DEVELOPING SAFETY PERFORMANCE MEASURES FOR ROUNDABOUT APPLICATIONS IN THE STATE OF OREGON

Final Report

SPR 733

Oregon Department of Transportation

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by

Karen K. Dixon, Principal Investigator
Jianfei Zheng, Graduate Research Assistant

Oregon State University
School of Civil and Construction Engineering
Corvallis, OR 97330

for

Oregon Department of Transportation
Research Section
555 13th St. NE
Salem OR 97301

and

Federal Highway Administration
400 Seventh Street, SW
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16. Abstract

This report documents the research effort to quantify the safety performance of roundabouts in the State of Oregon. 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 performance of single-lane, four-leg roundabouts. These safety metrics generally conform to the 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).

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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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EXECUTIVE SUMMARY

This report documents the research effort to quantify the safety performance of roundabouts in the State of Oregon. 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 performance of single-lane, four-leg roundabouts. These safety metrics generally conform to the 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).

Chapter 1.0 introduces the project and reviews the specific objectives of this research effort. Chapter 2.0 of this report includes a literature review summarizing previous research efforts on evaluating safety performance of roundabouts and discussing two commonly used methodologies in transportation safety analysis field. A summary of the data description and data collection process is included in Chapter 3.0. Chapter 4.0 then summarizes in detail the data analysis and resulting models for the Oregon roundabouts. Chapter 5.0 extends the analysis to a sample of Washington roundabouts. Finally, Chapter 6.0 reviews and summarizes the overall research effort. The report also includes five appendices that summarize the specific study sites and the detailed data analysis process.

1.0 INTRODUCTION

In recent years the construction of roundabouts as alternatives to signalized or STOP-controlled intersections has increased in Oregon and in the United States. Conceptually, a roundabout makes sense as it reduces delay (resulting in capacity improvements) and minimizes the number of potential conflicts between users in the traffic stream. Public acceptance of roundabouts, however, has been mixed and determination of the actual, quantifiable safety benefits of roundabouts in Oregon and the Pacific Northwest will enable the Oregon Department of Transportation (ODOT) and other regional transportation agencies to make informed decisions about the potential construction of these unique intersections.

Published literature suggests that the conversion of signalized intersections to roundabouts reduces total crashes by approximately 35 % and reduces injury crashes by around 65 %; however, these frequently cited statistics are primarily based on British and Australian research. The 2010 Highway Safety Manual (HSM) published by the American Association of State Highway and Transportation Officials (AASHTO) includes several roundabout crash modification factors (CMFs) that are based on a limited United States data set and which suggest a wide range of safety expectations ranging from a 1 % reduction in total crashes (CMF=0.99) up to an 80 % reduction in total crashes (CMF=0.20) when converting a signalized intersection to a roundabout. The HSM also includes CMFs for converting a STOP-controlled intersection to a roundabout. These values suggest a variety of expected CMFs ranging from an 87 % reduction in total crashes (CMF=0.13) up to a 3 % increase in total crashes (CMF=1.03). Collectively the HSM CMFs represent the overall effect of converting signalized intersections and STOP-controlled intersections to roundabouts. The reason for these vastly different estimates might be that there is little consideration of detailed information for explaining how geometric design features and other characteristics of the roundabout directly affect the safety performance. Thus, there is a strong need to develop roundabout safety performance functions or crash modification functions similar to those of other intersection facilities included in the HSM. In addition, where feasible the safety assessment of roundabouts should incorporate consideration for all users including motorized vehicles, bicycles, and pedestrians. The goal of this proposed research, therefore, is to develop safety performance functions (SPFs) for roundabouts located in the State of Oregon.

The primary goal of this research is to provide ODOT with SPFs that can be used to evaluate the predicted number of crashes at roundabout locations. The project team also empirically investigated the relationship between safety (crash frequency and severity) and the geometric design features for roundabouts. Since the use of roundabouts is relatively new in Oregon, most of the available roundabout configurations are single-lane, four-leg roundabouts. This study focused on these specific single-lane roundabouts. In addition, the research team evaluated a select number of similar roundabouts in the State of Washington.

The goal of this report is to quantify the safety performance of roundabouts in Oregon. Chapter 2.0 summarizes the published literature regarding the various factors that affect roundabout safety performance. Chapter 3.0 discusses in detail the data collection process and gives the descriptive summary of data. Chapter 4.0 provides final data analysis results. Chapter 5.0 then extends the findings to Washington roundabout locations. The conclusions and recommendations are included in Chapter 6.0. This report concludes with a list of cited references (Chapter 7.0), an overview of abbreviations (Appendix A), a brief inventory overview as well as detailed information for candidate Oregon roundabouts (Appendices B and C), a summary of modeling trial efforts (Appendix D), and a detailed summary of individual candidate roundabouts from Washington (Appendix E).

2.0 LITERATURE REVIEW

The goal of this literature review is to identify the critical issues presumed to contribute to crash risk at roundabouts and identify research to date associated with the safety performance of roundabouts. Included in this review is a brief overview of common safety performance study types and data distribution considerations.

2.1 ROUNDABOUT ELEMENTS EXPECTED TO INFLUENCE SAFETY

Currently the transportation research community has a need to comprehensively quantify how roadway elements at roundabout locations directly contribute to crash occurrence and expected facility safety performance. A roundabout is characterized by a wide range of features that may individually or collectively influence driver behavior and performance. A common approach to empirically assessing roundabout safety performance is through the development of equations that include the annual average daily traffic (AADT) and controlling roundabout geometric features. These models can be developed for total crashes or for a subset or crash severity or crash types. To date most roundabout safety assessment studies included, as a minimum, AADT as one key independent variable as confirmed by Daniels et al. (*2010*) in their assessment of safety variation at roundabouts.

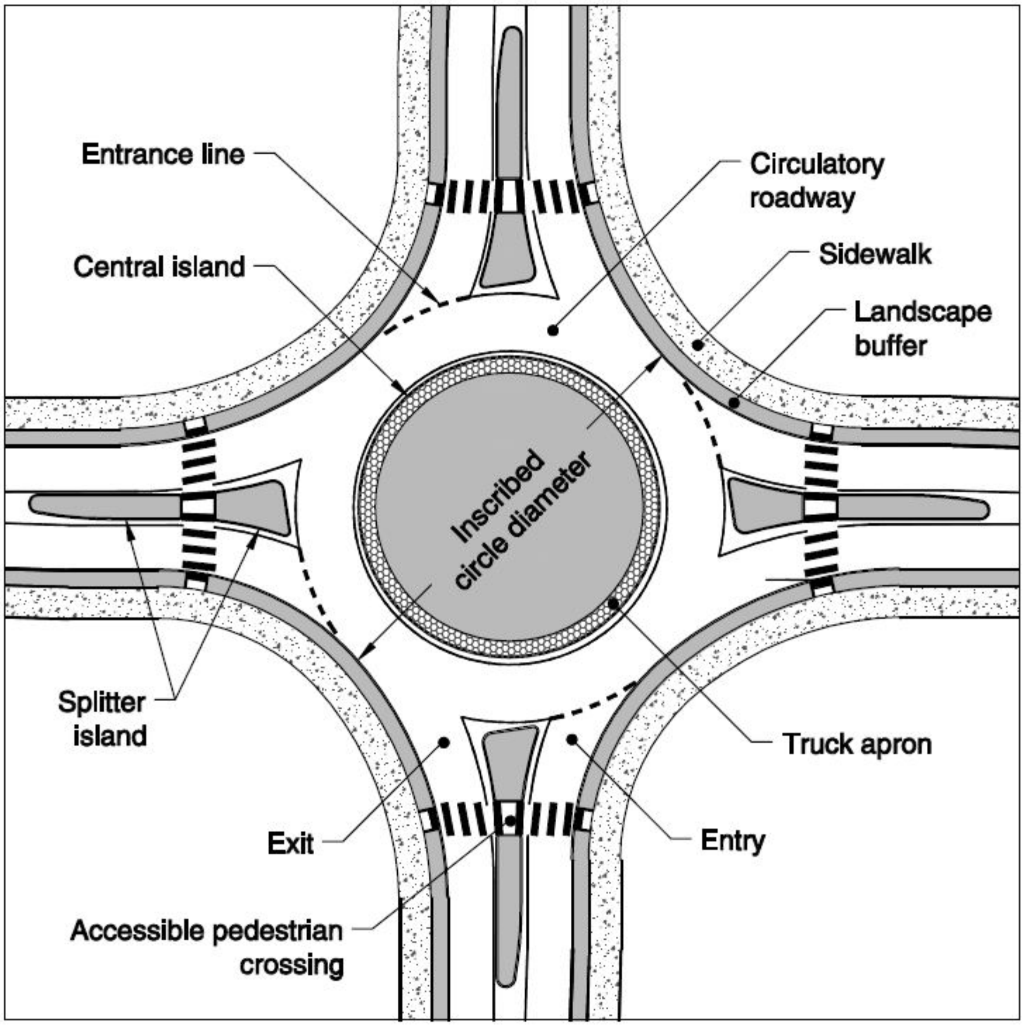
Rodegerdts et al. (*2007*) were not able to identify a reliable relationship between crash frequency and speed at roundabout locations. Research performed by Daniels et al. (*2010*) evaluated crashes located within a distance of 30.5 ft (100 m) of the center of roundabouts in Belgium. They identified average daily traffic (ADT) and bicycle volume and two significant variables, with the ADT value identified as the more significant of the two variables. Roundabout dimensions and geometric characteristics did not significantly contribute to their model.

A wide variety of roundabout data elements could potentially influence safety performance. Key characteristics are summarized as follows and depicted in Figure 2.1:

- Inscribed circle,
- Central island,
- Truck apron,
- Circulatory lane,
- Bicycle lane / path,
- Sidewalk,
- Landscape buffer,
- Entry alignment,
- Offset alignment,
- Angle between intersection legs,
- Presence of splitter island and number of crosswalks,
- Number of approach curves,

- Number of approach with bypass for right turn, and
- Entry curve.

The roundabout features are further described in the following sections.



Source: NCHRP Report 672 (Rodegerdts et al., 2010)

Figure 2.1: Geometric Features of a Single-Lane Roundabout

2.1.1 Inscribed Circle Diameter

The inscribed circle diameter delineates the outside edge of the circulatory lane (see Figure 2.1). The inscribed circle diameter is usually governed by design vehicles and speed. The larger inscribed circle diameter results in less deflection of circulating vehicles as they negotiate through the roundabout, which potentially increases circulating speed (*Rodegerdts et al., 2010*).

2.1.2 Central Island

The central island is usually constructed as a raised, non-traversable area that physically forces entering traffic to circulate around it. This feature reduces entering traffic speed by forcing an entry deflection and also reduces the number of conflict points from the 32 points associated with a traditional intersection to the 8 points typical of a roundabout. The entry deflection and the circulating characteristic of a roundabout substantially reduces the right-angle crashes often observed at the traditional intersection when vehicles turn left across the path of approaching traffic (*Rodegerdts et al., 2010*).

2.1.3 Truck Apron

The traversable truck apron is designed to provide extra space for heavy vehicles to negotiate through the roundabout without compromising the deflection for small vehicles. The truck apron is also designed for emergency vehicles quickly passing the roundabout while minimizing the influence of deflection (*Rodegerdts et al., 2010*).

2.1.4 Circulatory Lane

As depicted in Figure 2.1, the circulatory lane serves as the space dedicated for vehicles to travel. The width of the circulatory lane has influence on both safety and capacity. An excessively wide circulatory lane can have vehicles attempting to pass each other resulting in high speed driving. A circulatory lane that is too narrow, on the other hand, can be difficult to maneuver and result in additional travel delay and limit the capacity of the roundabout (*Rodegerdts et al., 2010*).

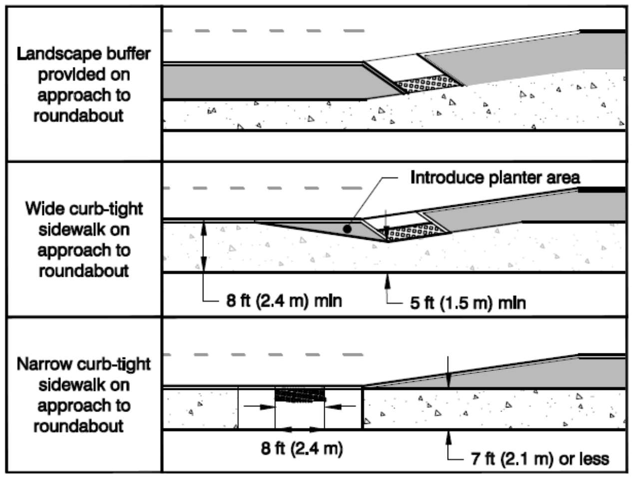
2.1.5 Bicycle Lane or Path

Three typical bicycle facilities are designed for bicyclists to negotiate through the roundabout. The shared lane design is similar to a sharrow as bicyclists have the priority while sharing the circulatory lane with vehicles. The bicycle lane design provides bicyclists an individual lane adjacent to circulatory lane so that bicyclists and vehicles can travel side by side. The bicycle path is usually designed as a physically separated bicycle facility often combined with a sidewalk (*Rodegerdts et al., 2010*).

In a Belgium study, Daniels et al. (*2009*) noted that roundabouts with bicycle lanes were associated with a 93 % increase in total injury crashes that involved bicyclists. The use of a bicycle lane does allow the bicycle to have a dedicated lane located immediately adjacent to the circulatory lane; however, at each access point the bicycle and the motor vehicle can encounter potential conflicts. Alternatively the use of a shared lane does not give the bicycle any additional buffer area between it and a vehicle, but does enable the cyclist to “own the lane.” The shared lane technique can be subject to motor vehicles attempting to pass a bicycle if the bicycle does not move to the center of the lane to prevent such a maneuver.

2.1.6 Sidewalk

A sidewalk can be constructed outside of the circulatory lane, usually physically separated by a landscape buffer area. A common roundabout design combines sidewalk and bicycle lane together as an elevated area that separates vulnerable road users, such like bicyclists and pedestrians, from the active traffic region of the roundabout (*Rodegerdts et al., 2010*). Three recommended bicycle ramps for connecting the approaching bicycle lane with the sidewalk/shared use path are shown in Figure 2.2.



