool to help identify consistent corridor segments. Initial testing procedures using aerial maps and companion ODOT road databases to determine the feasibility of this approach made it clear that this larger site evaluation approach would be extremely labor intensive and well beyond the budget for this research effort. As a result, the project team used the segment data used for this test as a means for estimating the population size (number of homogeneous segments) and, subsequently, the required sample size.

4.1.1 Estimation of the Population Size

As previously mentioned, the project team collected a limited amount of roadway segment data for both urban and rural areas using an initial data collection test. Considering the key factors known to influence driveway safety (see Chapter 2.0), the test samples were divided into homogenous segments. In urban areas, the analysts collected data for a total of 654 segments, with an average segment length of 0.37 miles. Given that there are approximately 390 miles of urban principal arterial state highways in Oregon, the research team estimated that segmentation would result in approximately 1,021 to 1,080 segments (95% confidence interval).

In rural areas, a total of 2,624 miles of principal arterial state highways existed at the time of analysis, of which 392 miles (255 segments) were collected in the preliminary data collection effort. This resulted in an average segment length of 1.54 miles, resulting in considerably longer segments than those observed for the urban average segment length. This is an expected result as rural highways have far fewer geometric changes and a much lower intersection density than in urban areas. During subsequent analysis, however, the project team determined that driveway density in the rural environments varied considerably over a "homogeneous" segment as identified using the seven key factors. This observation ultimately resulted in an additional segmentation for rural corridors. Given the total number of rural highway miles and the average segment length, between 1,628 and 1,784 (95% confidence interval) of the longer segments (based on the seven key factors) could be expected after segmentation.

4.1.1.1 Sample Size Determination

Based on the estimates of the population size, the project team estimated the required sample size. As a starting point, the target sample size was assumed to be 4% to 5% of the total population size. This calculation resulted in a target sample size of 41 to 54 segments in urban areas and 65 to 89 segments in rural areas. In addition, the team excluded segments that may be too small to analyze (less than 0.1 miles in urban areas and 0.25 miles in rural areas). Ultimately, budget constraints limited sample size to 40 urban (the lower end of our target value) and 40 rural sites; however, the rural sites were further subdivided as needed for uniformity resulting in a sample size much greater than 40 segments.

4.1.1.2 Sampling Procedure

Ensuring a randomly selected sample is a vital component to the sampling procedure so that inferences resulting from analysis of the random sample can then be applied to the total population upon completion of the analyses. In previous research efforts, the project team had developed a GIS database that included every hundredth-of-a-mile point on the state highway system in Oregon. Initially using the ODOT road databases, the researchers extracted urban and rural principal arterial state highways using the ODOT functional classification as an indicator of region type. They then confirmed the accuracy of this information for a select number of sites using the urban area GIS maps already created (as described in Chapter 3).

Through the use of a random number generator, the researchers selected target locations based on randomly selected hundredth-of-a-mile points. Each of these points then acted as the center of a homogeneous segment whose length would be determined based on the key geometric characteristics previously identified (see Chapter 2.0). The segment endpoints naturally then occurred on either side of the selected point at the nearest location in which the roadway geometry changed or at an intersection (whichever occurred first). In the case where the selected point fell within an intersection, the point would be used as either the northern or eastern endpoint of the segment. In the case of very long homogeneous segments, the maximum segment length was set at two miles. Any resulting segments less than 0.1 miles in urban areas or 0.25 miles in rural areas were discarded as they did not provide sufficient data for analysis. Table 4.1 depicts the randomly selected final study corridors.

Upon inspection of the selected random corridors, the research team observed that many of the rural corridors, with the longer lengths approaching two-miles, had driveways clustered at one or sometimes both ends. Though the key factors used for identifying homogeneity considered driveway location and type, they did not explicitly consider driveway frequency or clustering of this nature. For several corridors, all of the driveways occurred at one end and so the resulting average driveway density did not appropriately represent the entire corridor and under stated driveways at the end where they occurred. As a result, the project team further divided these rural corridors into sub-segments for continued analysis.

4.2 ROADWAY DATA VARIABLE IDENTIFICATION AND COLLECTION

For each of the identified study segments, the project team examined aerial and roadside (from the driver's view) perspectives to confirm uniform segments and begin the data collection effort for driveway, road characteristics, and land use information. The ODOT road databases served as the source for the required traffic volume information in the form of annual average daily traffic (AADT). This data collection effort included the systematic acquisition of the key factors identified as a result of the literature review and as shown in Table 4.2. In some instances, the specific "factors" required additional clarification as to tangible roadway data variables that could be collected. In addition, the project team elected to also acquire traffic volume and posted speed limit for consideration in the analysis.

Table 4.1: Summary of Study Corridors

Urban Study Corridors				***Rural Study Corridors***			
Hwy. Name	**Hwy. No.**	**Begin MP**	**End MP**	**Hwy. Name**	**Hwy. No.**	**Begin MP**	**End MP**
Ochoco	041	20.09	20.22	Corvallis-Newport	033	33.46	34.34
Pacific Highway West	091	2.71	3.07	Willamina-Salem	030	4.18	4.65
Rogue Valley	063	14.68	14.89	Florence-Eugene	062	5.79	7.79
Pacific Highway East	081	42.78	43.19	Redwood	025	12.81	14.16
Olds Ferry-Ontario	455	29.55	29.79	Coos Bay-Roseburg	035	22.58	23.22
Pacific Highway West	091	75.7	75.92	Santiam	016	39.92	41.36
Clackamas-Boring	174	3.78	4.2	Santiam	016	73.92	74.58
Lower Columbia River	092	5.3	6.22	Florence-Eugene	062	23.33	24
La Grande-Baker	066	52.76	53.14	John Day	005	133.85	136.85
Klamath Falls-Malin	050	0.08	0.23	Ochoco	041	34.83	36.83
Clackamas-Boring	174	1.88	2.03	Central Oregon	007	87.44	89.44
Albany-Junction City	058	1.45	1.71	Klamath Falls-Lakeview	020	35.87	37.87
Lower Columbia River	092	27.88	28.18	Lake of the Woods	270	9.62	11.62
Albany-Junction City	058	0.75	0.88	Klamath Falls-Lakeview	020	41.74	43.74
Northeast Portland	123	13.04	13.26	Central Oregon	007	200.73	202.73
Pacific Highway West	091	13.32	19.43	Central Oregon	007	177.93	178.69
The Dalles-California	004	122.84	123.19	Central Oregon	007	241.83	243.3
Pacific Highway East	081	8.1	8.21	Sunset	047	27.75	28.52
The Dalles-California	004	92.46	92.58	Santiam	016	84.51	85.47
Clackamas	171	6.21	6.57	John Day-Burns	048	51.31	52.21
Tualatin Valley	029	11.72	11.96	Coos Bay-Roseburg	035	38.69	39.03
Umatilla-Stanfield	054	6.62	6.94	The Dalles-California	004	192.35	193.04
The Dalles-California	004	120.28	120.4	Sunset	047	10.17	11.82
Warm Springs	053	115.86	116.15	North Santiam	162	54.07	54.54
Jacksonville	272	0.96	1.15	Clear Lake-Belknap Springs	215	3.34	4.61
Crater Lake	022	3.26	3.56	Central Oregon	007	147.94	149.94
Albany-Junction City	058	1.15	1.25	John Day-Burns	048	36.79	38.79
Lower Columbia River	092	48.13	48.38	Central Oregon	007	224.42	226.42
Northeast Portland	123	14.20	14.30	Oregon Coast	009	247.54	248.97
South Klamath Falls	424	0.64	1.56	North Santiam	162	80.87	81.51
McKenzie	015	4.30	4.41	McKenzie	015	20.3	21.36
The Dalles-California	004	92.58	92.68	Sunset	047	4.7	6.7
Pacific Highway West	091	85.55	85.84	Oregon-Washington	008	9.07	11.05
Pacific Highway West	091	16.66	16.96	Florence-Eugene	062	28.02	29.66
Lake of the Woods	270	1.03	2.28	Lakeview-Burns	049	78.18	79.28
The Dalles-California	004	166.78	167.26	Oregon Coast	009	25.72	26.21
The Dalles-California	004	132.19	133.07	Central Oregon	007	136.31	138.3
The Dallas-Rickreall	189	0.00	0.22	John Day	005	271.51	272.11
Salmon River	039	44.61	45.76	Central Oregon	007	110.43	112.43
Lower Columbia River	092	28.25	28.37	Umpqua	045	53.91	54.68

Table 4.2: Roadway Variables with Corresponding Factors and Collection Method

Roadway Data Variables	Factors Affecting Driveway Safety	Collection Method
Traffic Volume (AADT)	n/a	ODOT Databases
Driveway Location	Driveway Spacing, Proximity to Intersections and Interchanges, Signalized Intersection Spacing	Google Earth
Driveway Width	Driveway Design	Google Earth
Driveway Type (land use being served)	Land Use	Google Earth/Video Log
Number of Lanes	Roadway Design	Google Earth
Median Configuration	Median Configuration	Google Earth/Video Log
Posted Speed	n/a	Google Earth/Video Log/ODOT Databases
Traffic Control	Signalized Intersection Spacing	Google Earth/Video Log

Note: The "n/a" notation indicates the literature review findings did not specifically address this variable.

For some of the variables, a variety of metrics could be collected to represent the condition. For example, for land use (representing driveway type), the research team used the photographic data collection process to determine the general purpose of the driveway as well as other factors such as number of parking spots and number of access points to the site as indicators for land use type.

Driveway data then included driveway purpose (commercial, industrial, residential, other), driveway design (primarily width), and driveway location. As shown in Table 4.2, at least one data variable is associated with each of the primary factors affecting driveway safety. Due to the limited data available as well as time and budget constraints, it is not possible to completely account for every factor. For example, including the effects of signal coordination at each driveway would require analyzing the timing plans for each signal, which is outside the scope of this project. However, it is feasible to include the spacing between signalized intersections.

As indicated in the previous section, the project team collected data for randomly selected principal arterial driveways on the Oregon state highway. Due to this large geographic data set, it was not feasible to manually collect the data via site visits for the entire study population. As a result, the majority of the data collection effort was conducted using digital video logs and aerial photography via Google Earth. In an effort to maximize the efficiency of the data collection process, the project team developed a data collection method utilizing the free aerial photography provided through Google Earth. This method involved the use of paths to denote segments and place marks to identify segment endpoints and driveway locations. Each path and place mark (tools included in the software) was edited to include site-specific information, such as roadway name and segment number. This information can then be exported to Excel, where it can be easily manipulated into usable data. The specific procedure for collecting this data has been included as Appendix Section 7.2 of this report.

The resulting eight data variables/categories and their corresponding data collection methods are shown in Table 4.2.

Table 4.3 depicts the roadway and driveway data elements directly collected during the data collection process. In addition to the use of Google Earth and/or ODOT digital video logs, the project team also conducted a small number of field visits to verify the accuracy of the information collected digitally.

4.3 CRASH DATA IDENTIFICATION

The project team first used the 2004 through 2008 ODOT crash data to assess the number of crashes indicated as "driveway-related" in an effort to determine the reliability of this variable as an item to predict. Unfortunately, the quality and frequency of this crash reporting variable led the research team to the conclusion that the use of this driveway-related indicator as a sole representation of driveway crashes would likely underestimate the actual related crashes. For example, secondary crashes that occurred due to a conflict at a driveway may have simply been noted as rear-end same-direction crashes without any driveway association. Similarly, abrupt lane changes that may have been executed by a driver as an evasive action at a driveway could result in run-off-road, sideswipe, or even head-on crashes that are attributable to the driveway (but probably not associated with the driveway in the crash report and database). As a result, the project team arrived at the conclusion that the most effective way to predict safety as a result of driveways located on arterial roadway segments was to predict the total number of non-intersection crashes. Though other crash types were also captured with this approach, the project team elected to develop safety performance functions that would then represent the road characteristics as well as the driveway features. The predicted number of crashes for a segment and the associated impact of driveways could then be assessed using relative comparisons. Ideally, the analysis could then be expanded to crash severity; however, the randomly selected sites predominantly included property damage only crashes and so the modeling of severity for this study was not a feasible option. In Chapter 5.0, the resulting safety performance factors and example applications will demonstrate the influence of driveways on arterial segment safety in Oregon.

4.4 SUMMARY

This chapter summarized the data collection plan including the method for estimating a target sample size and the associated random sampling procedure use for urban and rural arterials. The resulting study segments are depicted in Table 4.1. This chapter also reviewed the key factors identified in the literature review and their companion data variables and sources (see Table 4.2). Table 4.3 shows the specific data items collected for the various roadway and driveway configurations at each segment. Finally, the chapter concluded with a review of the target crash type collected for analysis. This resulting total non-intersection crash category serves as the target for subsequent modeling efforts.

Table 4.3: Actual Data Variables Collected

Variables Common to Roadway and Driveway		**Description**	
Highway name		Local name of highway	
Highway number		State highway number designation	
Roadway-Specific Data Items		Driveway-Specific Data Items	
Road width	To edge-of-outside-lanes (ft)	Road name	Name if available and different from highway name
Number of lanes	Total both directions	Rural/urban	Select either rural or urban
Median type	Raised, painted, TWLTL, grass, or none	Generic land use	Select one of the following: Residential Commercial Industrial Institutional Agricultural Other (recreational, ports, etc. Public road Unknown
Speed limit	Posted value (mph)	Parking spots	Number of visible parking spots
Bicycle lane	Yes or No	Dwelling units	Number of visible dwelling units
Sidewalks	Yes or No	Additional driveways into same facility	Number
On-street parking	Yes or No	Width	Driveway width at edge of road (ft)
Number of driveways in segment boundaries	Total both direction (identify side of road)	Lanes	Number of lanes at driveway
Segment length	Based on milepoints (miles)	Neck	Yes or no
Segment beginning break type	Intersection, change in cross-section, speed limit, urban or rural boundary, other	Neck width	Width if answer to "neck" was yes
Segment beginning additional information	Comment -- information pertaining to break type, old segment width, speed limit, other	Neck lanes	Number
Segment ending break type	Intersection, change in cross-section, speed limit, urban or rural boundary, other	Distance from start	Measurement in feet
Segment ending additional information	Comment -- information pertaining to break type, old segment width, speed limit, other		

5.0 DATA ANALYSIS AND RESULTS

This research effort is based on two arterial road segment probability samples, one from rural and one from urban environments. Models to help determine the predicted number of crashes associated with driveways are included in this section. In addition, a step-by-step procedure with companion examples seeks to clarify the use of the resulting statistical equations.

5.1 DATA CHARACTERISTICS

Previous chapters of this report have identified expected critical variables for the prediction of driveway-related crashes. Included in the previous review is a list of candidate variables that were physically collected during the data collection process. In addition, a wide variety of variables can be compiled using this information. For example, information at each driveway can be acquired and then variables such as proportion of commercial driveways or similar could then evolve from this basic site information.

The research team geo-coded each segment and annotated the location of each driveway along the road, as well as key indicators of land use associated with such driveways: types of activity (residential, commercial, industrial, etc.), number of available parking spots, and number of redundant driveways, among others. A sample of this acquired data can be found in Table 5.1.

Based on the coded information, the research team created several associated variables in order to explore the influence of driveways on road safety. Example variables included average lane widths, proportion commercial driveways, and similar perturbations of the original acquired data.

5.2 STATISTICAL ANALYSIS OF URBAN SEGMENTS

Due to their fundamental corridor differences, the research team separately evaluated urban and rural sites in the statistical modeling portion of this analysis.

The urban sites were characterized by more variability in the cross-sectional design when they contrasted to the rural site characteristics. As a result, several analysis iterations were necessary in order to properly account for the observed cross-sectional variability before then attempting to account for the effect of driveways. The authors conducted a step-wise model selection because roughly 95 candidate variables with relevant site characteristics were available from the rich data set. The first stage of the model selection did not include driveway nor land-use related variables, so as to assess the impact of a later stage to address driveway safety influences.

Table 5.1: Example of Acquired Data for Five Urban Corridors

Highway Name	**Ochoco**	**Pacific Highway West**	**Rouge Valley**	**Pacific Highway East**	**Olds Ferry-Ontario**
Highway #	41	91	63	81	455
Road Width	24	75	48	24	75
Road Number of Lanes	2	5	4	2	5
Median	None	None	None	None	TWLTL
Speed Limit (mph)	45	35	45	55	55
Bicycle Lane	No	Yes	Yes	No	No
Sidewalks	Partial	No	Partial	No	Yes
On-Street Parking	No	No	No	No	No
Length	0.13	0.36	0.21	0.41	0.24
Beginning break type	Intersection	X-Section	X-Section	Intersection	Intersection
Beginning additional info	NE Willowdale Dr.	Raised Median	Raised Median	Perkins St. NE	Airport Way
Ending break type	Urban Limit	X-Section	Intersection	Intersection	Urban Limit
Ending additional info	---	On-Ramp / Add Lane	Arnos Rd.	Nevada St NE	---
Number Residential Dwy	3	0	1	2	6
Number Commercial Dwy	3	0	8	0	5
Number Agricultural Dwy	0	0	0	0	0
Number Industrial Dwy	0	0	1	0	0
Number Dwy with Unknown Land Use	3	0	0	0	2
Number Other Dwy	0	0	2	0	3
Total Number of Segment Driveways	9	0	12	2	16

After accounting for exposure to crashes (i.e. including a term for AADT and segment length), the importance of accounting for driveway safety became evident. The selection algorithm procedure suggested only driveway-related variables, as supplements to the six geometric-design variables considered, were likely to improve the balance between complexity and goodness-of-fit in the statistical model.

The project team assessed several alternatives that would implicitly model driveway safety, including various driveway clustering rules, as well as spatial and land-use characteristics. Table 5.2 shows the resulting model.

Table 5.2: Best Performing Crash Prediction Model for Urban Environments

Term	Estimate	Standard Error	z-value	p-value	Significance[1]
(Intercept)	-12.891	2.380	-5.417	6.06E-08	***
LnAADT	1.686	0.253	6.670	2.57E-11	***
LnSegmentLength	0.358	0.159	2.244	0.0248	***
Speed.Lim.over.35	-0.469	0.215	-2.178	0.0294	*
MedianTWLTL	-0.898	0.339	-2.652	0.0080	**
Four.Travel.Lanes	-1.631	0.376	-4.335	1.46E-05	***
MedianTWLTL:Four.Travel.Lanes	1.098	0.445	2.465	0.0137	*
Com.andInd.DW	0.058	0.021	2.808	0.0050	**
Other.DW	-0.131	0.033	-3.972	7.14E-05	***

[1] *Significance values are as follows:*
º $p<0.1$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$

NB2 Theta: 6.43 (Standard Error: 3.59)

AIC: 209.66

5.3 URBAN CRASH PREDICTION MODEL COMPUTATIONAL TOOLS

Using the fundamental model depicted in Table 5.2, the following collection of equations can then be applied to the urban arterial to determine the predicted number of crashes associated with exposure, road elements, and driveway-related conditions.

Equation 1. General Estimation of Predicted Number of Crashes
Predicted Number of Crashes = (Baseline Exposure Values) x *(Effect from Roadway)* x *(Effect from Roadside / Driveways)*
Equation 2. Baseline from Exposure at Urban Environments
$$\textit{Baseline Exposure Values} = (2.521 \times 10^{-6}) \times (AADT^{1.686}) \times (\textit{Segment Length}^{\,0.358})$$
Where:
AADT = Annual Average Daily Traffic (vehicles per day), and
Segment Length = study corridor length (miles)

Equation 3. Effect of Roadway on Crashes at Urban Environments
Effect from Roadway = exp [1.098 x *MedianTWLTL:Four.Travel.Lanes - (0.898* x *MedianTWLTL) - (1.631* x *Four.Travel.Lanes) - (0.469* x *Speed.Limit.over.35)]*
Where:
MedianTWLTL = 1 if a two-way left-turn lane is present (0 value if not),
Four.Travel.Lanes = 1 if segment has 4 through lanes (2 lanes in each direction) or a value of zero if the segment has only 2 lanes (1 lane in each direction)
Speed.Limit.over.35 = 1 if the speed limit is greater than 35 mph and zero if the speed limit is 35 mph or less

Since Equation 3 includes a large number of variables and the input factors associated with the equation are easily determined, Table 5.3 directly summarizes the results of Equation 3 for the various input values. A user can just go to this table to determine input values instead of inputting site features into Equation 3.

Table 5.3: Table of Possible Cases of the Effect of Roadway at Urban Environments

	Case 1: Speed Limits up to 35 mph		**Case 2: Speed Limits above 35 mph**	
Median Type \ # of Lanes	*Two Travel Lanes*	*Four Travel Lanes*	*Two Travel Lanes*	*Four Travel Lanes*
TWLTL Median	0.4074	0.2391	0.2549	0.1496
Other types of Medians or No Median Present	1.0000	0.1957	0.6256	0.1225

Finally, equation 4 directly addresses roadside elements as they relate to safety. These "roadside" features are primarily land use for the urban environment.

<u>Equation 4. Effect of Roadside Elements on Crashes at Urban Environments</u>
Effect from Roadside/Driveways = exp [0.058 x *(Com.and.Ind.DW - 2.259* x *Other.DW)]*
Where:
Com.and.Ind.DW = number of commercial plus industrial driveways
Other.DW = number of driveways that are not commercial or industrial (Note: *Com.and.Ind.DW* + *Other.DW* = Total Driveways)

The following section reviews the use of the urban model and presents a sample application.

5.3.1 Use of the Urban Model

To predict the number of segment crashes for urban arterial locations, the following information is needed:

- Length of the road segment to analyze (in miles),
- AADT for the segment,
- Speed limit for the road segment,
- Cross-section information: Number of travel lanes and presence of TWLTL median,
- Total number of driveways dedicated to commercial and industrial land uses, and
- Total number of driveways dedicated to other land uses.