Source: NCHRP Report 672 (Rodegerdts et al., 2010)

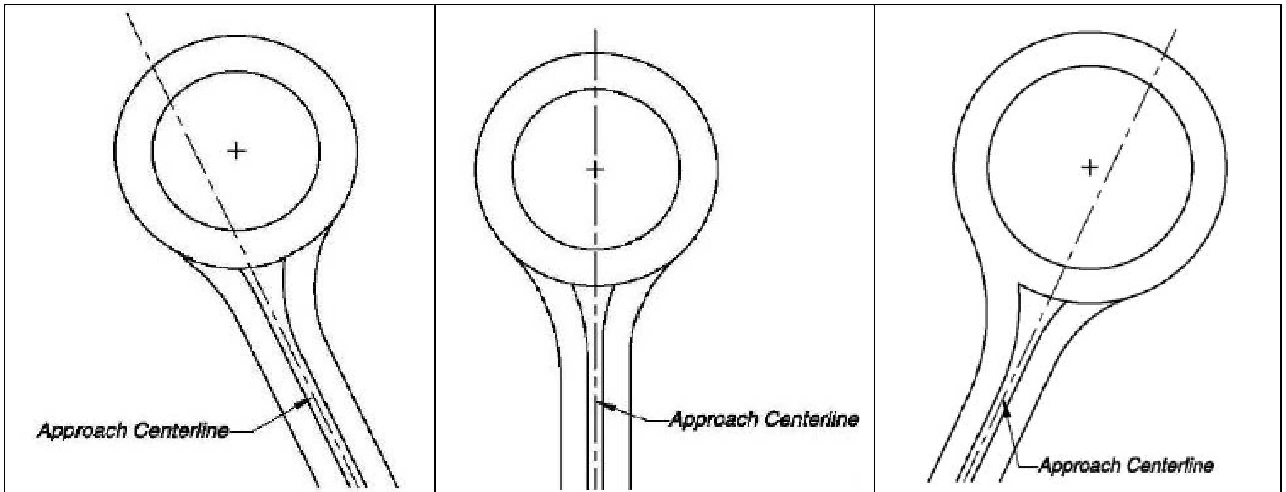
Figure 2.2: Regular Bicycle Ramps

2.1.7 Landscape Buffer

A landscape buffer located between the circulatory lane and sidewalk is reserved as an area for snow storage, street furniture, traffic control sign, street lights and other utilities. The most important role of the landscape buffer is to delineate the sidewalk so as to help to guide pedestrians, including those with visual impairments, to designated crosswalk locations (*Rodegerdts et al., 2010*).

2.1.8 Entry Alignment and Offset

The center of an inscribed circle is usually aligned with the central line of the approach leg. An entry offset may be needed when there are environmental restrictions or geometric requirements for the construction of roundabouts. The left or right offset alignment can influence the extent of deflection that in turn affects the entering speed and exiting speed (*Rodegerdts et al., 2010*). Three typical alignment and offset setting are shown in Figure 2.3.



(a) Alignment Offset to the Left of Center	(b) No Offset -- Alignment Through Center	(c) Offset alignment to the right of center

Source: NCHRP Report 672 (Rodegerdts et al., 2010)

Figure 2.3: Roundabout Offsets

2.1.9 Angle between Intersection Legs

As a traditional intersection, an optimal four-leg roundabout has the four approach legs oriented perpendicular to each other (*Rodegerdts et al., 2010*). The relatively large angle between legs might result in speeding while excessively sharp angles might contribute to under steering.

2.1.10 Presence of Splitter Island and Number of Crosswalks

The splitter island is reserved as an area for mounting traffic control sign and providing pedestrians a refuge to cross the traffic separately. The splitter island also deflects entering traffic as to reduce entering speed and separates entering and exiting vehicles (*Rodegerdts et al., 2010*).

2.1.11 Number of Approach Curves

The approach curve is design along the approach legs as a traffic calming facility used to reduce vehicles' speed as they approach the roundabout. An excessively small approach curve radius can cause driver expectancy issues and result in additional rear-end crashes (*Rodegerdts et al., 2010*).

2.1.12 Number of Approaches with a Right-Turn Bypass

The construction of a right-turn bypass is desirable when a location has a high right-turn traffic volume. The right-turn bypass can increase the capacity and efficiency of a roundabout with high right-turn volume while it might introduce more conflict points among vehicle, bicyclists and pedestrians and merging conflicts downstream (*Rodegerdts et al., 2010*).

2.1.13 Entry Curve

In addition to the entry width, circulatory roadway width, and the central island geometry, the entry curve and its associated curb radius helps to influence the amount of deflection required of a vehicle entering the roundabout. The entry curve can be a single, simple circular curve or it can be constructed as a 3 centered curve. Very large entry curb radii, for example, are more likely to be associated with faster entry speeds. Sharp entry curves, however, can be too abrupt and contribute to single-vehicle crashes at the roundabout entry location (*Rodegerdts et al., 2010*).

2.2 OVERVIEW OF SAFETY PERFORMANCE FOR ROUNDABOUTS

The successful implementation of roundabouts in Europe and Australia and the associated operational and safety benefits of those roundabouts has been a catalyst for constructing roundabouts in the United States. In many instances, new roundabouts have been constructed at locations where traditional intersections were previously constructed. Though overall the construction of these unique intersections appears to offer substantial safety benefits at select locations, there is a need to quantify when and where roundabouts will directly contribute to consistent crash reductions. Though international roundabout safety research appears promising, the modern roundabout constructed in the United States requires additional safety assessment due to differences in intersection design, driving conditions, drivers' knowledge, and drivers' expectancy.

The recently released HSM includes SPFs and corresponding CMFs for conventional intersections. However, the HSM did not include roundabout SPFs. Developing SPFs for roundabouts is of interest to reveal the nature of roundabout safety so as to quantify the safety effect of roundabouts. Most of the previous literature focused on the safety effects of converting a traditional intersection to a roundabout. The results from literature suggested a wide range of potential safety effects.

2.2.1 Converting Traditional Intersections to Roundabouts

As demonstrated in Table 2.1, several researchers have assessed the overall safety implications of converting traditional intersections to roundabouts. Though the type of before condition (traffic control, number of lanes, rural versus urban) will certainly influence expected crash reductions following construction of the roundabout, a few studies provide a CMF to generally address this conversion. Retting et al. (*2001*), for example, determined that a conversion of traditional intersections to roundabouts can provide a 38 % reduction in total crashes (CMF = 0.62) and a 76 % (CMF = 0.24) reduction in injury crashes. Their study evaluated 24 intersection locations and included an empirical Bayes before-after assessment. They also identified an expected reduction in fatal and serious injury crashes of approximately 90 % (CMF = 0.10).

Rodegerdts et al. (*2007*) performed an empirical Bayes before-after study for 55 intersections and estimated that an overall conversion of traditional intersections to roundabouts provided a 35.4 % reduction in total crashes (CMF = 0.646) and a 75.8 % reduction in injury crashes (CMF = 0.242). Similarly, Persaud et al. (*2001*) determined the conversion from traditional intersections to roundabouts had a 40 % total crash reduction (CMF = 0.60) and an 80 % injury crash reduction (CMF = 0.20).

Isebrands (*2009*) specifically focused on rural high-speed traditional intersection conversions to roundabouts at 17 sites in the United States. This before-after study identified an expected reduction of 52 % in total crashes (CMF = 0.48) and an 84 % reduction in injury crashes (CMF = 0.16). Isebrands also assessed crash severity and identified a 100 % reduction in fatal crashes (CMF = 0.00), an 89 % reduction in incapacitating crashes (CMF = 0.11), an 83 % reduction in non-incapacitating crashes (CMF = 0.17), and no reduction in property damage only crashes. Isebrands also assessed changes in expected crash types and determined a reduction in angle crashes of 86 % (CMF = 0.14) and rear-end crashes of 19 % (CMF = 0.81). This research effort also determined an increase in fixed-object crashes of 320 % (CMF = 4.20) and a 140 % increase in sideswipe crashes (CMF = 2.40).

Collectively the overall effect of converting a traditional intersection to a roundabout resulted in a reduction in total crashes of approximately 35 to 40 %, while conversions at high speed rural locations further reduced crashes to a total of approximately 52 %.

Table 2.1: Overview of Available Roundabout CMFs

Location	Prior to Roundabout	Roundabout Type	Setting	Crash Modification Factor: Total Crashes	Total Injury Crash	Fatal Crash	Serious Injury Crash	Minor Injury Crash	Property Damage Only Crash	Author
Within United States	All	All	All	0.60	0.20	--	--	--	--	Persaud et al. (2001)
				0.646	0.242	--	--	--	--	Rodegerdts et al. (2007)
				0.62	0.24	0.10		--	--	Retting et al. (2001)
			Rural	0.48	0.16	0.00	0.11	0.17	1.00	Isebrands (2009)
	Stop-Controlled	All	All	0.558 (2-way STOP)	0.182 (2-way STOP)	--	--	--	--	Rodegerdts et al. (2007)
				1.033 (All-way STOP)	1.282 (All-way STOP)	--	--	--	--	Rodegerdts et al. (2007)
			Rural	0.285 (2-way STOP)	0.127 (2-way STOP)	--	--	--	--	Rodegerdts et al. (2007)
			Urban/ Suburban	0.692 (2-way STOP)	0.256 (2-way STOP)	--	--	--	--	Rodegerdts et al. (2007)
		Single-Lane	Urban	0.28	0.12	--	--	--	--	Persaud et al. (2001)
			Rural	0.42	0.18	--	--	--	--	Persaud et al. (2001)
		Multi-Lane	All	1.00	1.00	--	--	--	--	Persaud et al. (2001)
	Signalized	All	All	0.65	0.26	--	--	--	--	Persaud et al. (2001)
				0.522	0.223	--	--	--	--	Rodegerdts et al. (2007)
			Suburban	0.333	--	--	--	--	--	Rodegerdts et al. (2007)
			Urban	0.986	0.399	--	--	--	--	Rodegerdts et al. (2007)
Outside United States	All	All	All	--	0.61	--	0.83	0.62	--	De Brabander & Vereeck (2007)
	Stop-Controlled	All	All	--	0.56	--	0.80	0.54	--	De Brabander & Vereeck (2007)
		Single-Lane	All	--	0.213	--	--	--	--	Fortuijn (2009)
				--	0.319	--	--	--	--	Fortuijn (2009)
	Signalized	All	All	--	0.68	--	0.87	0.69	--	De Brabander & Vereeck (2007)

2.2.2 Converting STOP-Controlled Intersections to Roundabouts

STOP-controlled intersections, when converted to roundabouts, may have varying safety effects depending on the number of legs with STOP control, the number of lanes for the roundabout, and the region (urban, suburban, or rural) where the intersection is located.

Persaud et al. (*2001*) observed a 72 % reduction (CMF = 0.28) in the number of total crashes at urban locations where STOP-controlled intersections were converted to single-lane roundabouts. They also noted an 88 % reduction (CMF = 0.12) in injury crashes at the same locations. For similar STOP-controlled to single-lane roundabout conversions in rural areas, Persaud et al. observed crash reductions of 58 % (CMF = 0.42) in the number of total crashes and 82 % (CMF = 0.18) in the number of injury crashes. They did not observe any reduction in total or injury crashes for STOP-controlled intersection conversions to multi-lane roundabouts (CMF = 1.00). Table 2.1 provides an overview of these as well as other CMFs.

Rodegerdts et al. (*2007*) evaluated 10 sites where all-way STOP-controlled intersections were converted to roundabouts and observed a 3.3 % increase in total crashes (CMF = 1.033) and a 28.2 % increase in injury crashes (CMF = 1.282). Rodegerdts et al. separately assessed the conversion of two-way STOP controlled intersections to roundabouts and observed a 44.2 % reduction in total crashes (CMF = 0.558) and an 81.8 % reduction in injury crashes (CMF = 0.182) at all conversion sites. When they further assessed urban, suburban, and rural they identified expected crash reductions ranging from 11.6 % up to 78.2 % depending on unique intersection and roundabout configurations. This wide variability reinforces the hypothesis that unique site features may be critical to the expected safety benefits of the conversion.

2.2.3 Converting Signalized Intersections to Roundabouts

United States research regarding the conversion of signalized intersections to roundabouts is limited. Persaud et al. (*2001*) evaluated roundabouts converted from signalized intersections and observed a 35 % reduction in total crashes (CMF = 0.65) and 74 % reduction in injury crashes (CMF = 0.26). Rodegerdts et al. (*2007*) evaluated 9 signalized intersection conversions to roundabouts (4 in suburban regions and 5 in urban regions) and observed a 47.8 % reduction in total crashes (CMF = 0.522) and a 77.7 % reduction in injury crashes (CMF = 0.223); however, the small sample size cannot be assumed representative of the larger intersection population.

2.2.4 Recent International Research

Over the years, international researchers have conducted a variety of roundabout research assessments. Recent international studies can also help to provide insight into the expected safety performance for roundabouts at locations with speed variations as well as non-motorized users. De Brabander and Vereeck (*2007*) conducted a before-after empirical Bayes study and determined that the overall effect of implementing roundabouts was positive. Overall, they found a 39 % reduction in injury crashes (CMF = 0.61) with a 17 % reduction in serious injury crashes (CMF = 0.83) and a 38 % in minor injury crashes (CMF = 0.62). Table 2.1 depicts additional findings from their research, but their results varied considerably with changes in speed limits on major street and minor street as well as the "before" traffic control configuration. Generally, the higher the speed limit combination of the “before” major and minor street approaches resulted in the most effective “after” conditions. One important observation by De Brabander and Vereeck was that the number of injury crashes involving vulnerable road users, such as pedestrians and bicyclists, was found to increase on roundabouts following conversions from signalized intersections.

Daniels et al. (*2008*) similarly noted an increased risk associated with injury crashes involving bicyclists at locations where roundabouts replaced traditional intersections. The before-after study with the empirical Bayes method for 91 roundabouts in Flanders, Belgium indicated the overall effects of converting traditional intersections to roundabouts on injury crashes and fatal crashes involving bicyclists were increased by 27 % (CMF = 1.27) and 44 % (CMF = 1.44), respectively.

Subsequently, Daniels et al. (*2009*) determined that safety performance involving bicyclists varied with different types of bicycle facilities. They evaluated roundabout locations with 4 typical bicycle facilities: mixed traffic, bicycle lane within roundabout, separate bicycle path, and grade separated bicycle path. For total injury crashes, only roundabouts with bicycle lanes experienced a poorer safety performance with the roundabout in place.

In the Netherlands, Fortuijn (*2009*) performed two before-after studies to measure safety performance on single-lane roundabouts converted from yield controlled intersections for different periods of time (39 intersections in the period 1991-2002 and 29 intersections in the period 1995-2002). They observed reductions in total injury crashes ranging from 78.7 % (CMF = 0.213) to 68.1 % (CMF = 0.319).

2.3 ASSESSMENT TECHNIQUES FOR ROAD SAFETY MODELING

The use of statistical methodologies provides a good approach to quantify the expected safety performance of roundabouts. Two methodologies that the transportation safety analysis community commonly uses include the before-after study and the cross-sectional study.

2.3.1 Before-After Study

The before-after study serves as the most commonly used methodology to assess the safety effects of treatments. The simplest approach for using a before-after study for safety performance, known as a naive before-after study, is to compare the crash rate or crash frequency for a group of traffic crashes "before" and "after" the deployment of a safety treatment. This simple before-after study strategy might not fully capture the cause and effect of the treatments, since traffic volume is dynamic over time and other factors may also influence safety performance of the facility. For instance, it could be difficult to determine whether the safety effects resulted from the change of traffic volume or the deployed treatment at a location where a traffic calming treatment is constructed. The traffic calmed facility might reduce crashes as the result of reducing traffic speeds on the roadway. The reduction on crashes might also be attributed to the fact that the roadway experiences less traffic exposure due to normal systemic changes in traffic volumes.

To avoid this ambiguity about the interpretation of safety effects determined for naive before-after studies, the use of univariate analysis can be used in a manner similar to that commonly applied to biology and other fields in evaluating the effects of one treatment. In transportation safety analysis this before-after study can include the following two groups of facilities:

- Treatment group, and
- Comparison group.

The treatment group includes facilities where a treatment has been deployed. The comparison group includes facilities that serve as a control group and are similar to the treatment group sites but without any treatment deployed.

The before-after study includes two time periods:

- Before-treatment period, and
- After-treatment period.

The assumption of a before-after study is that the treatment group and comparison group share similar traffic exposures and geometric features during both "before" and "after" periods. Crash frequency from both groups then should be similar if countermeasures are not applied to the treatment group. The difference in crashes, if any, then could be attributed to any treatments applied to the treatment group during the "after" period (*Gross et al., 2010*). The basic strategy of a before-after study is shown in Figure 2.4.

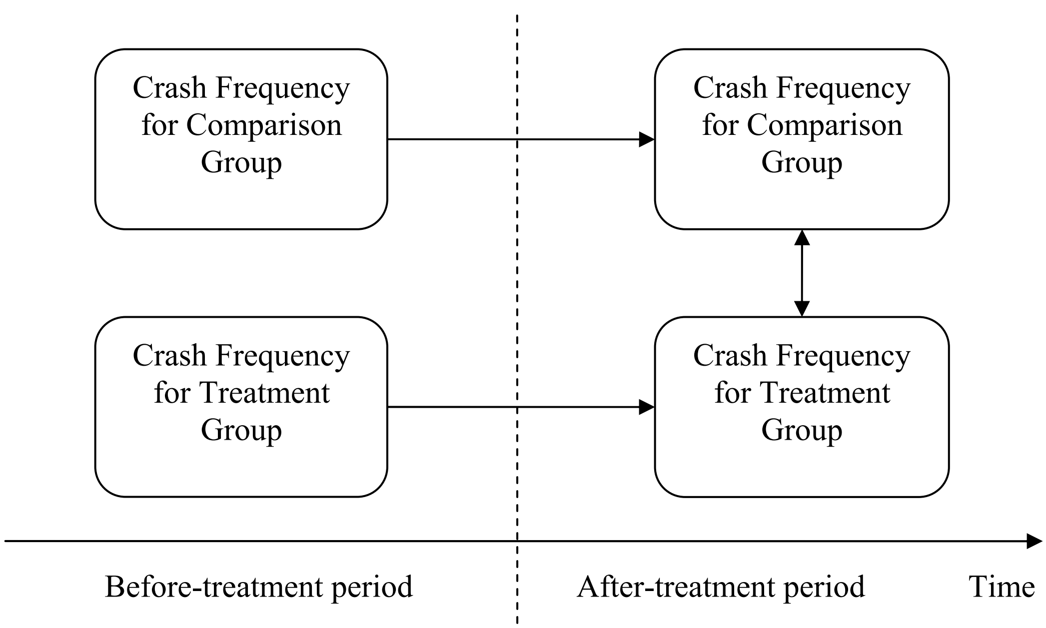


Figure 2.4: Basic strategy of a before-after study

Hauer (*2010*) indicated that the disadvantage of a before-after study is the fact that one treatment might introduce many changes simultaneously to the facility that safety effects cannot be quantified by a specific change.

Converting a traditional intersection to a roundabout changes not only geometric features but also the nature of travel behavior. Though the intersection is under constant traffic exposure before and after the construction of the roundabout, the before-after study can only provide a general interpretation that the difference in crash frequency is associated with the construction of a roundabout.

2.3.2 Cross-Sectional Study

A cross-sectional study can be used to assess safety performance using statistical regression methods to build relationships between crash frequency and important features of the facility. Hauer (*2010*) pointed out that the cross-sectional study is a feasible and reliable approach to explore expected safety performance for traffic facilities. The current HSM provides all SPFs based on this methodology for traditional intersections. The CMFs derived for these functions then have the ability to represent safety effects of corresponding changes.

The Poisson distribution is a good approach to model frequency data such as the number of crashes. The Poisson regression then is used to regress crash data based on other independent features. As crash data appears to have the feature that the mean is less than the corresponding variance, many research efforts suggest the use of negative binomial regression to model the crash data (*AASHTO, 2010*; *Abdel-Aty and Radwan, 2000*; *Hauer 2001*; and *Daniels et al., 2010*). The fact that the variance of crash frequencies is larger than the corresponding mean under each scenario is known as over dispersion. The negative binomial regression serves as an alternative approach of the Poisson regression that has the ability to account for that over dispersion.

3.0 OREGON ROUNDABOUTS -- DATA DESCRIPTION AND COLLECTION

This research effort focused on the safety performance of single-lane, four-leg roundabouts in the State of Oregon. The comprehensive assessment of roundabout safety performance requires the consideration of geometric features, traffic volume, and crash history information as part of the analysis process. For this research effort, the project team acquired this essential data from a variety of existing data sources and supplemented the available data with observational data as needed. This section of the report provides details about the selected Oregon roundabout sites, including a summary of the geometric characteristics, traffic volume information, and crash history elements with their respective summary statistics.

3.1 ROUNDABOUT GEOMETRIC CHARACTERISTICS

Since this research effort specifically targeted single-lane, four-leg roundabouts in Oregon, the project team acquired comprehensive geometric information so as to determine if varying geometric features directly influence the safety performance of the facility. Appendix C provides summary data for the individual representative Oregon roundabouts. As an example, Figure 3.1 demonstrates the type of data assembled for each study site. The example site is located at the intersection of Mt. Washington Drive and NW Shevlin Park Road in Deschutes County, Oregon. This site is referred to as Site #4 and represented by the site identification name of OR-S4-4 where the "S4" represents a single lane with a four leg approach.

As shown in Figure 3.1, geometric information included the diameter of the inscribed circle, the diameter of the central island, the truck apron width , the bicycle lane or path presence and width, sideway presence and width, and various other features including marked crosswalks, pedestrian refuge areas, splitter islands, signal control, and lighting. The summary also includes orientation and horizontal geometry of the approaches.

The geometric feature data sources included information obtained from Google maps, the ODOT digital video log, the Kittelson & Associates, Inc. roundabout website, and site visits by project team members. In Oregon, 23 single-lane, four-leg roundabouts were constructed in time to be included in this study (i.e. 2008 or earlier so as to have adequate roundabout crash data).

Table 3.1 identifies these Oregon roundabout study sites.

Source: Google Maps

Basic Information	
Intersecting Approaches	Mt. Washington Dr.
	NW Shevlin Park Rd.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2000

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	127	Minimum Distance between Sidewalk and	8
Central Island Diameter (ft)	106	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	10	Minimum Angle between Legs (degrees)	75
Bicycle Lane/Path Width (ft)	6	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	2
Number of Approach with Bypass for Right	0		

Figure 3.1: Example Geometric Feature Summary (Site #4 -- OR-S4-4)

Table 3.1: Summary of Oregon Roundabout Study Sites

Site No.	Site ID	Major Road	Minor Road	County
1	OR-S4-1	Monterey Ave.	SE Stevens Rd.	Clackamas
2	OR-S4-2	SW Century Dr.	SW Colorado Ave.	Deschutes
3	OR-S4-3	Mt. Washington Dr.	Skyliners Rd.	Deschutes
4	OR-S4-4	Mt. Washington Dr.	NW Shevlin Park Rd.	Deschutes
5	OR-S4-5	Mt. Washington Dr.	NW Crossing Dr.	Deschutes
6	OR-S4-6	SW Century Dr.	Mt. Washington Dr. / SW Reed Market Dr.	Deschutes
7	OR-S4-7	SW Century Dr.	SW Simpson Ave.	Deschutes
8	OR-S4-8	NW 14th St.	NW Galveston Ave.	Deschutes
9	OR-S4-9	NW 14th St.	NW Newport Ave.	Deschutes
10	OR-S4-10	NW Newport Ave.	NW Nashville Ave.	Deschutes
11	OR-S4-11	SW Terwilliger Blvd.	SW Palater Rd.	Multnomah
12	OR-S4-12	Carman Dr.	Meadows Rd.	Clackamas
13	OR-S4-13	SW Colorado Ave.	SW Simpson Ave.	Deschutes
14	OR-S4-14	NE 8th St./9th St.	NE Franklin Ave.	Deschutes
15	OR-S4-15	SW Bond St.	SW Reed Market Rd.	Deschutes
16	OR-S4-16	SW Reed Market Rd.	Century Dr.	Deschutes
17	OR-S4-17	58th St.	Thurston Rd.	Lane
18	OR-S4-18	SW Stafford Rd.	Rosemont Rd.	Clackamas
19	OR-S4-19	NW Verboort Rd.	Martin Rd.	Washington
20	OR-S4-20	SE 15th St.	NE Bear Creek Rd.	Deschutes
21	OR-S4-21	SW Hart Rd. / SW Juniper Terrace	SW Sorrento Rd.	Washington
22	OR-S4-22	Highland Dr.	Siskiyou Blvd.	Jackson
23	OR-S4-23	SW Barrows Rd.	SW Roshak Rd.	Washington

Section 2.1 identified candidate geometric features that are expected to influence the operational and safety performance of roundabouts. Generally, widths and turning radii features are presumed to have the most direct impact on operating speed within the roundabout and, consequently, on the expected safety. Table 3.2 summarizes the minimum, maximum, average, and standard deviations for the inscribed circle diameter, the central island diameter, the truck apron width, and the circulating lane width.

Table 3.2: Description of Roundabout Geometric Characteristics

Geometric Feature	Minimum	Maximum	Average	Standard Deviation
Inscribed Circle Diameter (ft)	104	192	134.4	25.41
Central Island Diameter (ft)	70	165	99.6	26.41
Truck Apron Width (ft)	0	20	12.0	4.06
Circulating Lane Width (ft)	10	20	16.6	2.78
Truck Apron + Lane Width (ft)	18	38	28.6	5.01

The inscribed circle diameter for the study sites ranged from 104 to 192 feet with an average of approximately 134 feet. As shown in Figure 3.2, the distribution of the inscribed circle diameter is slightly skewed; however, 78% of the sites have inscribed circle diameters that are within one standard deviation of the average. Similarly 91% (or 21 out of the 23 sites) have diameter values within two standard deviations of the average. Only sites OR-S4-6 and OR-S4-19 have inscribed circle diameters outside these thresholds.

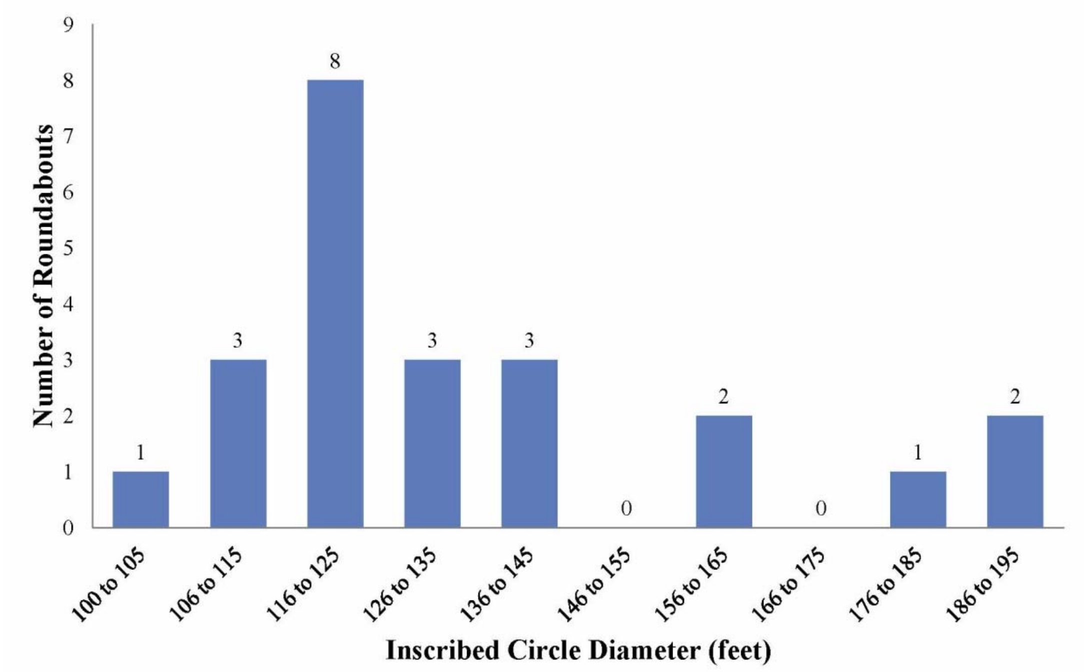


Figure 3.2: Distribution Based on Inscribed Circle Diameter

The central island diameter can be expected to have a similar distribution to that of the inscribed circle diameter. For the 23 study sites in Oregon, the central island diameter ranged from 70 to 165 feet with an average value of approximately 100 feet. Figure 3.3 demonstrates the distribution of the central island diameter values. Approximately 78% of the sites were characterized by central island diameters that were within one standard deviation of the average (similar to that observed for the inscribed circle); however, only one site (Site OR-S4-19) was characterized by a value beyond the two standard deviation threshold.

All but one of the study roundabouts (Site OR-S4-21) included a truck apron as a key geometric element. The truck aprons that were constructed ranged from 9 to 20 feet in width with an average value of 12 feet. Aprons located at sites OR-S4-3, OR-S4-10, and OR-S4-19 had widths ranging from 18 to 20 feet; however, these larger values were still within two standard deviations of the average apron width.