The predictive procedure can then be performed by applying the following steps:

1. Compute the Effect of Exposure Factors using Equation 2.
2. Select the corresponding roadway effect factor from Table 5.3 of by using Equation 3.
3. Compute the effect of driveways using Equation 4.
4. Multiply the results as in the general estimation methodology (established in Equation 1) to obtain the expected number of crashes for the study segment.

5.3.2 Example Use of the Urban Model

This section demonstrates how to use the methodology outlined in the previous section. For this demonstration, a sample site was selected from the pool of sites in this study. This site, located in Redmond, Oregon, is illustrated in Figure 5.1: .

Figure 5.1: Sample Site #23, Redmond, Oregon

The required information from this site is identified in :

Table 5.4: Sample Input for Urban Example Problem from Redmond, Oregon

Urban Segment Features	Characteristics
Segment length	0.12 miles
AADT	24,800 vpd
Speed limit	45
Number of travel lanes	4
TWLTL median	Yes
Total commercial and industrial driveways	7
Total driveways for other land uses	1

Step 1: Compute the Effect of Exposure Factors using Equation 2.

$\textit{Baseline Exposure Values} = (2.521 \times 10^{-6}) \times (\textit{AADT}^{1.686}) \times (\textit{Segment Length}^{\,0.358})$

$\textit{Baseline Exposure Values} = (2.521 \times 10^{-6}) \times (24{,}800^{1.686}) \times (0.12^{\,0.358}) = 30.26$

Step 2: Select the adjustment factor for roadway design characteristics from Table 5.3.

Since this segment has a speed limit above 35 mph, has a TWLTL median, and has 4 travel lanes, the adjustment factor should be 0.1496 (from Table 5.3).

Step 3: Compute the effect of driveways, via Equation 4
Effect from Roadside/Driveways = exp [0.058 x *(Com.and.Ind.DW - 2.259* x *Other.DW)]*
Effect from Roadside/Driveways = exp [0.058 x *(7 - 2.259* x *1)] = 1.32*

Step 4: Obtain the predicted number of crashes for the segment by multiplying all of the above results
Predicted Number of Crashes = (Baseline Exposure Values) x *(Effect from Roadway)* x *(Effect from Roadside / Driveways)*
Predicted Number of Crashes = 30.26 x *0.1496* x *1.32 = 5.9589 predicted crashes in 5 years*

Example problem conclusion:

Based on exposure, roadway, and roadside characteristics we can predict that over a period of 5 years approximately 6 (rounded from 5.96) segment crashes will occur.

5.4 RURAL MODEL SPECIFICATION

As expected, the mathematical form of the rural model differed substantially from that of the urban model. In fact, the differences between these environments became evident from the initial contrasting examination between the two data sets. The next section briefly discusses some relevant aspects of this contrast, and the need for further preparation of the data prior to the statistical analysis.

5.4.1 Segment Heterogeneity and the Need for Further Segmentation

The research team found early evidence of important differences between the rural and urban samples, even when the procedure used to randomly select both samples was virtually the same. For instance, while the average, the minimum, and the maximum segment length for the urban samples were, respectively, 0.318, 0.1 and 1.25 miles; those numbers contrast with their rural counterparts of 1.434, 0.34 and 2.0 miles. The rural sample is also less diverse in terms of speed limit (all sites but one are 55 mph, the remaining site is 50 mph) and median treatment (no median present).

Additionally, there are issues associated with the two variables of interest to this report: on the one hand, the number of crashes, in general, is smaller for the rural sample (average of 4.05 crashes per site, as opposed to 7.625 in the urban sample). On the other hand, the average driveway density is substantially different between the two samples: 18.23 dwy/mi for urban, 3.67 dw/mi for rural. This disparity contrasts with a similar frequency of driveways between the two samples (range of 0 to 23 driveways, with an average of 5.8 in the urban sample; range from 0 to 26 driveways, with an average of 5.25 in the rural sample). However, it also should be considered that both samples have very different segment lengths. The average urban segment is roughly 1/5th as long as the average rural segment.

An additional and perhaps more significant complication emerged from the fact that clustering of driveways is a pervading characteristic in the rural sample, as opposed to the urban sample, where driveways are closer together and driveway density is generally more consistent. An example of the clustering of existing driveways for the rural segments is illustrated in Figure 5.2.

Primarily as a result of the clustering, the research team decided to ensure the consistency of the safety assessment of this sample by further segmenting the rural sample in order to obtain more uniform segments. The original set of 40 rural segments was examined and re-segmented in the case of clustered driveways separated by a long segment without driveways. This procedure yields smaller segments whose characteristics are still representative of Oregon rural highways (via a statistical sampling procedure known as One Stage Complete Cluster Random Sampling).

The new rural sample comprised 82 segments with an average number of driveways of 2.549, and with an average length of 0.660 mi. Although this new segmentation resulted in more uniform segments due to the clustering, the average driveway density is very similar to the original segmentation (3.86 dwy/mi) which reinforces the fact that both segmentations are probability samples for the rural highways in Oregon, and as such, both yield representative estimates for the rest of the variables.

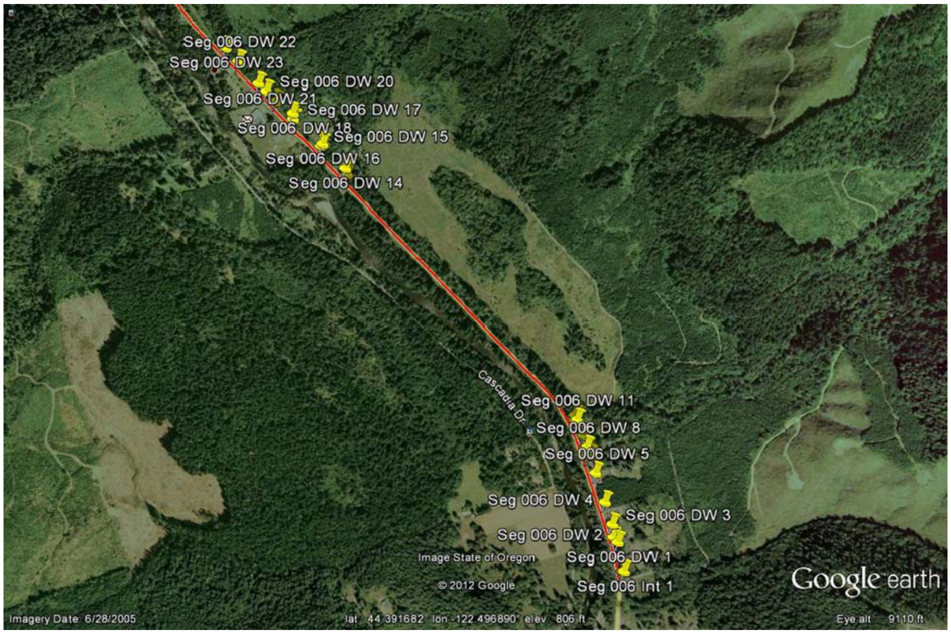


Figure 5.2: Clustering in rural segments

Although the new segmentation was such that the clustering of driveways was less prominent, some clustering was still present in the new rural sample. Therefore, clustering was still a potential covariate to consider in the modeling, since the influence of an isolated driveway on road safety would likely differ from that of a closely located group of driveways.

5.4.2 Modeling Process

For the modeling process, the research team considered the same pool of initial data variables used for developing the urban model. However, two additional covariates were initially considered for this new modeling: shoulder width and curb presence. The project team reviewed these two new candidate variables and found that none of the rural sample sites actually had any curbs, thereby eliminating this as a potential input into the modeling process.

The likelihood of arriving at a statistical model as rich and intricate as the urban was unlikely given the reduced span of key covariates in rural environments, with sites having lower traffic volumes and therefore fewer crashes.

The project team used a similar approach as shown for the urban modeling effort. First they explored the model variables available from the data that would explain crashes without the use of any driveway related variables. The research team would use this 'base model' to assess the degree to which considering driveway-related information would help to improve the overall prediction of crashes. The base model was determined by using a step-wise statistical modeling procedure. Basically, this procedure considers a large pool of potential covariates as well as the available sample size, and arrives at a model that balances an appropriate degree of complexity and a reasonable goodness-of-fit to the data.

The researchers found that the best available 'base model' consists of only three covariates: the power functions of two exposure variables (i.e. AADT and Segment length), and a 'shift' factor depending on a third covariate (i.e. whether or not the road has four travel lanes), collectively these variables denote the influence of roadway characteristics (see **Table 5.5**).

Table 5.5: Base Crash Prediction Model for Rural Environments

Term	Estimate	Standard Error	z-value	p-value	Significance[1]
(Intercept)	-6.6009	1.1986	-5.507	3.65E-08	***
LnAADT	0.8638	0.1562	5.529	3.21E-08	***
LnSegmentLength	0.5595	0.2314	2.418	0.0156	*
Four.Travel.Lanes	0.2908	0.1892	1.538	0.1242	

[1] *Significance values are as follows:*
º $p<0.1$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$

NB2 Theta: 2.901

AIC: 283.36

Note: This table is included to help demonstrate the modeling process used for rural analysis. It does not represent the final model.

Two things are important to notice about this base model: first, only the exposure variables had statistically significant influence over safety at this initial state; second, although the influence of the shift factor is not statistically significant, this base model suggests that, converse to the trend in urban environments, four lane rural roads tend to have more crashes than roads with fewer travel lanes (i.e. the shift factor is 1.000 for less than four travel lanes, and 1.337 for roads with four travel lanes).

Driveway-related variables were explicitly considered in a second stage of the modeling process. This stage was aided by the same criterion of balancing fit and complexity whenever a new covariate was to enter or to exit the model specification. The resulting model from this effort is shown in Table 5.6.

Table 5.6: First Candidate Crash Prediction Model for Rural Environments

Term	Estimate	Standard Error	z-value	p-value	Significance[1]
(Intercept)	-5.5576	1.1477	-4.843	1.28E-06	***
LnAADT	0.8015	0.1457	5.501	3.77E-08	***
LnSeg.Len	0.3983	0.2258	1.764	0.0778	.
four.lanes	0.7821	0.3277	2.386	0.017	*
Proportion.Ind.DW	1.415	0.6038	2.344	0.0191	*
Number.of.Clusters	0.0589	0.0328	1.796	0.0726	.
Ave.DW.Density.in.Clusters	-0.3976	0.2361	-1.684	0.0922	.

[1] *Significance values are as follows:*
º $p<0.1$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$

NB2 Theta: 6.05 (Std.Err.: 4.65)

AIC: 281.17

The model in Table 5.6 improves the quality of information available from the base model, as denoted by a drop in the Akaike Information Criterion (AIC). This means the there is a gain in information by including three new covariates: proportion of industrial driveways, total number of clusters of closely located driveways, and the average driveway density within the clusters. A 'cluster of closely located driveways' is defined as the set of driveways such that the distance between two consecutive driveways can be traveled in 1.5 seconds or less. This distance is 121 ft and 110 ft for roads with speed limits of 55 mph and 50 mph respectively. These are the only two speed limits available from the sample of rural roads.