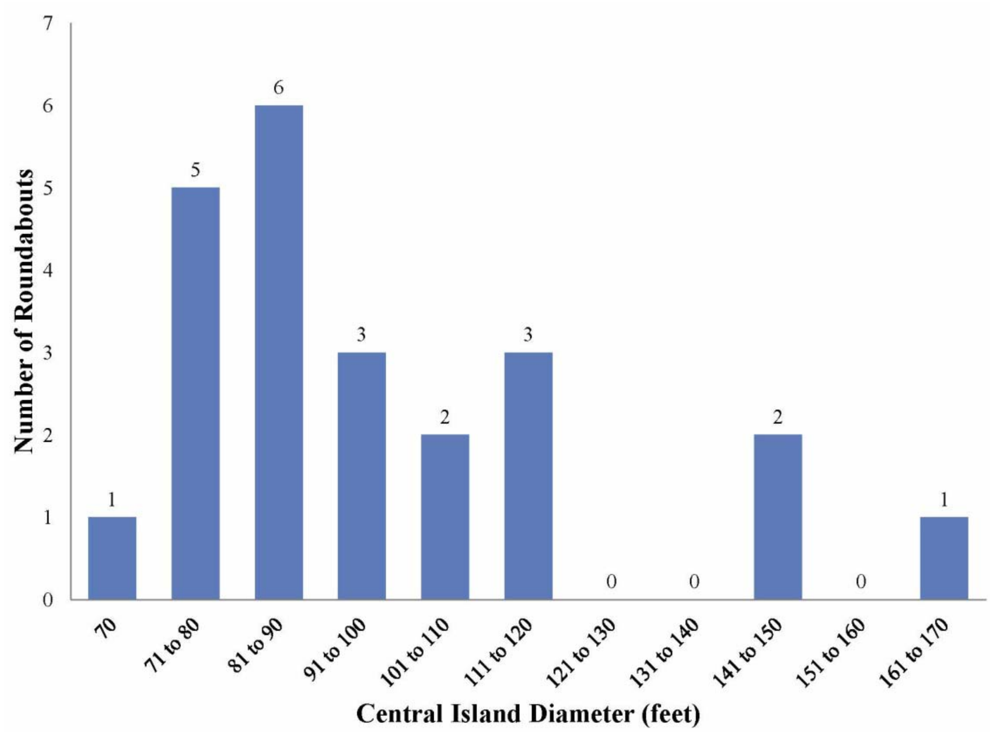


Figure 3.3: Distribution based on Central Island Diameter

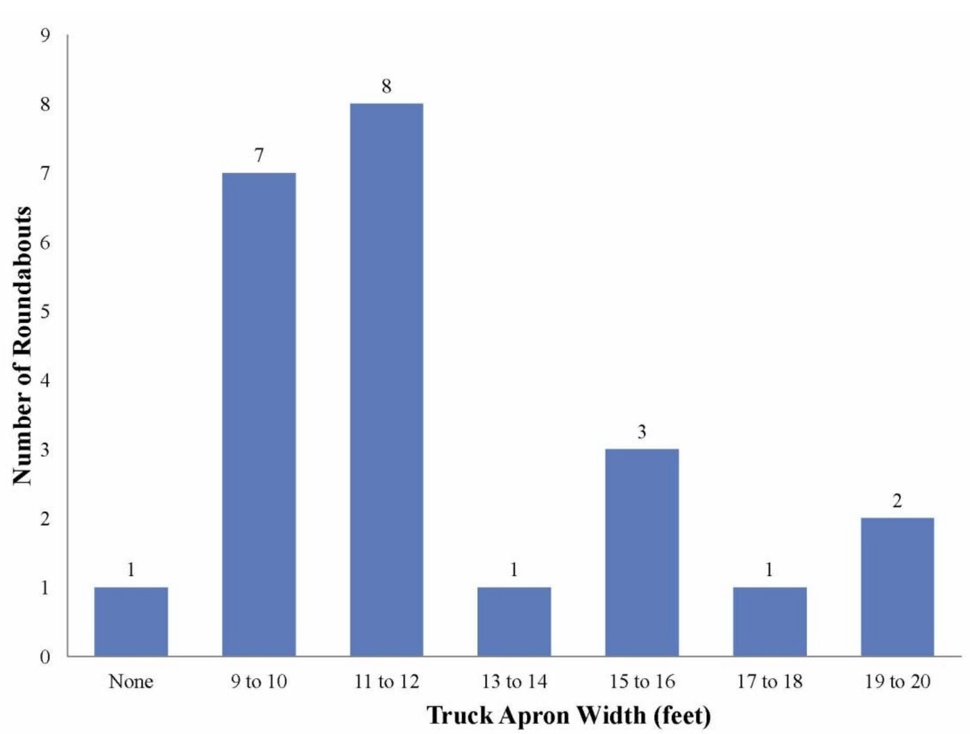


Figure 3.4: Distribution based on Truck Apron Width

The width of the circulating lane varied from 10 to 20 feet with an average width of approximately 16.6 feet. While only 15 of the 23 sites had lane width values within one standard deviation of the average, all but one site (OR-S4-4) had lane widths within the two standard deviation threshold.

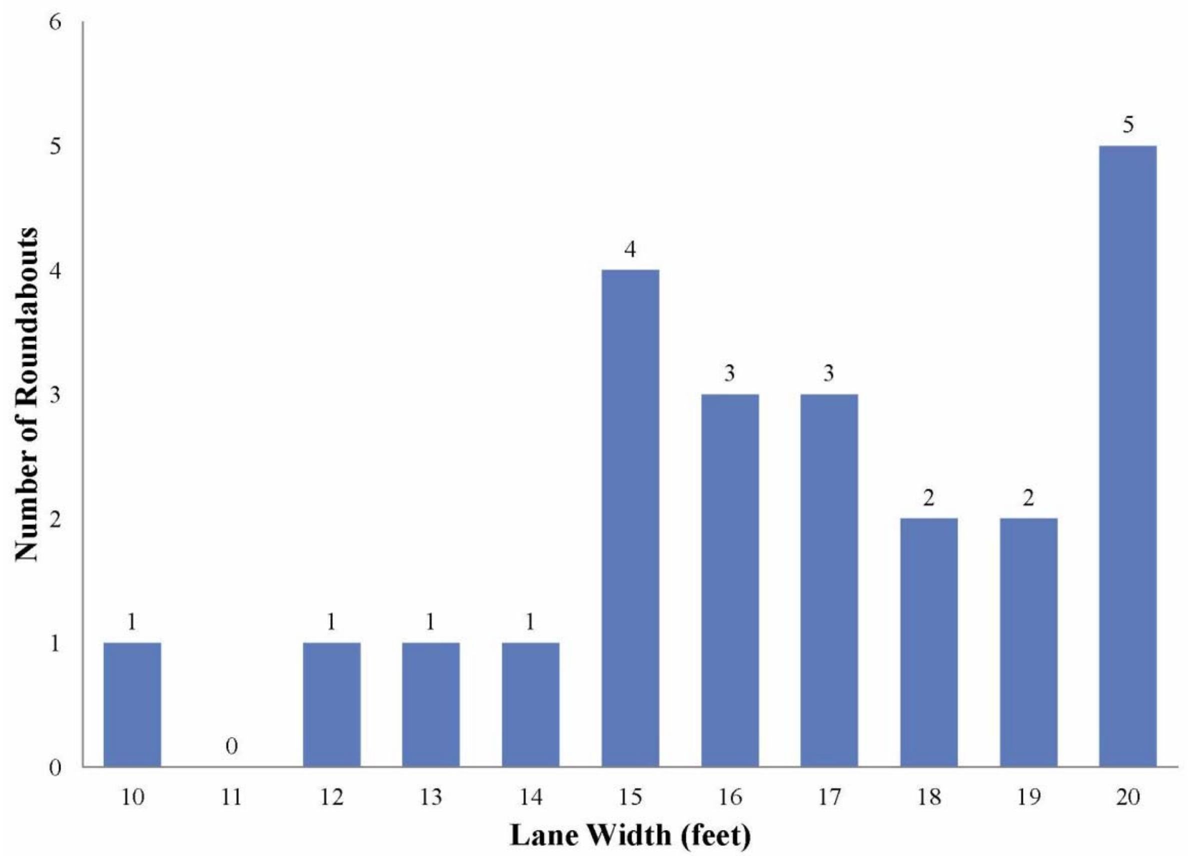


Figure 3.5: Distribution based on Circulating Lane Width

The consideration of lane width and truck apron as independent factors that influence safety could be misleading. The total traversable width available in the circulating region of the roundabout can be considered as the sum of these two values. If evaluated collectively, the sum of the apron and the circulating lane widths ranged from 18 to 38 feet with an average of approximately 29 feet. Though only 16 of the 23 sites have values within one standard deviation of the average width, only site OR-S4-21 (the site without a truck apron) is outside the limits of an interval within two standard deviation values. It should be noted, that site number 21 is the oldest study site as its construction dates back to 1980. Roundabout construction and associated geometric characteristics has continued to be refined since that construction time. As shown in Figure 3.6, the combined apron and lane width distribution appears to be normally distributed for the study sites.

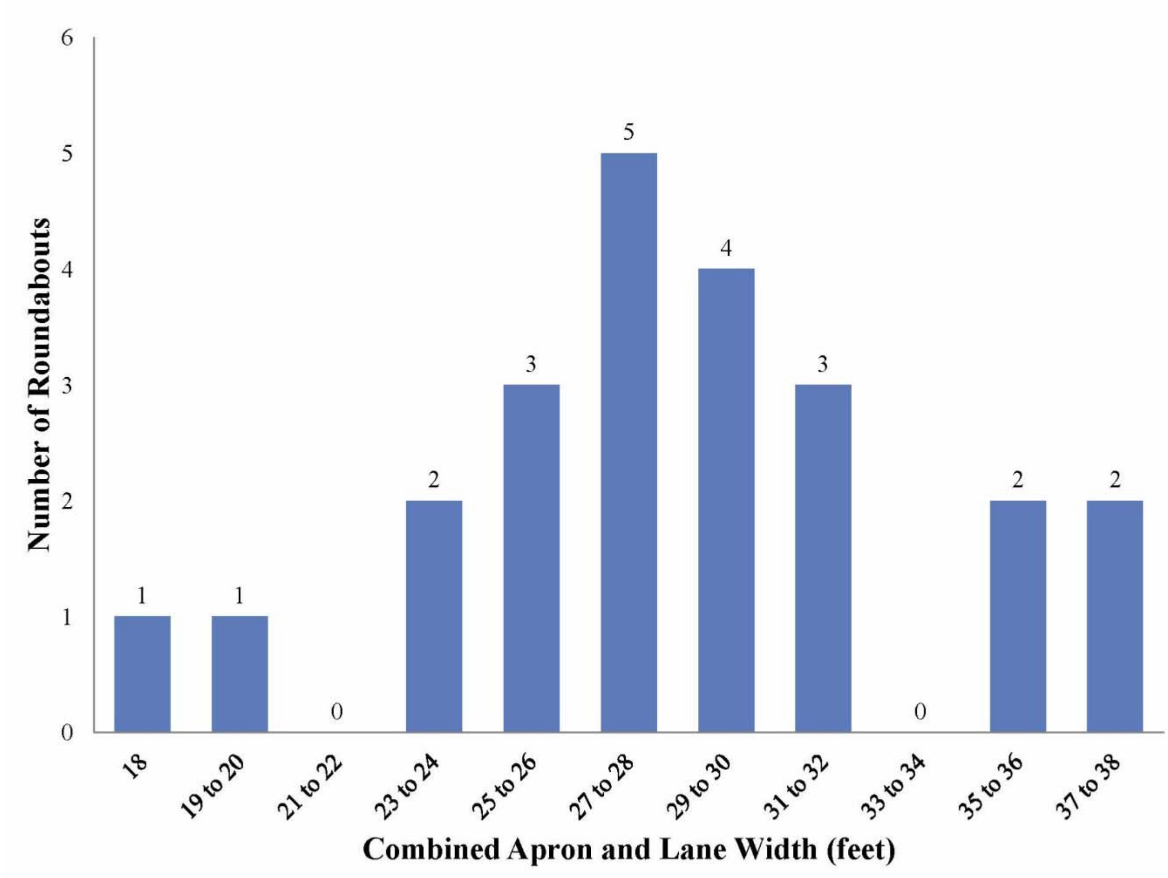


Figure 3.6: Distribution based on Combined Apron and Lane Width

One additional geometric characteristic that is designed to help reduce vehicle speed on the approaches to a roundabout is the use of horizontal curvature as a method for calming the approaching speeds. Figure 3.7 demonstrates that, for the Oregon study sites, six of the locations did not utilize approach curvature strategies. Three of the sites included approach curves on all four legs, while 14 of the 23 study locations used approach curves on at least one but not all four legs.

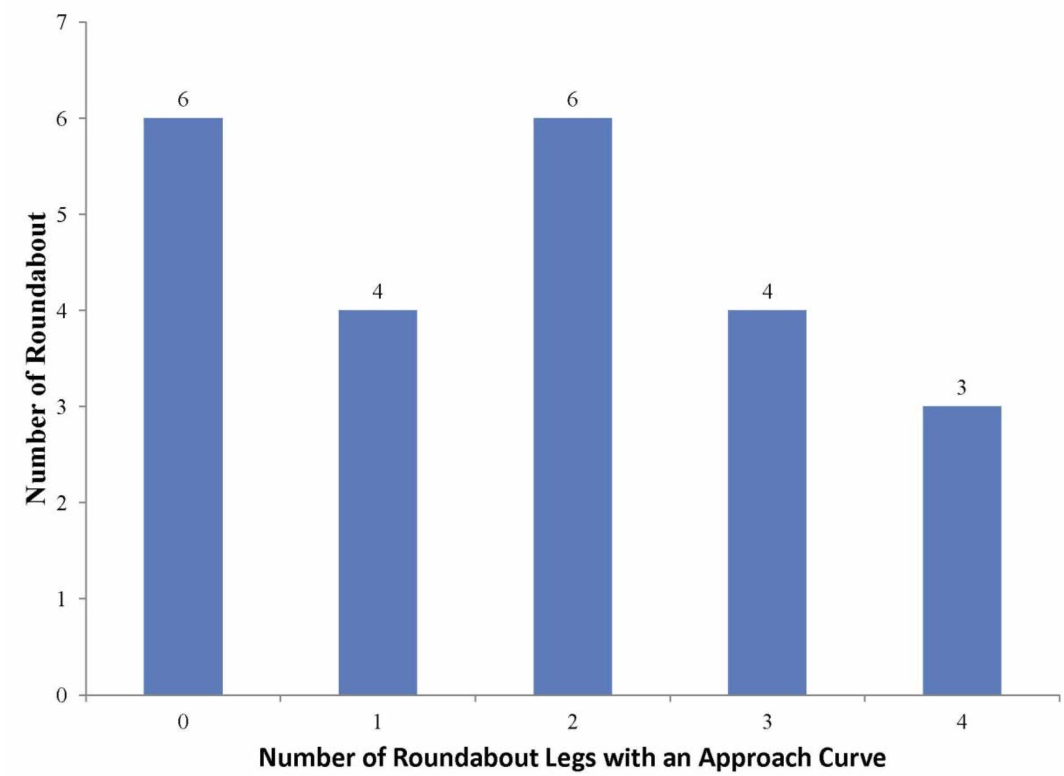


Figure 3.7: Use of Horizontal Curvature on Approach Legs

3.2 ROUNDABOUT TRAFFIC VOLUME DATA

Daniels et al. (*2010*) suggested that the entering traffic volume is one of the most important factors that affect the safety performance of traffic facilities. Similarly, the HSM uses traffic volume as a key input into the base condition safety performance functions. Roundabouts, as alternative intersections, are therefore likely to have a similar traffic volume influence on expected safety performance.