Considering all the three driveway variables, this model suggests that driveways increase the likelihood of crashes in general (as of the first two variables), but such increased likelihood "loses impact" as the clusters become more dense (i.e. the negative term is for driveway density within the clusters, the last variable in the table). However, when comparing Table 5.5 and Table 5.6, it becomes apparent that the inclusion of the three new variables seems to have no significant impact on the magnitude of the AADT influence, a mild effect on segment length, and a significant impact on the magnitude of the shift of four-lane roads. Additionally, the statistical significance of the two cluster variables is marginal. The authors considered that this may be so because of a degree of duplicity of information among some covariates.

For example, the authors expect that the average driveway density within clusters (average number of driveways per cluster) is a surrogate measure of typical driveway density (driveways per mile), a variable that appears in current literature as the reference of driveway safety. Therefore, driveway density within clusters may be accounting for exposure, to a certain extent. This is the reason why the authors chose to then test a new model based on Table 5.6, but disaggregating the implicit driveway density variable in the two variables it is expected to be aliasing: total driveways and segment length. However, segment length is already considered in the model. In order to arrive to a model from where an interpretation in terms of driveway density is possible, the researchers decided to restrain the coefficients of segment length and total driveways to share their magnitude but to have opposite signs. Not only does this technique of parameterization allow the model to relate safety to the traditionally used driveway density in combination with clustering and land use; it also improves the overall quality of information from the model and the statistical significance of the affected variables. This result is shown in Table 5.7.

Table 5.7: Best Performing Crash Prediction Model for Rural Environments

Term	Estimate	Standard Error	z-value	p-value	Significance[1]
(Intercept)	-5.6787	1.1412	-4.976	6.49E-07	***
LnAADT	0.7825	0.1429	5.476	4.35E-08	***
LnSegmentLength	0.2864	0.1259	2.276	0.02287	*
Four.Travel.Lanes	0.7862	0.3358	2.341	0.01922	*
Proportion.Ind.DW	1.2918	0.6077	2.126	0.03353	*
Number.of.DW.Clusters	0.1048	0.0347	3.021	0.00252	**
LnTotal.DW	-0.2864	0.1259	2.276	0.02287	*
[1]*Significance values are as follows:* º p<0.1; * p < 0.05; ** p < 0.01; and *** p < 0.001					
NB2 Theta: 5.5633 (Std.Err.: 4.04)					
AIC: 280.7					

Similar to the model in **Table 5.6**, the new model suggests that the presence of industrial driveways and the number of driveway clusters together tend to increase the likelihood of crashes, but that such impact diminishes when the driveway density increases (or the total number of driveways in the segment increases, if the effect of segment length is not considered).

5.4.3 Rural Crash Prediction Model Computational Tools

Following the same general estimation of crashes methodology, outlined in

Equation 1, the following set of equations establish the computational blocks to estimate the expected number of crashes for rural arterial environments:

Equation 5. Baseline from Exposure at Rural Environments

$Baseline\ Exposure\ Values = (3.418 \times 10^{-3}) \times (AADT^{0.7825}) \times (Segment\ Length^{0.2864})$

Where:

AADT = Annual Average Daily Traffic (vehicles per day), and

Segment Length = study corridor length (miles)

Equation 6. Effect of Roadway on Crashes at Rural Environments

$Effect\ from\ Roadway = \exp [0.7862 \times Four.Travel.Lanes]$

Where:

Four.Travel.Lanes = 1 if segment has 4 through lanes (2 lanes in each direction) or a value of zero if the segment has only 2 lanes (1 lane in each direction)

Table 5.8: Possible cases of the Effect of Roadway at Rural Environments

Two Travel Lanes	*Four Travel Lanes*
1.0000	2.1950

Equation 7. Effect of Roadside Elements on Crashes at Rural Environments

$$Roadside.effect = \exp[(1.2918 \times Prop.of.Ind.DW) + (0.1048 \times Total.\#.Clusters)] \;/\; (Total.\#.Driveways + 0.5)^{0.2864}$$

Where:

Prop.of.Ind.DW = proportion of industrial driveways (number of industrial driveways divided by the total number of driveways),

Total.#.Clusters = number of directional driveway clusters with a 1.5 second travel time (see Figure 5.3 for example directional driveway cluster calculations), and

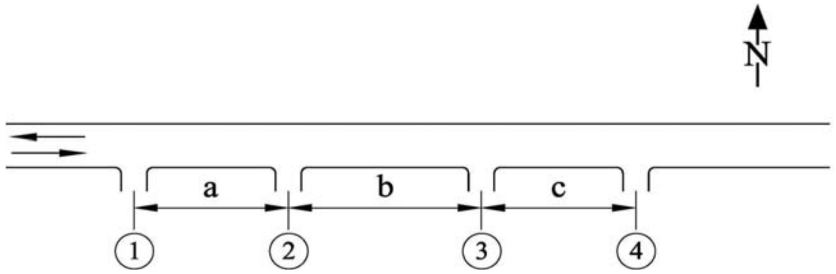
Total.#.Driveways = number of individual driveways (all land uses) located in the study corridor.

5.4.4 Use of the Rural Model

The information needed to use the rural model is similar to its urban counterpart, specifically:

- Length of the road segment to analyze (in miles)
- AADT for the segment
- In this case, the model is specified for speed limits of either 50 or 55 mph only.
- Cross-section information: Number of travel lanes.
- Total number of driveways in the segment, regardless of kinds of land use.
- Total number of driveways dedicated to Industrial land use.
- Total number of clusters of closely located driveways. A ‘cluster of closely located driveways’ is defined as the set of driveways such that the distance between two consecutive driveways on one side of the street can be traveled in 1.5 seconds or less. This distance is 121 ft and 110 ft for roads with speed limits of 55 mph and 50 mph respectively.

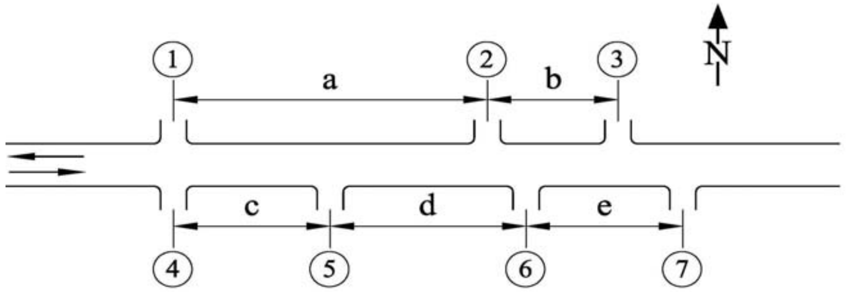
Case I. Driveways on Only One Side of the Road (based on 1.5 second spacing)



Example Calculation of Directional Clusters for Various Spacings:

a (ft)	b (ft)	c (ft)	# Drives	50 mph Speed Limit			55 mph Speed Limit		
				# Cluster	Clusters Noted	Comment	# Cluster	Clusters Noted	Comment
140	200	160	4	4	1, 2, 3, 4	All > 110’	4	1, 2, 3, 4	All > 121’
115	200	160	4	4	1, 2, 3, 4	All > 110’	3	1-2, 3, 4	a < 121’
80	115	125	4	3	1-2, 3, 4	a < 110’	2	1-2-3, 4	a & b < 110’
80	105	115	4	2	1-2-3, 4	a & b < 110’	1	1-2-3-4	All < 121’
80	105	90	4	1	1-2-3-4	All < 110’	1	1-2-3-4	All < 121’

Case II. Driveways on Both Sides of the Road (based on 1.5 second spacing)



Example Calculation of Directional Clusters for Various Spacings:

a (ft)	b (ft)	c (ft)	d (ft)	e (ft)	# Drives	50 mph Speed Limit			55 mph Speed Limit		
						# Cluster	Clusters Noted	Comment	# Cluster	Clusters Noted	Comment
200	125	130	125	150	7	7	WB: 1,2,3 EB: 4,5,6,7	All > 110’	7	WB: 1,2,3 EB: 4,5,6,7	All > 121’
200	115	130	125	150	7	7	WB: 1,2,3 EB: 4,5,6,7	All > 110’	6	WB: 1,2-3 EB: 4,5,6,7	b < 121’
200	105	120	125	150	7	6	WB: 1,2-3 EB: 4,5,6,7	b < 110’	5	WB: 1,2-3 EB: 4-5,6,7	b & c < 121’
200	105	105	105	150	7	4	WB: 1,2-3 EB: 4-5-6,7	b, c, & d < 110’	4	WB: 1,2-3 EB: 4-5-6,7	b, c, & d < 121’
120	90	90	95	105	7	3	WB: 1,2-3 EB:4-5-6-7	b, c, d, & e < 110’	2	WB: 1-2-3 EB:4-5-6-7	All < 121’
105	90	90	95	105	7	2	WB: 1-2-3 EB:4-5-6-7	All < 110’	2	WB: 1-2-3 EB:4-5-6-7	All < 121’

Figure 5.3: Example Calculations for Rural Directional Driveway Clusters

Steps:

1. Compute the effect of exposure factors using Equation 5.
2. Select the corresponding roadway effect factor form Table 5.8 or Equation 6.
3. Compute the effect of driveways using Equation 7.

Multiply the results as in the general estimation methodology (established in

4. Equation 1) to obtain the expected number of crashes for the study segment.

5.4.5 Example Use of the Rural Model

This section demonstrates how to use the methodology outlined in the previous section. For this demonstration, a sample site was selected from the pool of sites in this study. This site, located on highway US 20, between Corvallis and Newport, is illustrated in Figure 5.4.

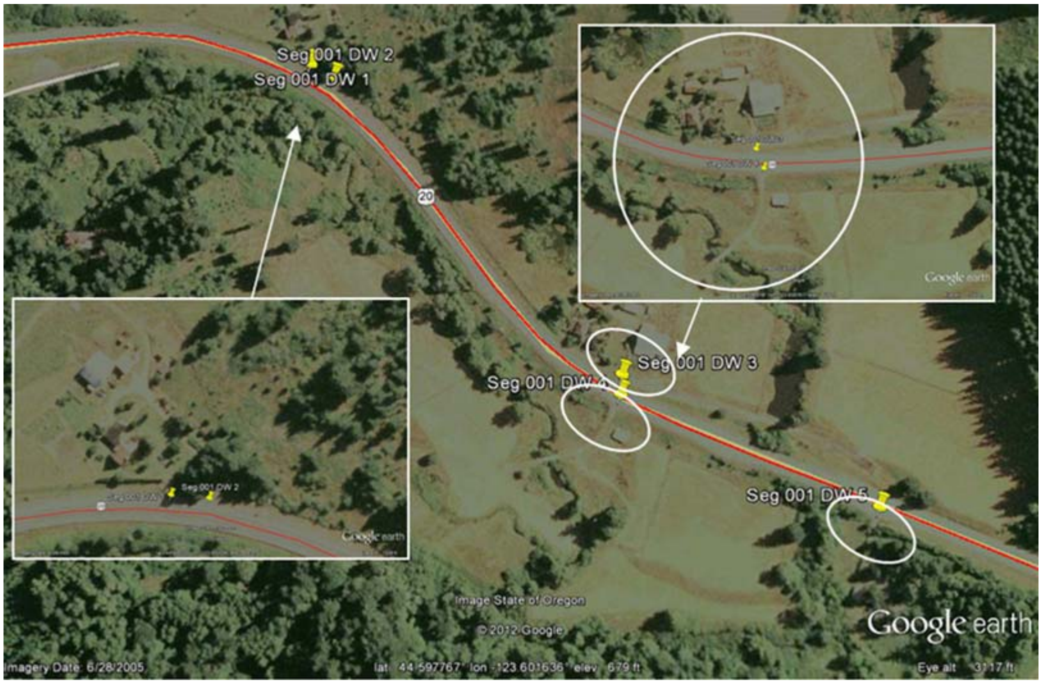


Figure 5.4: Sample Site, Corvallis-Newport, Oregon

The required information from this site:

Table 5.9: Sample Input for Rural Example Problem for Corvallis-Newport, Oregon

Rural Segment Features	Characteristics
Segment length (MP 33.78 to 34.34)	0.56 miles
AADT	4,940 vpd
Speed limit	55
Number of travel lanes	2
Total driveways in segment	5
Proportion of industrial driveways	0.00
Number of clusters of closely located driveways (such that the maximum distance between two driveways in a cluster is 121 ft for the 55 mph speed of this road)	4

Since there are no industrial driveways in this segment, the proportion of industrial driveways is then: 0 ÷ 5 = 0.00.

Determining the clusters may be the most intricate piece of information required in this model. Figure 5.4 shows 5 different driveways within the segment. While driveways 1 and 2 constitute a cluster because they are both at the same side of the road and located at approximately 75 ft of each other, driveways 4 and 5 do not. This is because they are on opposite sides of the road. So, except for driveways 1 and 2, each driveway in this segment is at least 122 ft from each neighbor driveway at the same side of the road. The number of clusters is then 4.

Next, we can proceed to estimate the predicted number of crashes associated with this segment.

Step 1: Compute the Effect of Exposure Factors using Equation 5

$$\text{Baseline Exposure Values} = (3.418 \times 10^{-3}) \times (\text{AADT}^{0.7825}) \times (\text{Segment Length}^{0.2864})$$
$$\text{Baseline Exposure Values} = (3.418 \times 10^{-3}) \times (4940^{0.7825}) \times (0.56^{0.2864}) = 2.249$$

Step 2: Select the adjustment factor for roadway design characteristics from Table 5.8**.**

Since this segment has two travel lanes, the adjustment factor is simply 1.000 (from Table 5.8).

Step 3: Compute the effect of driveways using via Equation 4

$$\text{Roadside.effect} = \exp[(1.2918 \times \text{Prop.of.Ind.DW}) + (0.1048 \times \text{Total.\#.Clusters})] \;/\; (\text{Total.\#.Driveways} + 0.5)^{0.2864}$$
$$\text{Roadside.effect} = \exp[(1.2918 \times 0.00) + (0.1048 \times 4)] \;/\; (5.5)^{0.2864} = 0.9333$$

Step 4: Obtain the predicted number of crashes for the segment by multiplying all of the above results (as established in Equation 1)

$$\text{Predicted Number of Crashes} = (\text{Baseline Exposure Values}) \times (\text{Effect from Roadway}) \times (\text{Effect from Roadside / Driveways})$$
$$\text{Predicted Number of Crashes} = 2.249 \times 1.000 \times 0.9333 = 2.099 \text{ expected crashes in 5 years}$$

Example problem conclusion:

Based on exposure, roadway, and roadside characteristics we can predict that over a period of 5 years approximately 2 (rounded from 2.099) segment crashes will occur.

5.5 SUMMARY

As demonstrated in this chapter, the direct modeling of driveway-related crashes did not prove to be an effective technique; therefore, the project team modeled total segment crashes and then developed an equation structure to help account for the influence of land use and driveways on the overall segment crash condition. For both the urban and rural environment, a general multiplicative relationship can be used that accounts for baseline exposure, roadway characteristics, and roadside elements. For the urban environment, the following critical variables were identified as influential:

- AADT (Baseline),
- Segment Length (Baseline),
- Median TWLTL (Roadway),
- Four Travel Lanes Present (Roadway),
- Speed Limit over 35 (Roadway),
- Number of commercial and industrial driveways (Roadside), and
- Number of other driveways (Roadside).

For the rural environment, the following variables were determined to be critical to segment crash prediction:

- AADT (Baseline),
- Segment Length (Baseline),
- Four Travel Lanes Present (Roadway),
- Proportion of Industrial Driveways (Roadside),
- Total Number of Driveway Clusters (Roadside), and
- Total Number of Driveways (Roadside).

6.0 CONCLUSIONS AND RECOMMENDATIONS

This report reviews the research effort performed for the Oregon driveway safety performance project and summarizes the site selection, data collection, analysis, and findings of a statistical analysis procedure to help ODOT better understand the effect of driveways on urban and rural arterials. The project team performed a literature review to identify the findings of previous research efforts, conducted investigatory analyses of the crash database to understand the trends surrounding driveway crashes across the state, assessed the practicality of using driveway-related crashes versus total segment crashes, developed and executed a data collection and reduction work plan, and performed an analysis using a randomly selected statistical sample for both rural and urban locations.

The literature review is summarized in Chapter 2.0. Previous research efforts have identified seven major factors shown to affect driveway safety. These factors include: driveway spacing, proximity to intersections and interchanges, signalized intersection spacing and signal coordination, driveway design, roadway design, median configuration, and land use. Chapter 2.0 also includes a brief review of analysis methods and related research projects currently underway.

Chapter 3.0 of this report presents a review of the data currently available through ODOT databases including crash data as well as driveway and road data. The project team investigated trends associated with various types of crash data, including crash locations, driver characteristics, vehicle movements, temporal distributions, and weather conditions, among others.

The data collection plan is outlined in Chapter 4.0. This chapter reviews the overall data collection process including determination of the target sample size and associated data variables. The method the research team used for developing a random probability sample for both the urban and rural arterials in Oregon is explained. The project team used a very limited number of field investigations for the data collection effort. Instead, the use of aerial photography coupled with video log information provided comprehensive driveway and corridor information. Items such as signal timing and progression within a corridor, unfortunately, were not available and collection of such information was not within the project scope.

Finally, Chapter 5.0 summarized the modeling effort for determining the safety performance of driveways along an urban or rural arterial corridor in Oregon. A three-stage procedure was introduced that accounts for baseline exposure, roadway, and roadside (primarily land use and driveways) information to be used to predict crashes. Though the project team developed the same computation format for both the rural and urban environment, the significant factors affecting safety varied for these two area types. For the urban environment, the following critical variables were identified as influential:

- AADT (Baseline),
- Segment Length (Baseline),
- Median TWLTL (Roadway),
- Four Travel Lanes Present (Roadway),
- Speed Limit over 35 (Roadway),
- Number of commercial and industrial driveways (Roadside), and
- Number of other driveways (Roadside).

For the rural environment, the following variables were determined to be critical to segment crash prediction:

- AADT (Baseline),
- Segment Length (Baseline),
- Four Travel Lanes Present (Roadway),
- Proportion of Industrial Driveways (Roadside),
- Total Number of Driveway Clusters (Roadside), and
- Total Number of Driveways (Roadside).

The models developed for this project provide a significant level of knowledge regarding the influence of both driveway (roadside) and roadway features on the crash condition in Oregon. This collection of models can be used to assess a variety of road features and predict their ultimate impact on the expected safety performance of a facility. Since the introduction of seemingly complex equations can be daunting, the authors also included an example application for the urban and rural crash prediction models.

During the development of this research effort, there are many future research issues that arise and merit specific identification. Anytime models are developed and the sample size is limited, the opportunity to perform validation and a completely separate data set will ensure that they appropriately predict crashes as expected. Therefore, the project team would like to recommend that a future effort validate these models. In addition, the focus of this research effort was on the urban and rural arterial corridors. The placement of driveways on roads designated as collectors is common, and so the project team would like to recommend a similar assessment be extended to the collector functional classification facilities.

7.0 REFERENCES

American Association of State Highway Transportation Officials. *A Policy on Geometric Design of Highways and Streets* (5th Ed. ed.). Washington, D.C., 2004.

Bindra, S., J. Ivan, and T. Jonsson. Predicting Segment-Intersection Crashes with Land Development Data. *Transportation Research Record: Journal of the Transportation Research Board* , No. 2102, 2009, pp. 9-17.

Brown, H.C., and A.P. Tarko. Effects of Access Control on Safety on Urban Arterial Streets. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1665, 1999, pp. 68-74.

Butorac, M.A., and J.C. Wen. *Access Management on Crossroads in the Vicinity of Interchanges.* National Cooperative Highway Research Program. Washington, D.C.: Transportation Research Board, 2004.

Castronovo, S., P.W. Dorothy, and T.L. Maleck. Investigation of the Effectiveness of Boulevard Roadways. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1635, 1998, pp. 147-154.

Dixon, K., I. van Schalkwyk, and R. Layton. Balancing Urban Driveway Design Demands Based on Stopping Sight Distance. *Transportation Research Record: Journal of the Transportation Research Board* , No. 2120, 2009, pp. 18-27.

Eisele, W. L., and W.E. Frawley. Estimating the Safety and Operational Impact of Raised Medians and Driveway Density. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1931, 2005, pp. 108-116.

Gattis, J., R. Balakumar, and L.K. Dunacan. Effects of Rural Highway Median Treatments and Access. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1935, 2005, pp. 99-107.

Gattis, J., J.S. Gluck, J.M. Barlow, R.W. Eck, W.F. Hecker, and H.S. Levinson. *Guide for the Geometric Design of Driveway*. NCHRP Report 659. Washington, D.C.: National Cooperative Highway Research Program, 2010.

Gluck, J., and P. King. Access Management at a High-Volume Interchange. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1858, 2003, pp.133-141.

Gluck, J., H.S. Levinson, and V. Stover. *Impacts of Access Management Techniques.* NCHRP Report 420. National Cooperative Highway Research Progam. Washington, D.C.: National Academy Press, 1999.

Hadi, M. A., J. Aruldhas, L.-F. Chow, and J.A. Wattleworth. Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1500, 1995, pp. 169-177.

Ivan, J., C. Wang, and N. Bernardo. Explaining Two-Lane Highway Crash Rates Using Land Use and Hourly Exposure. *Accident Analysis and Prevention*, No. 32, 2000, pp. 787-795.

Kim, D.-G., Y. Lee, S. Washington, and K. Choi. Modeling Crash Outcome Probabilities at Rural Intersections; Application of Hierarchical Binomial Logistic Models. *Accident Analysis and Prvenetion*, No. 39, 2007, pp. 125-134.