Traffic volume data is sometimes available from local and state transportation agencies. Based on these agency resources, the project team acquired traffic volumes for all 23 roundabouts included in the Oregon data set. Unfortunately, complete traffic volume information was available for only 12 of the roundabout locations. As a result, the project team initiated a supplemental traffic data collection effort. This section of the report reviews the available traffic volume information and outlines how traffic volume estimation, projection techniques, and supplemental field traffic count data were collectively used to populate the gaps in the ADT data. This section also provides some summary descriptive statistics about the resulting ADT values ultimately used for analysis.

3.2.1 Existing Traffic Volume Information

The availability of traffic volume data for assessing safety is most often in the form of ADT or AADT. Since this daily traffic volume value includes both directions of travel (for two-way roads), potential traffic data for use in statistical modeling may include major road ADT, minor road ADT, or total (major plus minor) ADT volumes. In addition, since crash data is associated with a specific time period, the traffic volume data should be adjusted to a common year that closely aligns with the crash data time period.

As a first step in developing representative traffic volume information, members of the project team created a historic traffic count table similar to the example shown in Table 3.3 for roundabout OR-S4-3. For this location, the major road is Mt. Washington Drive and the example traffic volumes represent the north leg of the intersection. During the time period extending from 2005 to 2012, traffic volume data for this intersection leg was only available for years 2005 and 2009. Since construction for this roundabout was completed in 2005, traffic volume data prior to that year is not suitable for this analysis effort. The two 2009 traffic volume sources were from Deschutes County and from ODOT.

Table 3.3: Example of Available Traffic Volume Data for One Leg of Roundabout

Basic Information		Historical Traffic Count		
		Year	Count (vpd)	
Site ID	OR-S4-3	2005	6,823	--
City	Bend	2006	--	--
County	Deschutes	2007	--	--
Street Name	Mt. Washington Dr.	2008	--	--
Location of Leg	North	2009	8,724	8,720
Traffic Direction	Both	2010	--	--
Traffic Volume Type	ADT	2011	--	--
		2012	--	--

3.2.2 Projecting Traffic Volume to a Common Year

For each of the Oregon roundabouts, regional transportation agencies have periodically collected traffic volume information. The use of traffic data projected to the same year (2012 for this study) will enable an agency to apply any resulting models by using current traffic volumes. Since traffic growth may not occur at a constant rate based on isolated ADT values, a reasonable predictor for growth is the change in regional population over time. Table 3.4 shows the 10-year population grown rate for the six counties where the selected study roundabouts are located. Since the ADT values could be associated with any particular year, the table also depicts the resulting average annual growth rate for each county. For the purposes of this analysis, this average annual growth rate is assumed to be constant.

Table 3.4: Annual Population Growth Rate for Counties

County Name	Total Population Change 4/1/2000 to 4/1/2010* (%)	Annual Growth Rate (%)
Clackamas	11.10	1.06
Deschutes	36.70	3.18
Jackson	12.10	1.15
Lane	8.90	0.86
Multnomah	11.30	1.08
Washington	18.90	1.75

* Ten year growth rate available at the following web site: http://www.indexmundi.com/facts/united-states/quick-facts/oregon/population-growth#table

For locations where multiple traffic volume information (often from different years) is available, a composite ADT can first be developed and then that value projected to the year of interest. As an example, there are two ADT traffic volume years with data points for the north leg of roundabout OR-S4-3 (see Table 3.3). To estimate the current ADT for an intersection leg, the following procedure can be applied:

1. For multiple ADT values for the same year, calculate the average. For the OR-S4-3 site, this would result in a year 2009 ADT value of 8722 (the average of 8724 and 8720).
2. For multiple years, adjust the traffic volume to a year between the measured years. For the OR-S4-3, since data is available for 2005 and 2009 the year 2007 can be used for this purpose.
3. Estimate the traffic volume for the common year. For the OR-S4-3 site, this would simply mean averaging 6823 and 8722.
4. To project the traffic volume to the current year, apply the average annual grown rate for the county where the roundabout is located. Since Deschutes County experienced an annual growth rate of 3.18% per year, use this rate for the example adjustment.

Table 3.5 demonstrates this example traffic volume projection calculation for the north leg of roundabout OR-S4-3. One potential drawback to using weighted ADT values from multiple years is that the procedure assumes that the traffic volumes associated with the candidate roads have growth rates that are typical to the region. Since changes in the geometric configuration of a facility can encourage or, in some cases, discourage corridor selection, the final conservative estimate of the ADT for each intersection leg used for this analysis was the largest ADT value observed. In other words, if the ADT value projected to 2012 was less than any of the previously observed traffic volumes at the site (following roundabout construction), the researchers used the largest observed volume.

Table 3.5: Procedure to Project Traffic Volume to the Current Year

Year				Projecting year	Growth Rate (%)
2005	2005*	2009	2009*	2012	
6823	--	8724	8720	9088	3.18

Projecting Calculation:

$$Traffic\ Volume_{2012} = \frac{6823 + \frac{(8724 + 8720)}{2}}{2} \times (1 + 0.0318)^{\left(2012 - \frac{2005 + 2009}{2}\right)} = 9088$$

3.2.3 Acquiring Supplemental Field Traffic Volume Data

For some intersection locations, traffic volume is not commonly available for all legs of the intersection. This issue is particularly common for minor intersection legs on locally maintained roads. For the 23 selected roundabouts, 11intersections had incomplete traffic volume information. The research team elected to sample the traffic volumes at these roundabout locations by acquired peak traffic volume information and then projecting that data to an approximate 24 hour value.

The traffic volume data collection process at each site encompassed both morning and afternoon peak hour traffic. Members of the project team collected traffic volume at a roundabout for 2 hours in the morning and 2 hours in the afternoon. A one day (per site) data collection strategy approach enabled the addition of supplemental data while working within the constraints of the project budget. For most of the locations with missing data, the target intersection leg was a low volume residential or collector corridor. The collection of traffic volume for all four intersection legs (some for which ADT values were previously identified) provided a mechanism to help inflate the peak traffic volume for the unknown intersection legs to a reasonable ADT estimate. The following briefly summarizes the procedure used for this effort.

Using the widely accepted design hourly volume equation (shown below), adjust the directional design hourly volume to the equivalent ADT.

$$DDHV = AADT \times D \times K$$

Where:

DDHV = Directional Design Hourly Volume, vehicle/hour,
AADT = Annual Average Daily Traffic, vpd,
D = Proportion of Peak Directional Traffic Volume, and
K = Proportion of the AADT that occurs in the peak hour.
By dividing both sides of the equation by D, the resulting equation is:

$$\frac{DDHV}{D} = AADT \times K$$

The left side of the new equation represents the peak hour traffic volume, which is in accordance with the definition of K as the proportion of daily traffic that occurs during the peak hour.

Since the data collection effort included all roundabouts with incomplete traffic data, the left side of the equation for intersection legs with missing ADT information can be calculated from the field data. The project team then developed a procedure to estimate the value of K based on the observed traffic distributions.

Since select approach legs already had associated historical traffic data, field data could be combined with ADT data to determine equivalent K values. The individual intersection legs were then sorted into categories with similar K values to estimate traffic distribution characteristics. Intersection legs with no available historic traffic volume data were then assigned to one of the groupings based on their similarity between their traffic distributions and each groups' trends and adjacent land use. The estimated ADT could then be calculated by using the equation and the average K values for the similar facilities along with the field measured peak hour volumes.

Several of the study roundabouts are located in front of a school, church, or exclusive area so that one of roundabout legs serves as the only entrance and exit for that area. These land use areas generate different traffic distribution over the entire day compared to adjacent collectors. For example, a school's afternoon peak hour is generally earlier than that for a business. As a result, the project team treated these special case locations separately and used the field collected traffic volume information in conjunction with land use categories available in the Institute of Transportation Engineering *Trip Generation Manual*. The *Trip Generation Manual* provides ADT estimates for different land uses based on three different categories: weekday, Saturday, and Sunday. For instance, the roundabout OR-S4-1 is located in front of a church. The west leg of this roundabout serves as one of two entrances and exits. The *Trip Generation Manual* provides three different charts for estimating ADT based on gross floor area as demonstrated in Table 3.6.

Table 3.6: Example of the Use of the ITE Trip Generation Manual, 7th Edition

Land Use Code		**560**	
Land Use Name		**Church**	
Condition: Average Vehicle Trip Ends vs: 1000 sq ft Gross Floor Area			
On a:	Weekday	Saturday	Sunday
Input Variables	1000 sq ft Gross Floor Area	1000 sq ft Gross Floor Area	1000 sq ft Gross Floor Area
Input Value (1000 sq ft)	27	27	27
Input Source	Google Earth	Google Earth	Google Earth
Fitted Curve Equation	Not Given	Not Given	Not Given
Average Vehicle Trip Ends (vehicles)	250	260	824
Estimate ADT = 824/2 = 412 vpd			

In Table 3.6, the Sunday chart provides the highest trip ends estimate and represents the highest traffic exposure that this west leg could experience during a week. Based on the conservative estimate approach, the project team chose the highest traffic exposure that the *Trip Generation Manual* could provide as the estimated ADT for the associated intersection leg. Since this roundabout serves as one of two entrances to this church, the project team assumed that half of these trip ends were distributed on this west leg. As a result of this estimation, the expected ADT for the west leg of roundabout OR-S4-1 is 412 vehicles per day for both directions.

3.2.4 Finalizing Traffic Volume Data for Use in Model Development

The roundabout ADT can be classified as the major road volume and the minor road volume. For traditional intersections, the HSM uses two types of traffic exposure. The first strategy uses the major road's AADT and the minor road's AADT. The second one uses the total traffic volume from the major and minor road. This second exposure represents the total entering traffic.

For an intersection with four legs, there are two entering traffic streams from the major road and another two entering streams from the minor road. As a conservative estimating approach for the major traffic exposure, the project team used the largest two-directional traffic volume from the major legs to represent the major ADT. The same strategy applied to the estimation of minor ADT as well as total entering volume.

Table 3.7: Finalizing Traffic Volume Estimation for Site OR-S4-1

Site No.	Site ID	Street Name	Location of Leg	Direction of Travel	Volume Type	AADT or ADT (vpd)
1	OR-S4-1	SE Stevens Rd.	N	Both	ADT	6,250
		Monterey Ave.	E	Both	ADT	1,400
		SE Stevens Rd.	S	Both	ADT	7,575
		Monterey Ave.	W	Both	ADT	412
Major ADT (vpd):			Since 7,575 > 6,250, use 7,575			
Minor ADT (vpd):			Since 1,400 > 412, use 1,400			
Total Entering (Major + Minor) ADT (vpd):			7,575 + 1,400 = 8,975			

At select intersections, the major road is not always represented by two opposing direction roadways (the major road may bend at the roundabout). The two legs with the largest volume, therefore, were considered the major legs. As shown in Table 3.7, the north and south legs then represent the major road. For this example site, the major ADT is the highest volume value for this major road, or 7,575 vpd. Similarly, the minor ADT has a value of 1,400 vpd. The total entering ADT for this roundabout then is the sum of the major and minor volumes. **Error! Reference source not found.** in Appendix B summarizes the projected raw traffic volume data identified for each intersection leg. **Error! Reference source not found.** shows the resulting major, minor, and total ADT values that were developed for the subsequent safety analysis.

Table 3.8 identifies the minimum, maximum, average, and standard deviations for the three ADT data elements. As shown in Figure 3.8, Figure 3.9, and Figure 3.10, the distribution of the major, minor, and total entering ADT values varies considerably for the 23 study sites; however, the maximum total entry volume is a relatively moderate value suggesting that the study roundabouts in Oregon have moderate to low traffic volumes. This lower volume condition is likely due to the single-lane configuration for all of the selected roundabouts, but it is also important to note that any findings from this research should only be applied to similar volume facilities.

Table 3.8: Description of Roundabout Traffic Volume Characteristics

Representative Traffic Volume	Minimum	Maximum	Average	Standard Deviation
ADT on Major Street (vpd)	6,430	19,350	11,697.1	3,837.73
ADT on Minor Street (vpd)	1,400	13,285	6,704.4	3,540.22
Total ADT (Major plus Minor) (vpd)	8,371	29,732	18,401.5	6,597.25