Liu, P., J.J. Lu, and H. Chen. Safety Effects of the Separation Distances Between Driveway Exits and Downstream U-Turn Locations. *Accident Analysis and Prevention*, No. 40, 2008, pp. 760-767.

Margiotta, R., and A. Chatterjee. Accidents on Suburban Highways - Tennessee's Experience. *Journal of Transportation Engineering* (May/June), 1995, pp. 255-261.

Mouskos, K. C., W. Sun, S.I. Chien, A. Eisdorfer, and T. Qu. Effect of Midblock Access Points on Traffic Accidents on State Highways in New Jersey. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1665, 1999, pp. 75-83.

Papayannoulis, V., J.S. Gluck, K. Feeney, and H.S. Levinson. Access Spacing and Traffic Safety. *Urban Street Symposium.* Dallas, Texas, 1999.

Potts, I.B., D.W. Harwood, D.J. Torbic, K.R. Richard, J.S. Gluck, H.S. Levinson, et al. *Safety of U-Turns at Unsignalized Median Openings,* NCHRP Report 524. National Cooperative Highway Research Program. Washington, D.C.: Transportation Research Board, 2004.

Rakha, H., A.M. Flintsch, M. Arafeh, A.-S.G. Abdel-Salam, D. Dua, and M. Abbas. *Access Control Design on Highway Interchanges.* Richmond, VA: Virginia Tech Transportation Institute, 2008.

Rodegerdts, L.A. *Signalized Intersections: Informational Guide.* 2004. http://www.fhwa.dot.gov/publications/research/safety/04091/index.cfm. Accessed April 2010.

Squires, C.A., and P.S. Parsonson. Accident Comparison of Raised Median and Two-Way Left-Turn Lane Median Treatments. *Transportation Research Record: Journal of the Transportation Research Board* , No. 1239, 1989, pp. 30-40.

Stover, V. *Signalized Intersection Spacing.* Oregon Transportation Research Institute, 1996.

Stover, V., and F. Koepke. *Transportation and Land Development* (2nd Edition ed.). Washington, D.C.: Institute of Transportation Engineers, 2002.

Transportation Research Board. *Access Management Manual.* Washington, D.C.: Transportation Research Board of the National Academies, 2003.

Transportation Research Institute. *Medians.* Discussion Paper No. 4, Oregon State University, Corvallis, OR, 1996.

APPENDIX A:
SUPPLEMENTAL TABLES AND DATA COLLECTION PROCESS

This appendix contains supplemental tables as well as a summary of the process used for collecting driveway data.

SUPPLEMENTAL TABLES

Table A-1: Abbreviations and Acronym Definitions

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
AADT	Average Annual Daily Traffic
ADA	Americans with Disabilities Act
AIC	Akaike Information Criterion
CMF	Crash Modification Factor (or Function)
FHWA	Federal Highway Administration
GIS	Geographical Information System
HSM	Highway Safety Manual
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
PDO	Property Damage Only
SPF	Safety Performance Function
TAC	Technical Advisory Committee
TRB	Transportation Research Board
TWLTL	Two-Way Left-Turn Lane
UBG	Urban Growth Boundaries

Table A-2: Summary of Factors Affecting Driveway Safety and Corresponding Citations

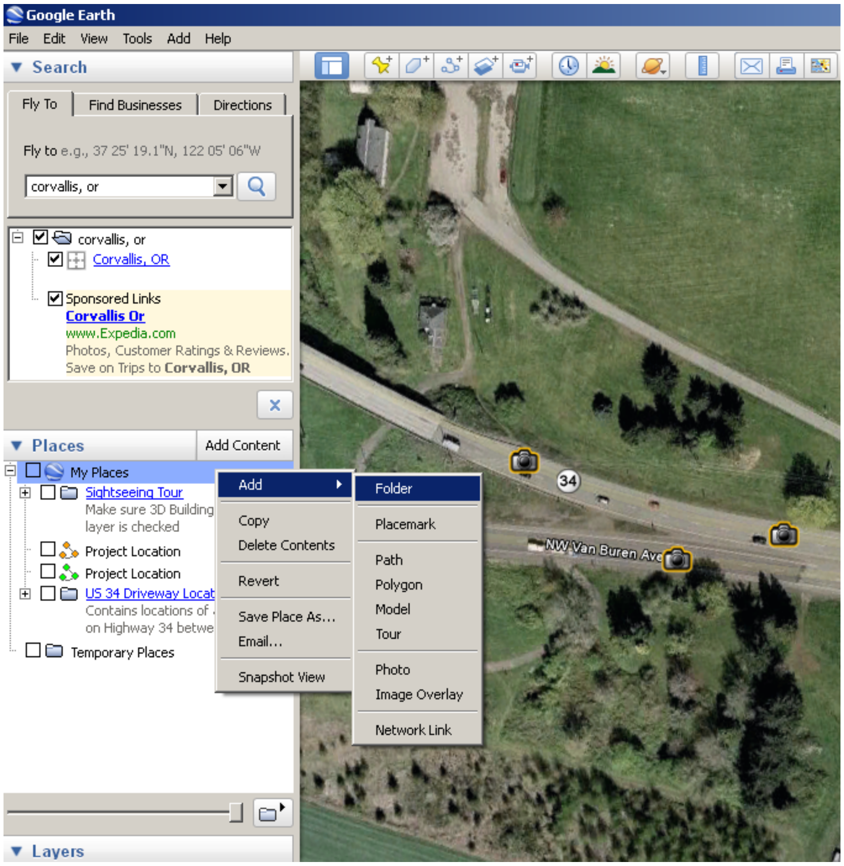
Factor	Findings	References	
		Title	**Author and Date**
Driveway Spacing	Increased access frequency or density (access points per mile) is associated with an increase in crash rates.	Effects of Access Control on Safety on Urban Arterial Streets.	Brown and Tarko (1999)
		Estimating the Safety and Operational Impact of Raised Medians and Driveway Density	Eisele and Frawley (2005)
		NCHRP Report 420: Impacts of Access Management Techniques.	Gluck et al. (1999)
		Effect of Midblock Access Points on Traffic Accidents on State Highways in New Jersey	Mouskos et al. (1999)
		Access Spacing and Traffic Safety	Papayannoulis et al. (1999)
Proximity to and Between Intersections	An increased spacing between access points and intersections is associated with a decrease in crash rates. Spacing distance should include perception-reaction distance, weaving distance, transition distance, and downstream storage.	NCHRP Synthesis 332: Access Management on Crossroads in the Vicinity of Interchanges	Butorac and Wren (2004)
		NCHRP Report 420: Impacts of Access Management Techniques.	Gluck et al. (1999)
		Access Management Manual	Committee on Access Management (2003)
		Access Control Design on Highway Interchanges	Rakha et al. (2008)
Signalized Intersection Spacing and Signal Coordination	An increase in the number of signals per segment is associated with an increase in crash rates. Progression and coordination should be maintained for adequate gaps and good operations.	Access Management Manual	Committee on Access Management (2003)
		Signalized Intersection Spacing	Stover (1996)
Driveway Design	Typically, driveways should always have simultaneous two-way operations or restricted one-way operations, but not alternating flow. Use clear and delineated striping or channelization to clearly define vehicle paths. Limit conflicts between different road users (vehicles, pedestrians, bicyclists).	Guide for the Geometric Design of Highways	Gattis et al. (2010)
		Transportation and Land Development	Stover, Koepke (2002)

Factor	Findings	References	
		Title	Author and Date
Road Design Elements	Wider lanes, medians and shoulders are associated with a reduction in crash rates. Bike lanes increase sight distance and on-street parking decreases sight distance, both of which impact safety. Auxiliary lanes may decrease crash rates but should only be considered when warranted.	Investigation of the Effectiveness of Boulevard Roadways	Castronovo et al. (1998)
		Access Management Manual	Committee on Access Management (2003)
		Balancing Urban Driveway Design Demands Based on Stopping Sight Distance	Dixon et al. (2009)
		Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression	Hadi et al. (1995)
Land Use	A correlation between land use and crash rate exists, but quantification of this correlation remains unclear. Actual GIS land use data may effectively be used instead of driveway frequency/type to enhance statistical models.	Effects of Rural Highway Median Treatments and Access	Gattis et al. (2005)
		Predicting Segment-Intersection Crashes with Land Development Data	Bindra, Ivan and Jonsson (2009)
		Explaining Two-Lane Highway Crash Rates Using Land Use and Hourly Exposure	Ivan, Wang and Bernardo (2000)
Median Configuration	Raised medians are typically safer than TWLTLs; whereas, indirect left-turns are safer than direct left-turns. Additional safety benefits can be expected with longer distances between access points and defined downstream U-turn locations.	Effects of Rural Highway Median Treatments and Access	Gattis et al. (2005)
		Safety Effects of the Separation Distances Between Driveway Exits and Downstream U-Turn Locations	Liu et al. (2008)
		Accidents on Suburban Highways - Tennessee's Experience	Margiotta and Chatterjee (1995)
		NCHRP Report 524: Safety of U-Turns at Unsignalized Median Openings	Potts et al. (2004)
		Transportation and Land Development	Stover and Koepke (2002)
		Accident Comparison of Raised Median and Two-Way Left-Turn Lane Median Treatments	Squires and Parsonson (1989)
Analysis Techniques	Negative binomial and Poisson regression are the most widely accepted for safety	Access Control Design on Highway Interchanges	Rakha et al. (2008)

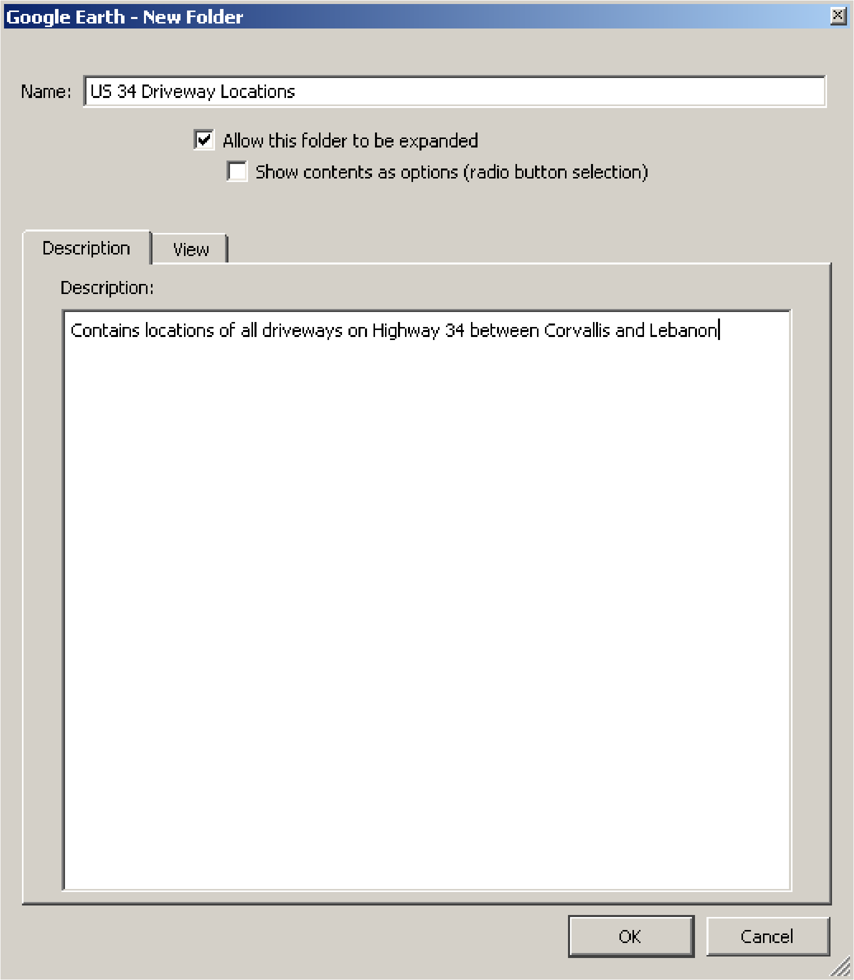
Factor	Findings	References	
		Title	**Author and Date**
	applications. The literature also includes suggestions of hierarchical structure for crash data analysis. Multiple analysis techniques should be investigated prior to completing analyses for any project.	Modeling Crash Outcome Probabilities at Rural Intersections; Application of Hierarchical Binomial Logistic Models	Kim et al. (2007)