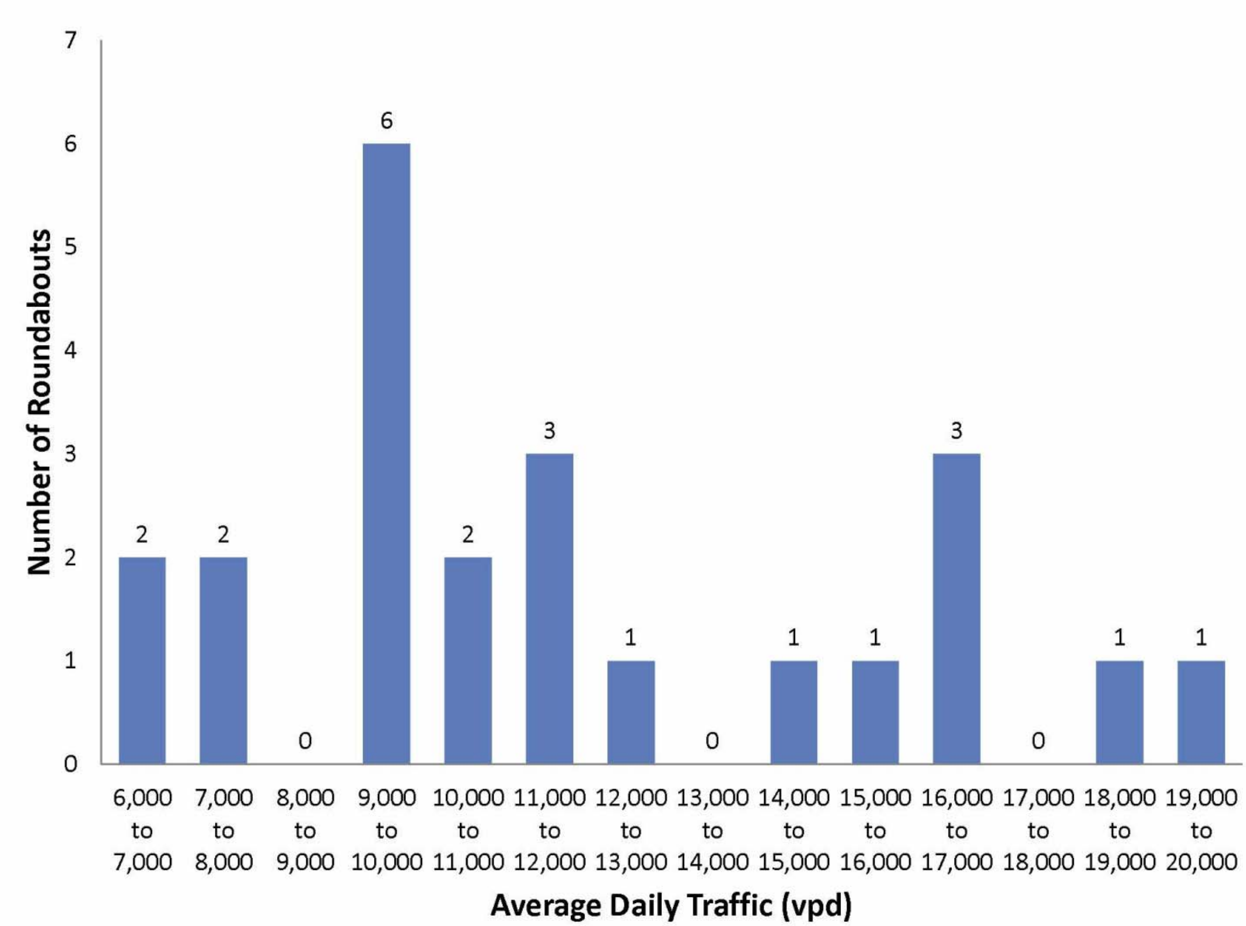


Figure 3.8: Distribution based on Major Street ADT

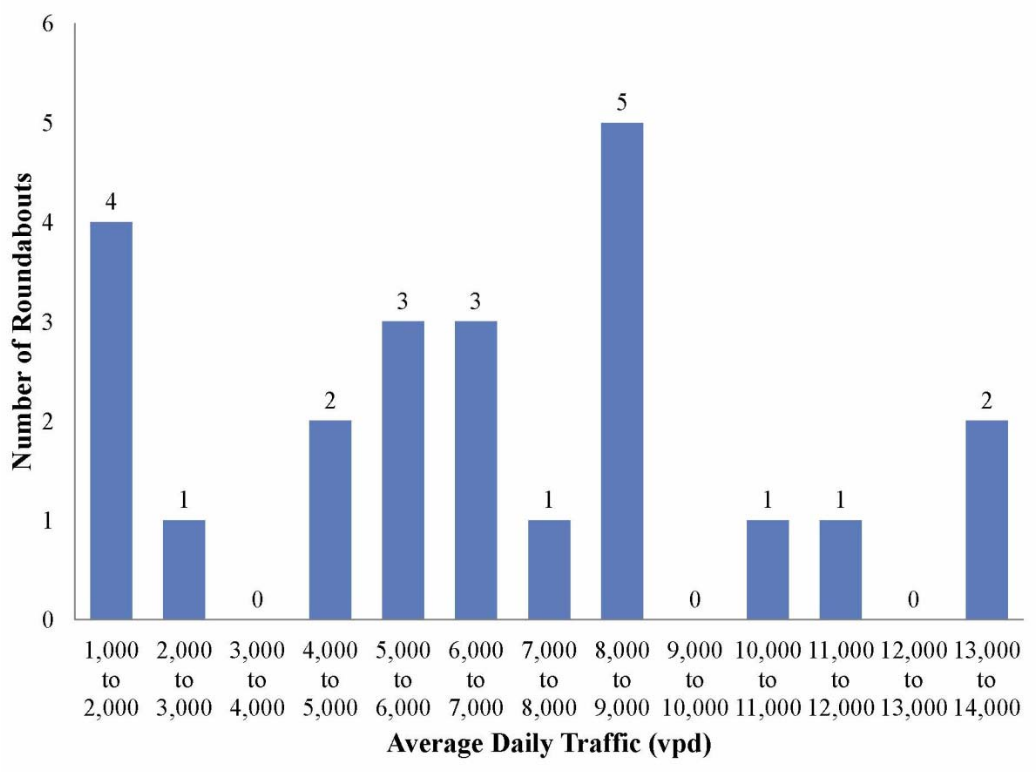


Figure 3.9: Distribution based on Minor Street ADT

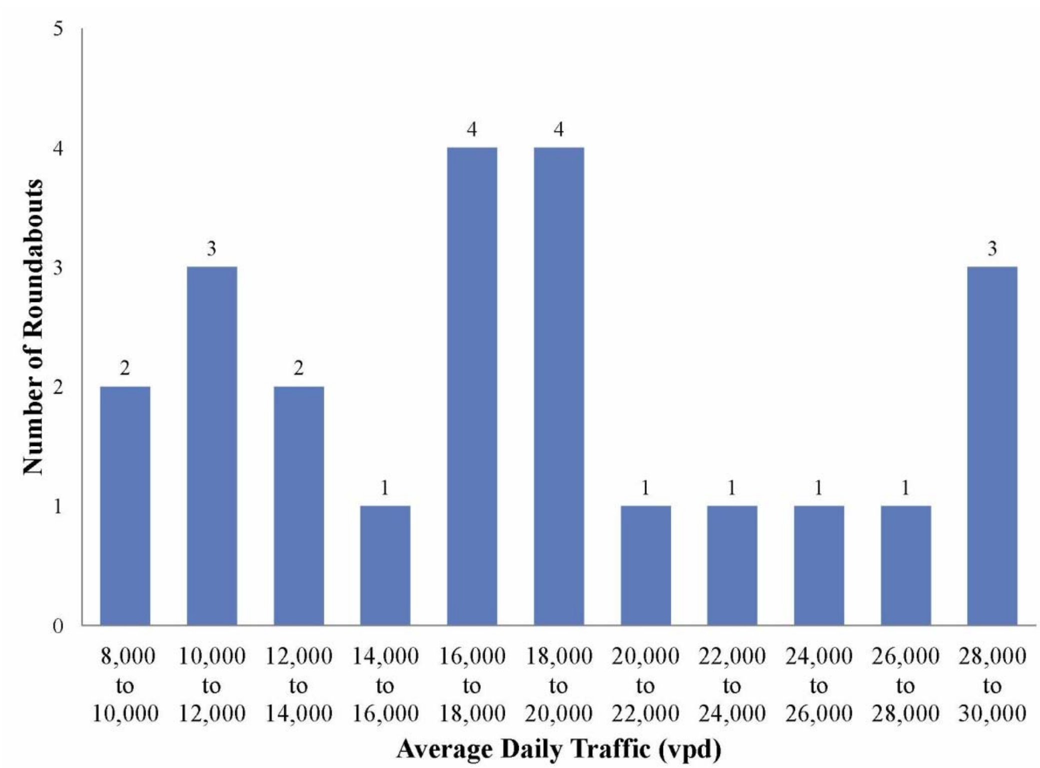


Figure 3.10: Distribution based on Total Entering ADT

3.3 ROUNDABOUT CRASH DATA

To assess the expected safety performance of a roundabout, historic crash information can be used to statistically evaluate crash trends. Two critical issues associated with crash analysis include: 1) identifying crashes related to intersection applications, and 2) evaluating crashes based on type and severity of collision. This section reviews these two crash-related components of the data.

3.3.1 Defining Roundabout Related Crash Boundaries

Crashes associated with an intersection often include vehicles located within the physical limits of an intersection; however, as vehicles approach an intersection they may also be involved in an intersection-related crash if the crash can be attributed to intersection operations. It is an important first step, therefore, to define the limits of the upstream intersection functional area for the purposes of crash identification. The intersection functional area is the area that extends upstream of the physical intersection of two roadways and includes the stopping sight distance and any required vehicle storage area. A similar functional area should be applied to roundabouts.

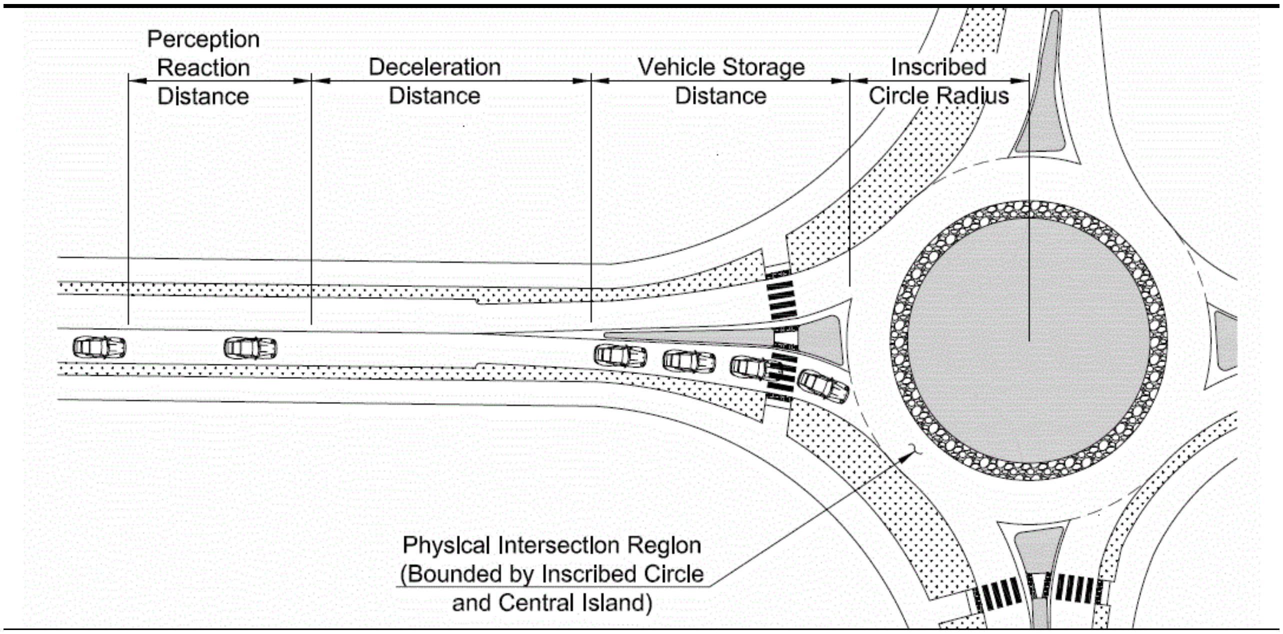
For the purpose of this research effort, the project team assumed that the vehicle storage area serves four vehicles with average distances of 25 feet each. Based on this four vehicle assumption, the vehicle storage area length should be 100 feet beyond the physical inscribed circle area.

The stopping sight distance is represented by the following equation:

$$SSD = 1.47Vt + 1.075\frac{V^2}{a}$$

Where:
SSD = stopping sight distance, ft
V = design speed, fps
t = perception reaction time, sec -- typically 2.5 sec for design
a = deceleration rate, fps ^{2}-- typically 11.2 fps ^{2}

The AASHTO publication *A Policy on Geometric Design of Highways and Streets* (*2001*) provides the guidance for the estimation of stopping sight distance. The perception reaction time for design purposes is assumed to be approximately 2.5 seconds. The deceleration rate is assumed to be 11.2 fps ^{2}. To consistently assess crashes across all sites, the speed used for this analysis was the highest posted speed limit (40 mph) for the roundabout approaches in this study. Using an assumption that the design speed is approximately 10 mph greater than the posted speed, the approximate design speed for the same facility would then be 50 mph. Figure 3.11 demonstrates the components needed to define roundabout-related crashes and their proximity to the centerline intersection of the roundabout approaches. The actual calculation is summarized in Table 3.9 with a final distance used to define the upstream boundary for including a crash to be conservatively rounded to 800 feet.



Notes:

1. Perception reaction distance represents the distance a driver will travel during his or her perception reaction time,
2. Deceleration distance represents the distance a driver will travel from the time the driver begins to brake until stop, and
3. The stopping sight distance is composed of the perception reaction distance and the deceleration distance.

Figure 3.11: Region Defining Roundabout Related Crashes

Table 3.9: Calculation of the Region used to Define Roundabout Related Crashes

Radius of the Largest Inscribed Circle (ft)	192
Length of Required Vehicle Storage Area (ft)	$4 \times 25 = 100$
Highest Posted Speed from Data Set (mph)	40
Corresponding Design Speed (mph)	50
Perception Reaction Distance (ft)	$1.47 \times 50 \times 2.5 = 184$
Braking Distance (ft)	$1.075 \times \frac{50^2}{11.2} = 240$
Length of Upstream Influence Area (ft)	$184 + 240 + 100 + 192 = 716$(say 800)

3.3.2 Crash Data Descriptive Statistics

A total of 131 crashes were reported for the Oregon single-lane, four-leg roundabouts during the five-year crash analysis period (2007 to 2011). This value represents an average of approximately 1.1 annual crashes per roundabout. As shown in Figure 3.12, the crash severity levels observed at the sites included property damage only or injury at 79 and 52 crashes for the five-year period respectively.

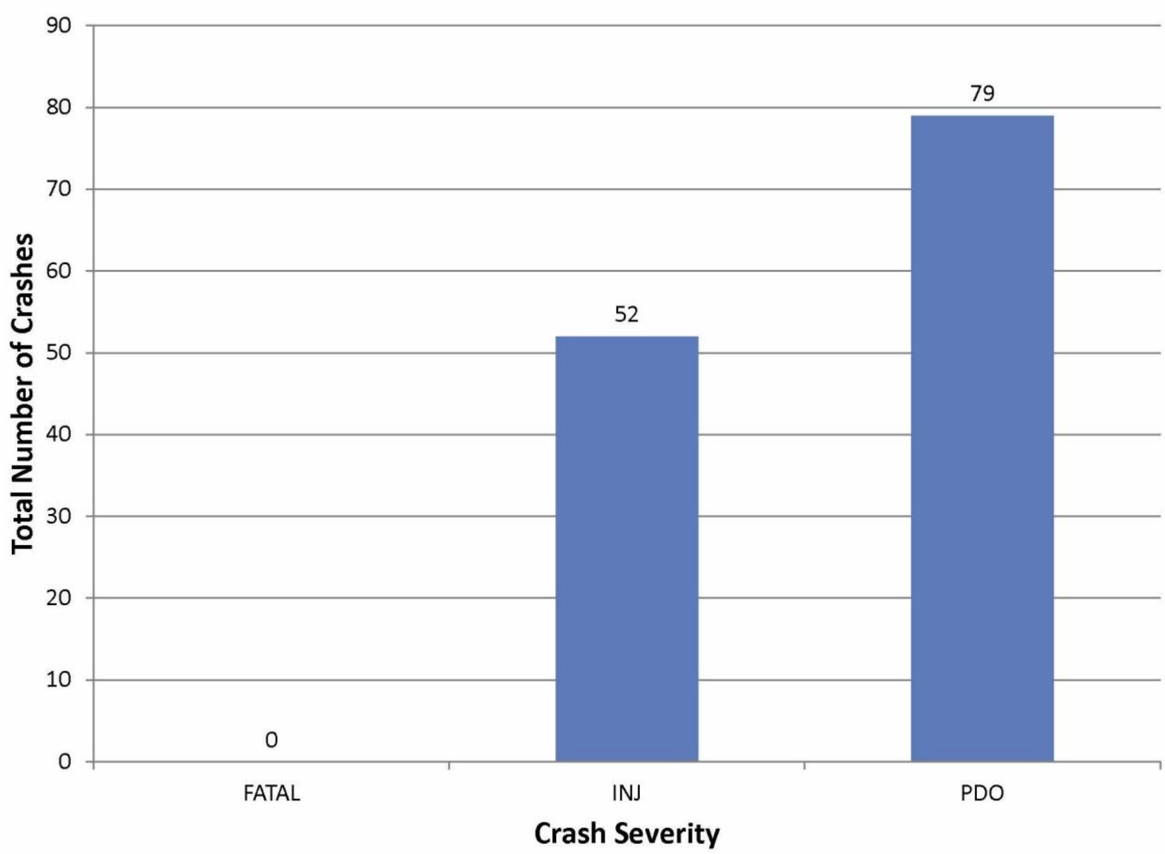


Figure 3.12: Total Number of Crashes by Severity Levels (2007 - 2011)

Ideally, an effective safety performance function should be developed based on total crashes as well as individual severity levels; however, since the roundabouts in this study experienced relatively low crash volumes, the severity model options may be limited. In addition, Oregon crash reporting for property damage only crashes is generally self-reported and may, as a result, under represent the actual number of crashes. For this reason, the project team pursued the crash analysis based on the total as well as severity level crashes while taking care to consider this potential data limitation.

As shown in Table 3.10, approximately 5.7 crashes, on average, occurred at the roundabouts during the five-year crash analysis period. **Error! Reference source not found.** (see Appendix B) provides a summary of the crash severities per site. As depicted in Figure 3.13, two sites (OR-S4-8 and OR-S4-15) were characterized by more than 16 total crashes. Figure 3.14 and Figure 3.15 further demonstrate the injury and property damage only crash distributions. Three sites (OR-S4-8, OR-S4-9, and OR-S4-15) exceeded six injury crashes during the five-year crash analysis period.

Table 3.10: Description of Crash Characteristics at Individual Roundabouts

5 Year Crash Data	Minimum	Maximum	Average	Standard Deviation
Total Crashes per Site	0	19	5.7	5.93
Total Injury Crashes per Site	0	9	2.26	3.02
Total Property Damage Only Crashes per Site	0	10	3.43	3.37

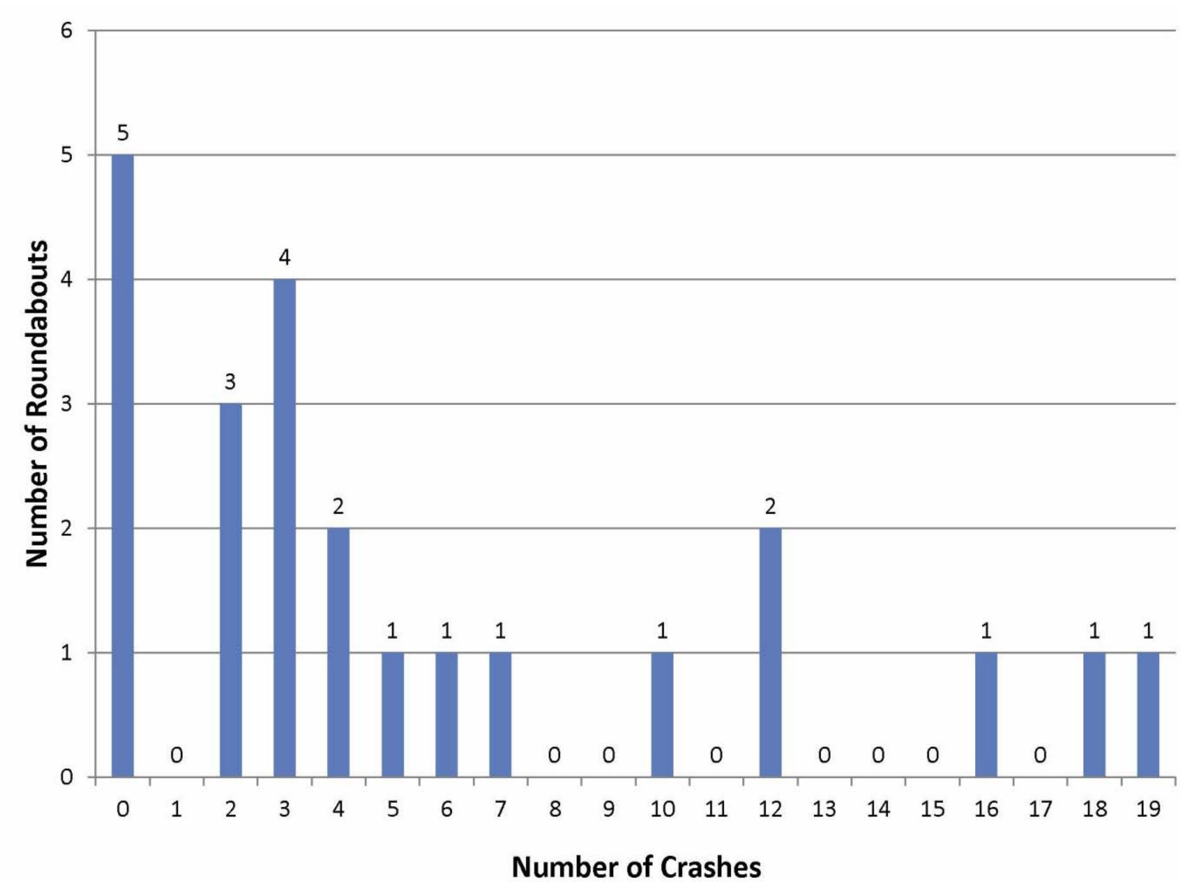


Figure 3.13: Distribution of Total Crashes (2007 - 2011)

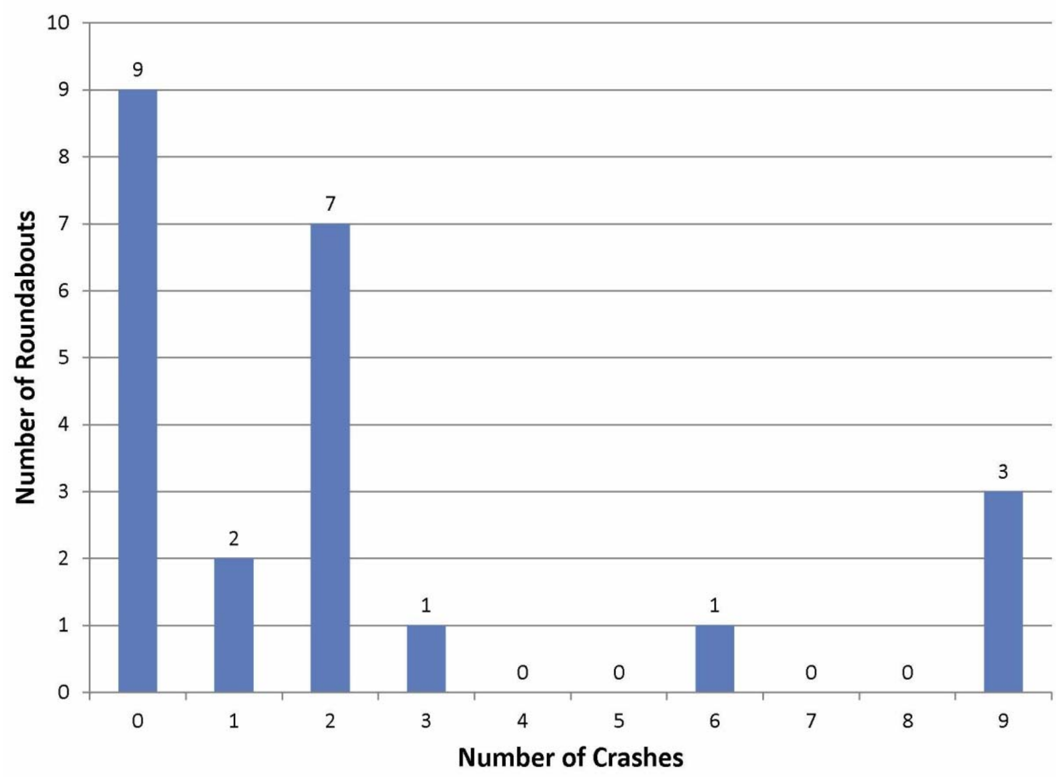


Figure 3.14: Distribution of Injury Crashes (2007 - 2011)

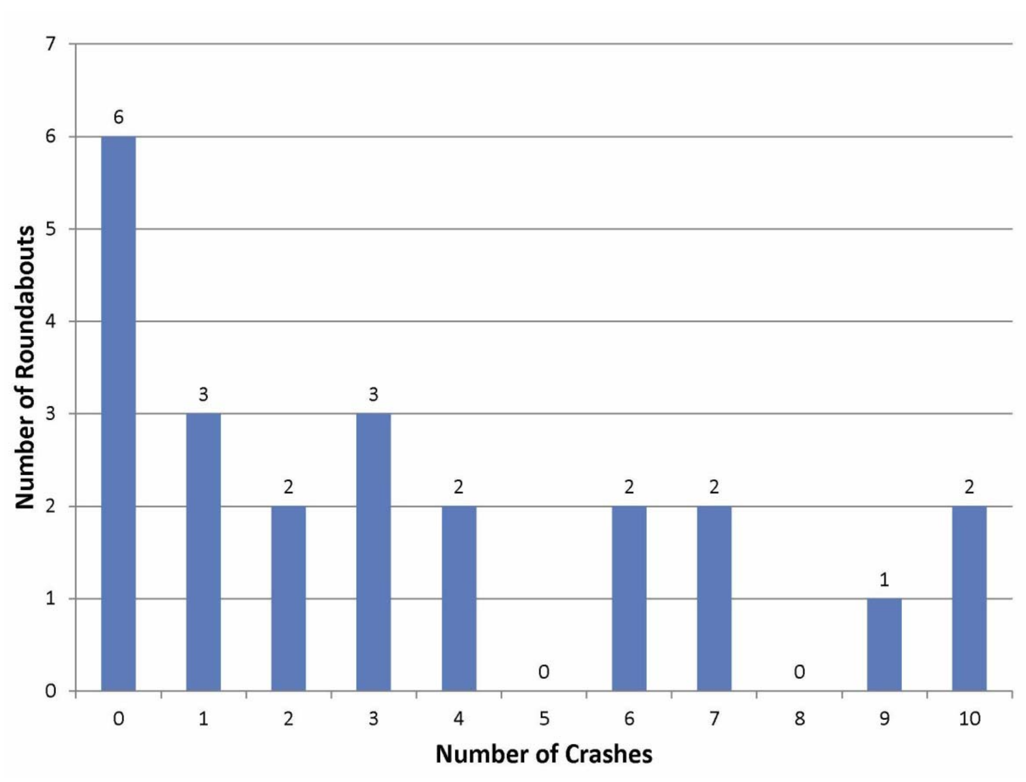


Figure 3.15: Distribution of PDO Crashes (2007 - 2011)

A common observation for roundabout crashes is that the number of conflict points is significantly reduced when contrasted with a traditional intersection. The more hazardous 90-degree or angle conflicts are reduced for roundabout configurations. It is important, therefore, to examine the collision type observed at the Oregon roundabouts to confirm that the observed crashes are associated with the type of collisions that are less likely to result in serious or fatal injuries.

As shown in Table 3.11, more than 51% of the crashes at the Oregon study roundabouts were associated with rear-end collision types (67 of the 131 crashes). Figure 3.16 graphically depicts the observed collision types. It should be noted that fixed object crashes, angle crashes, and turning maneuver crashes collectively totaled approximately 39% of the total observed crashes.

Since all of the study sites had roundabouts, these crash statistics are not contrasted with traditional intersections in this descriptive assessment. The project team did, however, include such a comparison in the statistical analysis section of this report (see Section 4.5).

Table 3.11: Distribution of Total Crashes by Collision Type and Severity

Collision Type	Injury	PDO	Total
Angle Collision	4	14	18
Fix Object or Other Object	8	11	19
Rear-end Collision	29	38	67
Miscellaneous	2	0	2
Turning Movement	4	10	14
Sideswipe - Meeting	0	2	2
Backing Movement	1	0	1
Collision with Pedestrian	2	0	2
Non - Collision	2	1	3
Head-on Collision	0	2	2
Parking Maneuver	0	1	1
Total Crashes	52	79	131

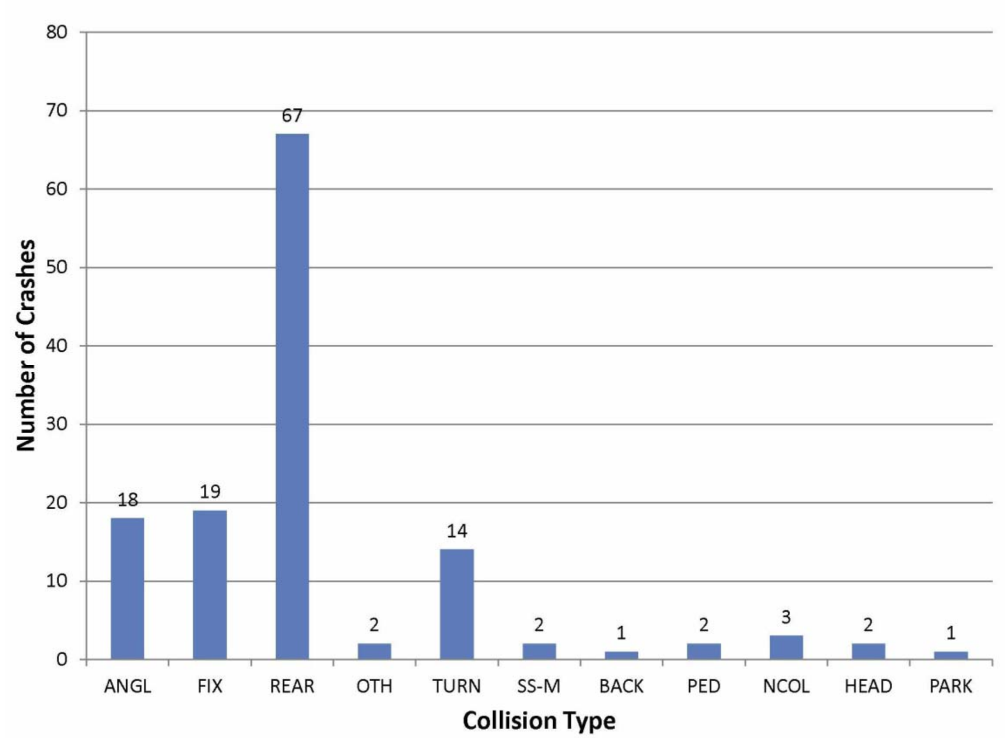


Figure 3.16: Distribution of Crashes by Collision Types (2007 - 2011)

3.4 SUMMARY DATA COLLECTION OVERVIEW

As shown in this section of the report, the project team used strategic data collection and analysis methods to assemble a comprehensive database for the 23 single-lane, four-leg Oregon roundabouts. This data set includes geometric data, traffic volume information, and crash data associated with the individual site locations.