PROCESS FOR COLLECTING DRIVEWAY DATA USING GOOGLE EARTH

1. **Open Google Earth**
2. **In the navigation side bar on the left, there should be a "Places" menu**.
3. **Highlight the "My Places" line (the top-most line)**.
4. **Right-click on the "My Places" line and add a new folder (Add->Folder)**.



5. **Name the folder and provide a brief description of the driveways to be collected**.



Name: US 34 Driveway Locations

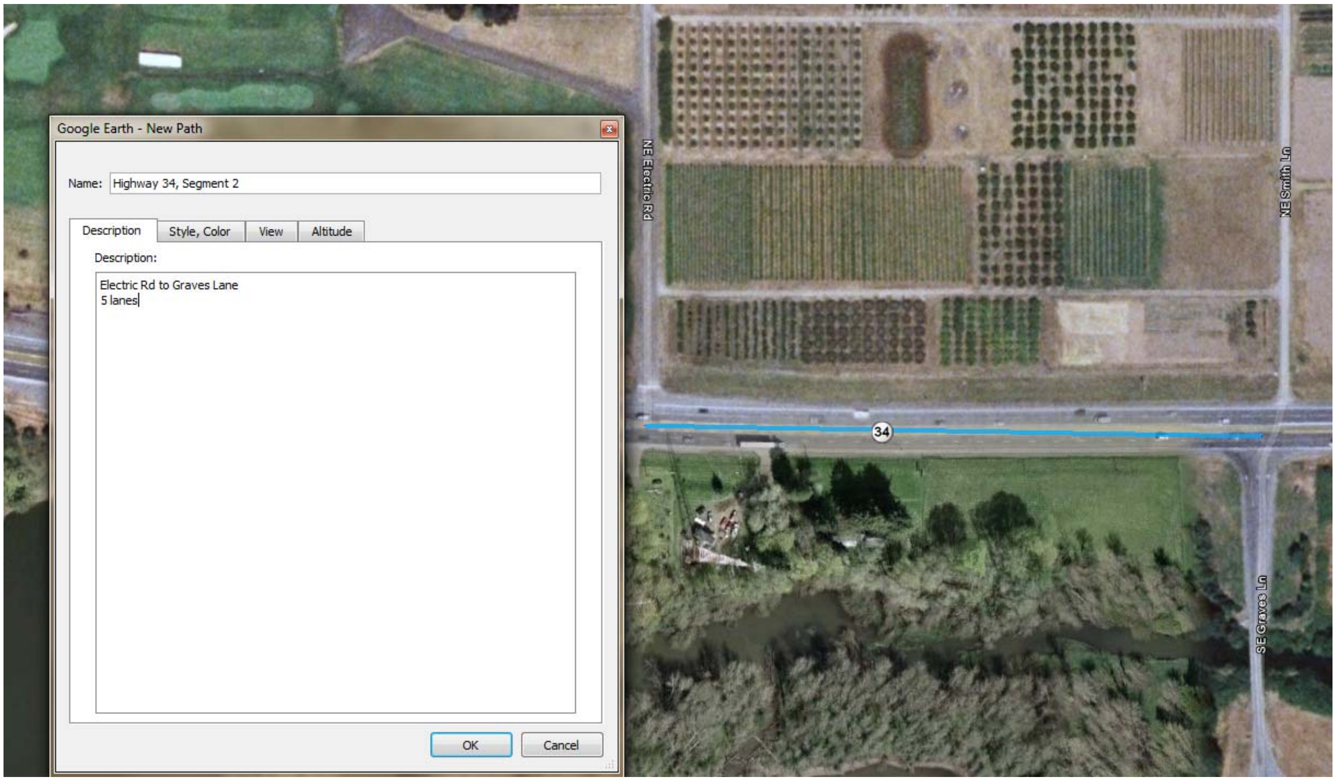
☑ Allow this folder to be expanded

☐ Show contents as options (radio button selection)

Description: Contains locations of all driveways on Highway 34 between Corvallis and Lebanon

The newly created folder will appear at the bottom of the "My Places" list.

6. **Locate the desired Highway/starting point on the map.** For this example, we started in Corvallis.
7. **The first thing to add to the map is a path of the current segment.** The path will define the endpoints of the homogeneous segment, and will typically have a length less than two miles.
8. **Make sure the newly created folder is selected (highlighted) in the "Places" menu**.
9. **Press CTRL+SHIFT+T or press the path icon in the menu bar at the top of the screen.** This will open the path dialog box. With the dialog box open, draw a path along the roadway between two pre-set locations, usually designated by an intersection or driveway. Name the segment with the highway name and segment number. In the description area, include the endpoint locations and number of lanes.

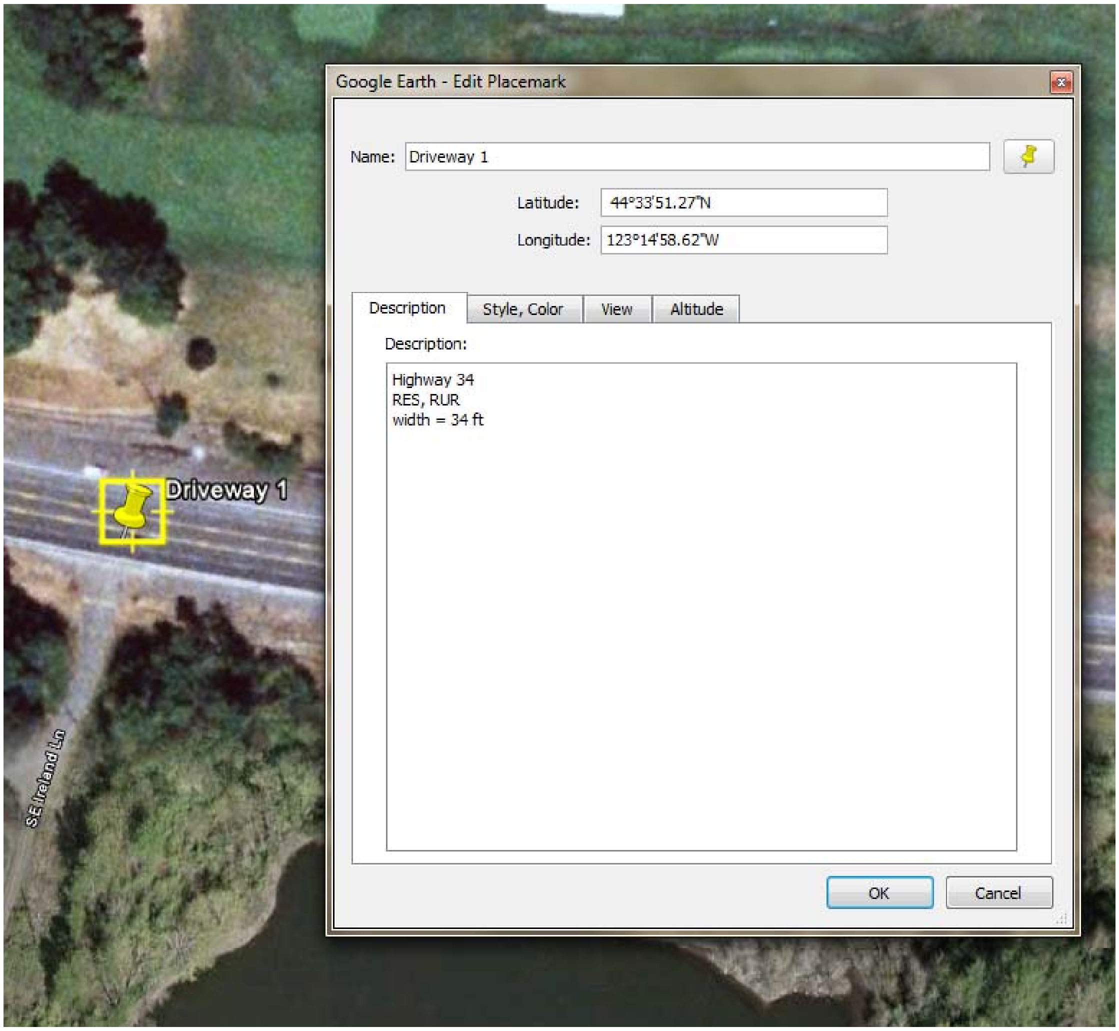


Name: Highway 34, Segment 2

Description:
Electric Rd to Graves Lane
5 lanes

The newly created path will appear on the map and will also be listed under the folder created in the "My Places" menu.

10. **Then, locate the first driveway to be tagged**.
11. **Press CTRL+SHIFT+P or press the push-pin icon in the menu at the top of the screen.** This will insert a push-pin icon (place mark) onto the map and open up a new dialog box.
12. **Move the push-pin icon to the desired location, and then enter descriptive information into the dialog box.** In this example, we have placed the icon at the center of the driveway at approximately the fog line. We've named the place mark "Driveway 1" and denoted the highway number in the description field. Visually inspect the type of development served by the driveway, and denote the land use as residential (RES), commercial (COM), rural (RUR), or industrial (IND). Lastly, measure the width of the driveway using the ruler tool and enter the width into the description box as well.



Name: Driveway 1

Latitude: 44°33'51.27"N

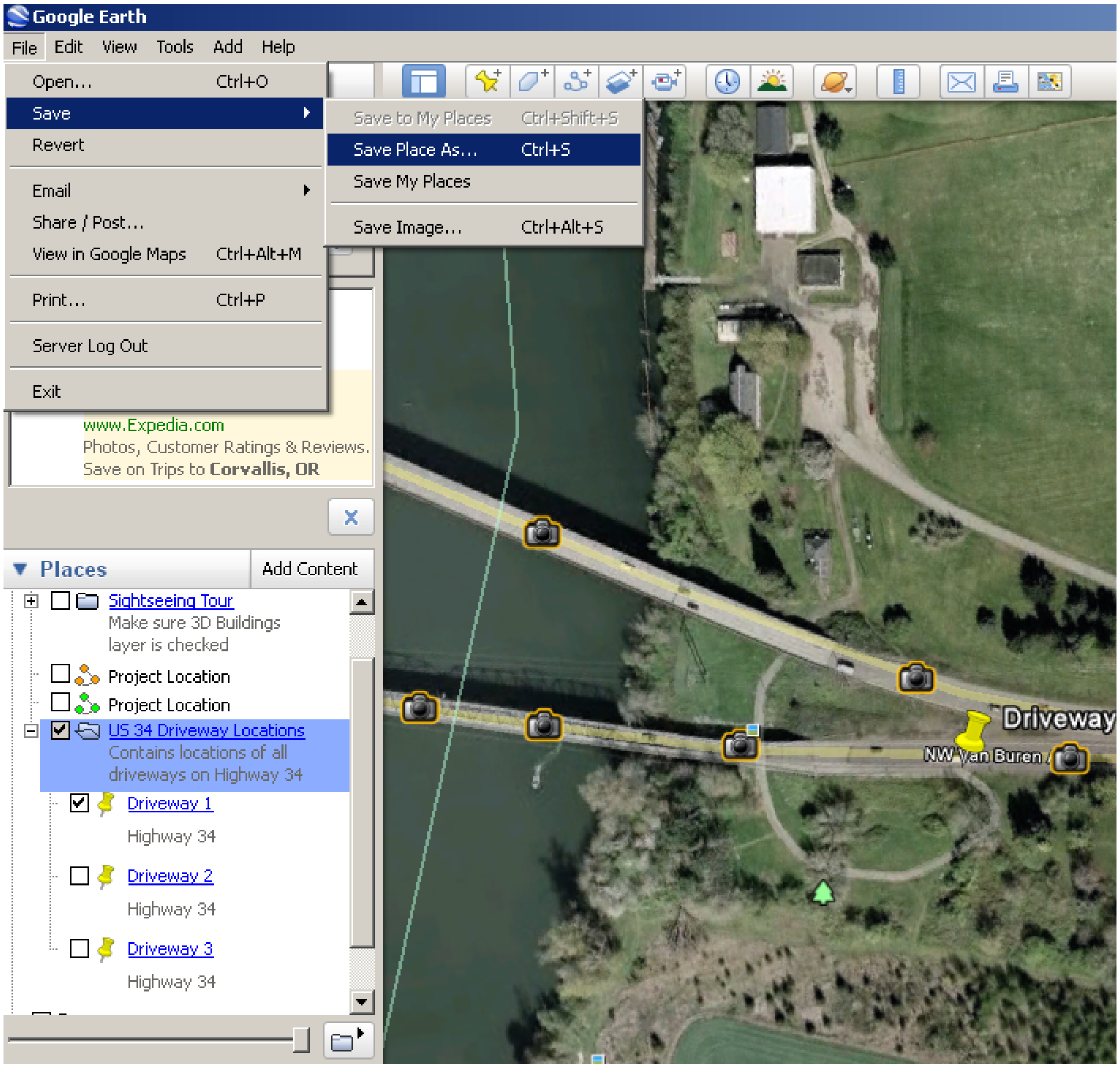
Longitude: 123°14'58.62"W

Description:

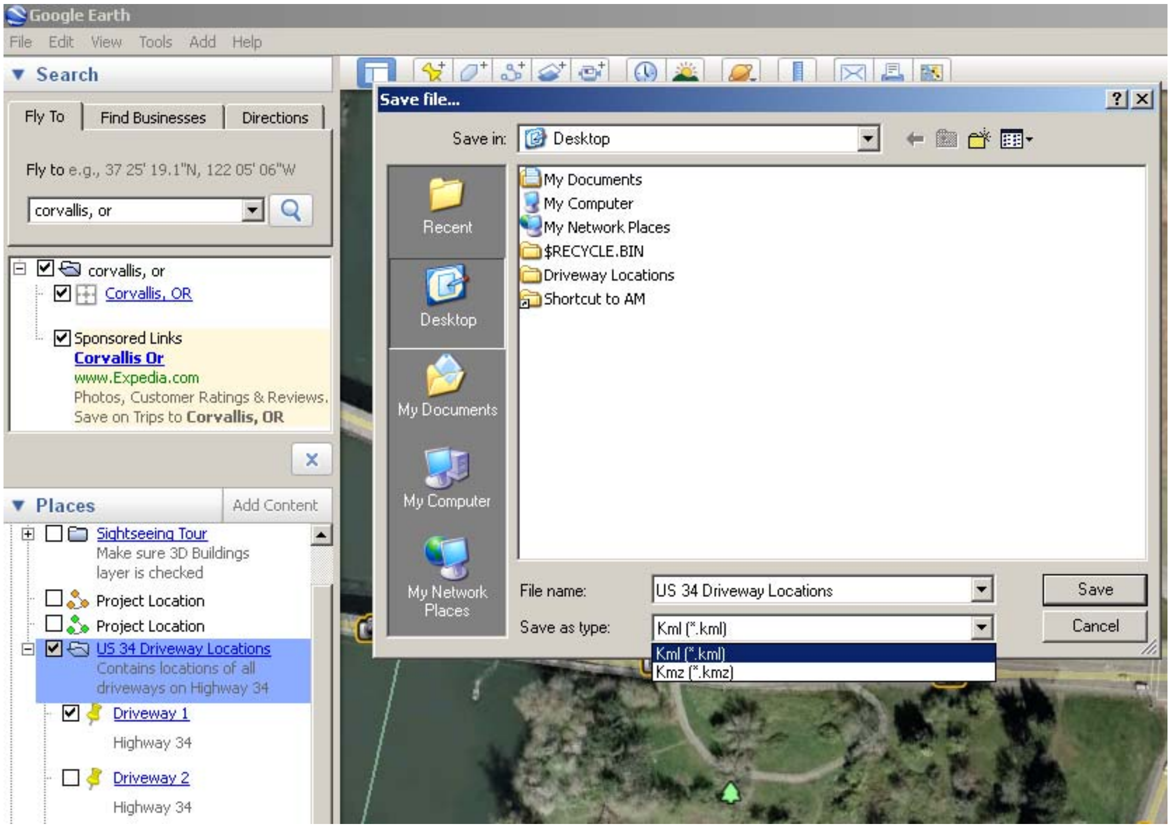
Highway 34
RES, RUR
width = 34 ft

The newly created place mark will appear on the map and will also be listed under the folder created in the "My Places" menu.

13. **Repeat steps 6 through 10 for all driveways along the same route/segment**.
14. **After all driveways have been located and marked, once again ensure that the main folder containing all place marks and the segment path is selected in the "My Places" menu**.
15. **Then, save the place marks in a .kml format. File->Save->Save Place As**.



Make sure that you select the "Kml" file type, NOT the "Kmz" file type!



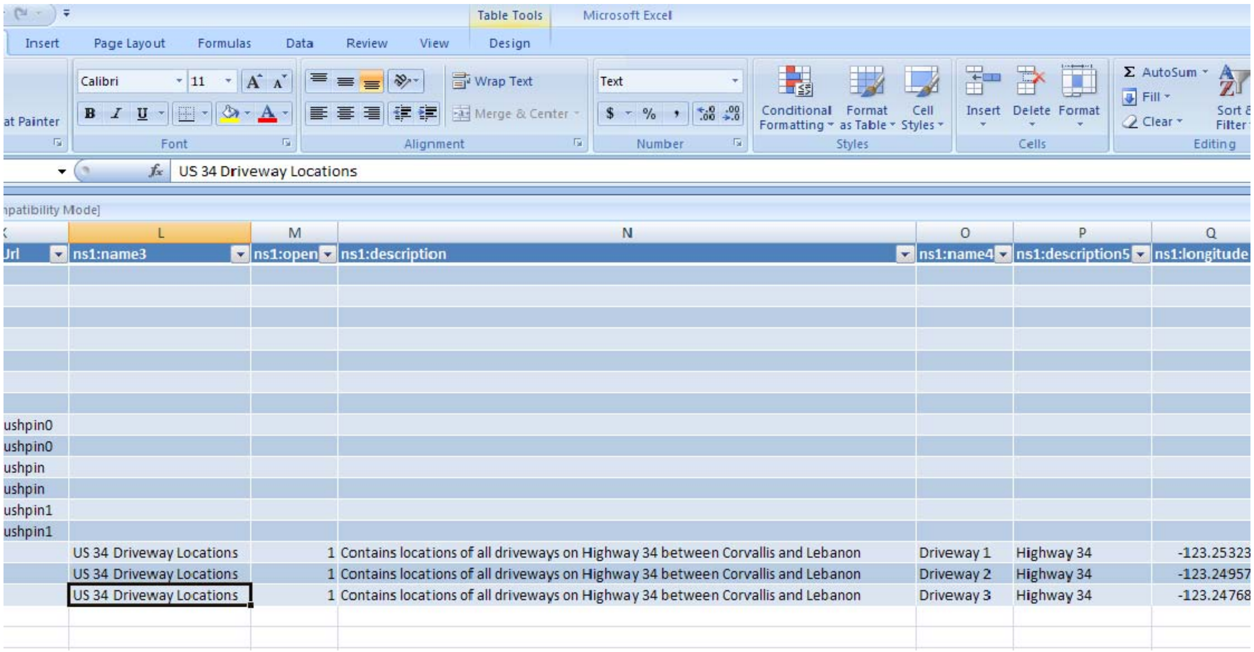
Save in: Desktop

File name: US 34 Driveway Locations

Save as type: Kml (*.kml)

16. **Next, locate the file wherever you saved it. Manually change the file extension from ".kml" to ".xml".** This will allow the file to be opened in Excel.
17. **Lastly, open the file from within Excel.** (Simply double-clicking the file will open it in an html/web browser format.)

The Excel spreadsheet contains all information for each place mark. The first set of rows contains display information for the push-pin icons, and can be ignored. The relevant information (coordinates, location name, and location description) can be found in columns L-Z.
Repeat these steps for each highway and segment.



Url	ns1:name3	ns1:open	ns1:description	ns1:name4	ns1:description5	ns1:longitude
ushpin0						
ushpin0						
ushpin						
ushpin						
ushpin1						
ushpin1						
	US 34 Driveway Locations	1	Contains locations of all driveways on Highway 34 between Corvallis and Lebanon	Driveway 1	Highway 34	-123.25323
	US 34 Driveway Locations	1	Contains locations of all driveways on Highway 34 between Corvallis and Lebanon	Driveway 2	Highway 34	-123.24957
	US 34 Driveway Locations	1	Contains locations of all driveways on Highway 34 between Corvallis and Lebanon	Driveway 3	Highway 34	-123.24768