Section 4 of this report will demonstrate how the project team then used this data to perform statistical analysis to develop ways to predict safety performance at these and similar Oregon roundabouts.

4.0 DATA ANALYSIS AND RESULTS

Statistical models can be used as a way of evaluating crash history and site characteristics to predict the number of crashes for similar facilities. The AASHTO HSM (*2010*) uses a traffic volume based SPF for this type of analysis.

Two candidate model configurations can be developed. A full model includes traffic volume as well as any geometric features that significantly influence safety performance. The second model approach uses a base model that, for intersections, considers traffic volume information as the primary input. This modeling approach should be used for scenarios where the facilities are similar and the sample size is relatively small. The similar facilities should have a defined set of base conditions that represent the typical design configuration. If an intersection has some geometric features that differ from these baseline conditions, CMFs can be applied, when available, by multiplying the SPF by the required CMFs to account for the effects of the varying geometric features.

Based on the roundabout data available for this research effort and the limited sample size, the project team elected to develop a base model. The baseline conditions can be assumed to conform to the following geometric features as these are typical for the majority of the selected roundabouts. These baseline conditions include:

- Single lane roundabout,
- Four approach legs,
- Raised central island present,
- Truck apron present,
- No bicycle lane,
- Sidewalk present,
- Splitter island associated with a pedestrian refuge area,
- Lighting system present,
- No bypass lane,
- Center alignment design,
- Circular roundabouts (no ovals),
- Inscribed circle diameter of approximately 135 feet (this is the average for all of the sites),
- Circulating lane width of approximately 16 to 17 feet (as shown in Table 3.2, the average observed was 16.6 feet), and
- A 15 mph circulating speed limit.

Based on these conditions, the statistical data set for the development of a base model should only include roundabouts with these features. Since site OR-S4-21 did not have a truck apron, this site should not be included in the data set used to develop the statistical base model. Similarly, the roundabout identified as OR-S4-22 has an oval configuration rather than the required circular shape. As a result, only 21 of the 23 roundabouts were retained for use in the subsequent modeling process.

4.1 STATISTICAL ANALYSIS APPROACH

Though the project team intended to develop a model with a similar functional form (shape) as those used in the HSM for traditional intersection SPFs, the roundabout data did not fit the model that assumes the relationship for both the number of crashes and the traffic volume has a logarithmic form. The regression approach, however, did use techniques consistent with those used to develop the HSM procedures.

Crash data is frequency data that should be described by the statistical Poisson or negative binomial model. The roundabout data appears to have a concave shape when plotting the number of crashes against the traffic volume. As a result of the modeling process, the project team added a quadratic term to the traffic volume in the model so as to improve model quality of fit. The important explanatory variables are determined by both the significance level from the regression model and engineering judgment. The goodness-of-fit, on the other hand, can be evaluated in multiple ways. The AIC index provides a relative quantitative measurement of the goodness-of-fit for each potential model. The smaller value for the AIC index is preferred.

The likelihood ratio test provides a way to compare models with different underlying probability assumptions, allowing a comparison between models assuming a Poisson distribution and models assuming a negative binomial distribution. The Poisson regression model is a special case of the negative binomial regression model by assuming that the mean is equal to the variance (or has a ratio equal to one). The negative binomial distribution has more flexibility in modeling crash data as the crash data is often over dispersed (i.e. variance greater than the mean). Since the project team evaluated the same data using both the Poisson and the negative binomial model, the likelihood ratio test then permitted assessment of the null hypothesis that the crash data is over dispersed. The negative binomial regression model was determined to be more appropriate for modeling the roundabout data.

A convenient graphical way to assess the resulting model is through the use of a cumulative residual (CURE) plot (*Hauer et al., 1997*). This technique visualizes the cumulative residuals that represent how the fitted model compares to the observed crash data. A CURE plot that represents a reasonable model fit will show the cumulative residuals oscillating around the cumulative residual line with a value of zero. This oscillation characteristic is usually described as the random walk or random path. This random path of cumulative residuals goes up if corresponding data points are above the regression line, otherwise the random path goes down. A regression line that fits the data well should be located in such a way that, when examining the scatter plot, the data points are distributed around the regression line. Similarly when examining the CURE plot, the plot of the cumulative residuals will oscillate around the horizontal line of zero.

The modeling procedures included in this report, therefore, used negative binomial regression, accompanied by CURE plots, to depict the analysis. Appendix D summarizes the various models considered during this analysis. The following sections include the final models. During the development of these models, the project team noted an outlier in the data set that had an unusually large number of crashes with relatively low traffic volume. After considerable analysis, the project team excluded this data point from the final data set for modeling. Ultimately the modeling results based on the original data set and the final data set were quite similar. Baseline models included in the following sections represent a total crash model and an injury crash model. If an Oregon agency needs to predict property damage only crashes, this value can easily be obtained by subtracting the predicted injury crashes from the total crashes.

4.2 TOTAL CRASHES BASELINE MODEL

As a first step towards analyzing the total crash model, members of the project team developed a scatter plot that shows the relationship of the number of crashes contrasted to the ADT (see Figure 4.1). For informational purposes, the two sites that do not meet base conditions are also shown in this figure.

Table 4.1 shows the final model, in tabular format, for both the Poisson and the negative binomial regression based on the final data set without the outlier. The negative binomial model is an appropriate model to describe the relationship based on the results from AIC and likelihood ratio test. Figure 4.2 shows the scatter plot with the negative binomial regression line superimposed. The CURE plot is depicted in Figure 4.3. Note that the cumulative residual line shows a random walk that oscillates around zero as expected.

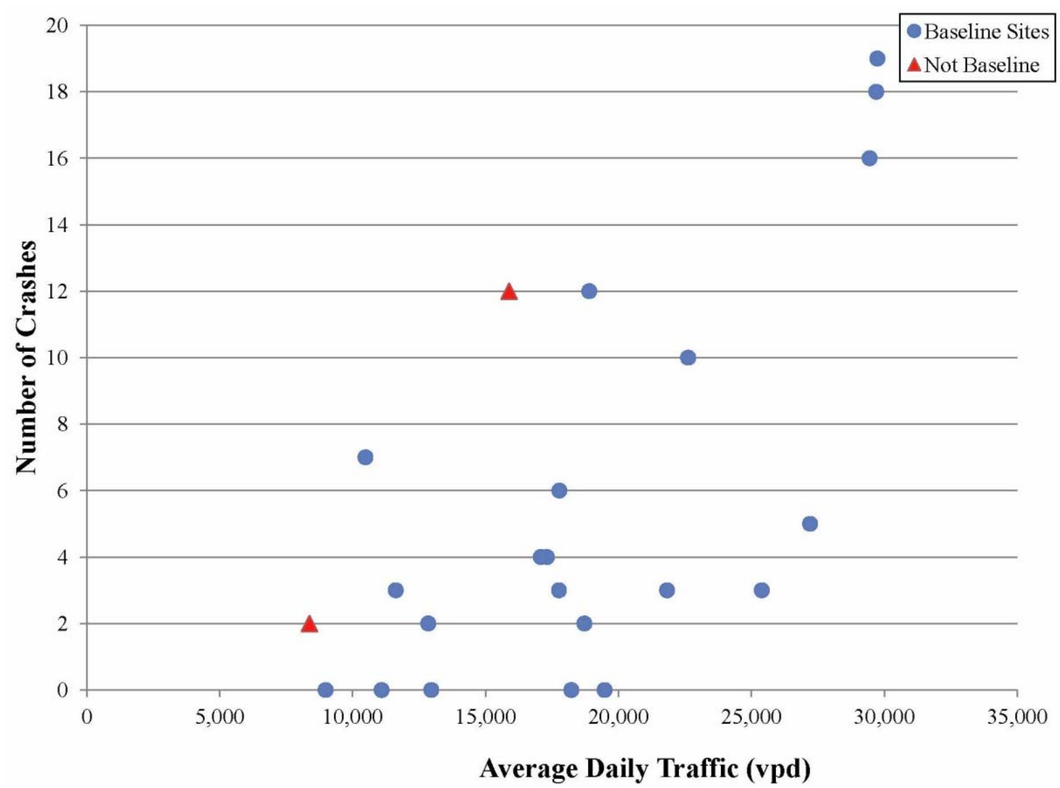


Figure 4.1: Scatter Plot of Total Crashes against Total Entering Volume (2007 – 2011)

Table 4.1: Total Crash Model for Poisson and Negative Binomial for Total Crashes

5-year Total Crash Model (without outlier)						
Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	1.292e-01	2.488e-01	0.519	0.604	
β_2	TOT_ADT^2	2.967e-09	3.635e-10	8.161	3.31e-16	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	2.447e-01	3.577e-01	0.684	0.494	
β_2	TOT_ADT^2	2.744e-09	6.536e-10	4.198	2.69e-05	***
θ		2.74	1.98			
Over dispersion 1/θ		0.365				
		Poisson Regression		Negative Binomial Regression		
AIC		107.25		103.47		
Likelihood Ratio Test (p-valve = 0.000355)		Null Hypothesis		Alternative Hypothesis		

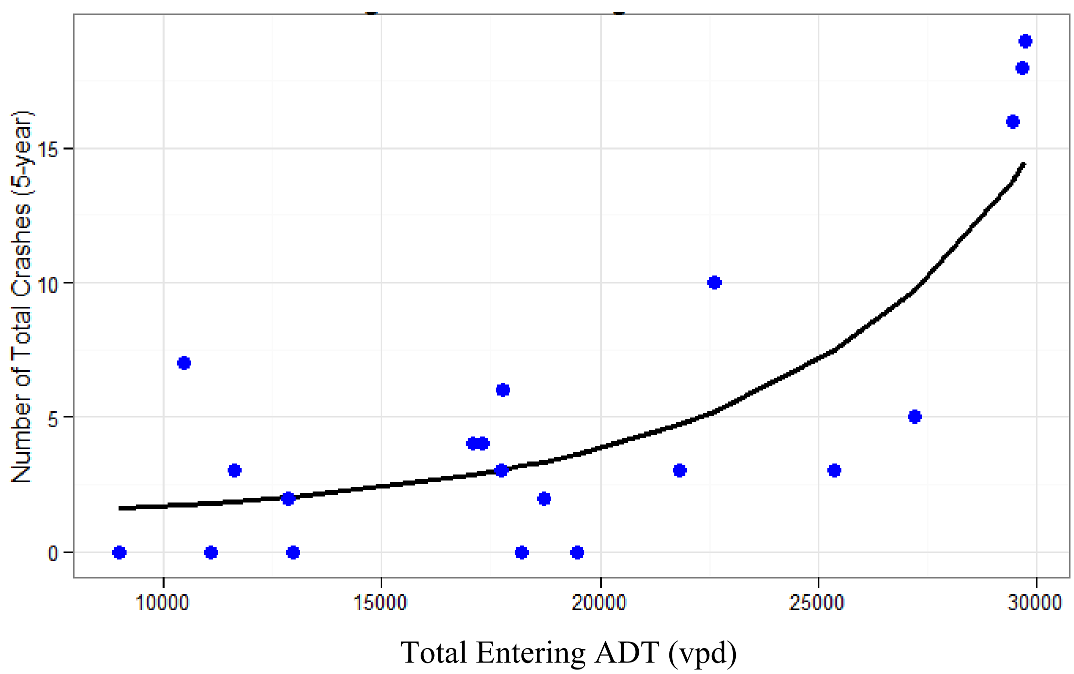


Figure 4.2: Negative Binomial Regression Model for Total Crashes (2007 – 2011)

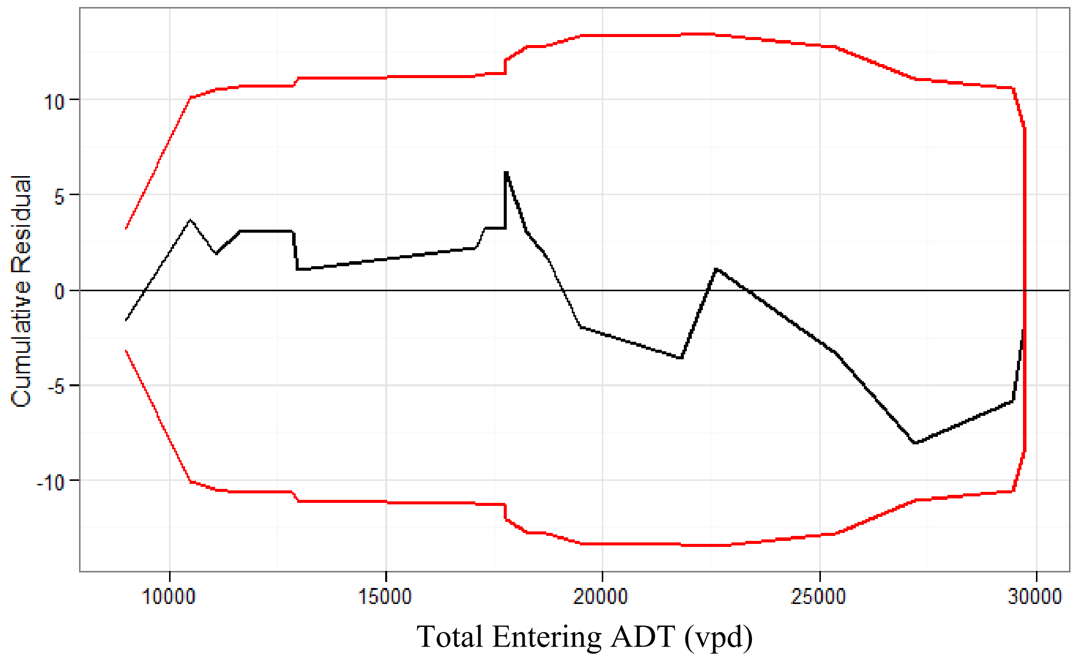


Figure 4.3: CURE Plot for the Total Crash Model

The model for the five-year total crash is represented by the square of total traffic as a controlling influence (explanatory variable). A high significance level for this variable indicates that this traffic volume information does a good job of explaining the variation in the crash data. The resulting regression equation is shown as follows:

$$N_{(5-year)} = e^{[0.34+(2.7\times10^{-9})(ADT_{total})^{2}]}$$

Where:
N (5-year) = The predicted total number of roundabout crashes that will occur for a similar roundabout during five years, and
ADTtotal = The total entering (major + minor) daily traffic volume, vpd.

It is important to note that this model is only appropriate for roundabout facilities with an entering ADT range from 8,975 to 29,732 vpd.

The model for estimating the annual total number of crashes can be derived from this five-year model by dividing by the number of years.

$$N = \frac{e^{[0.24+(2.7\times 10^{-9})(ADT_{total})^2]}}{5}$$

Where:

N = The predicted total annual number of roundabout crashes that will occur for a similar roundabout, and
ADTtotal = The total entering (major + minor) daily traffic volume, vpd.

This model is valid for total entering ADT ranging from 8,975 to 29,732 vpd.

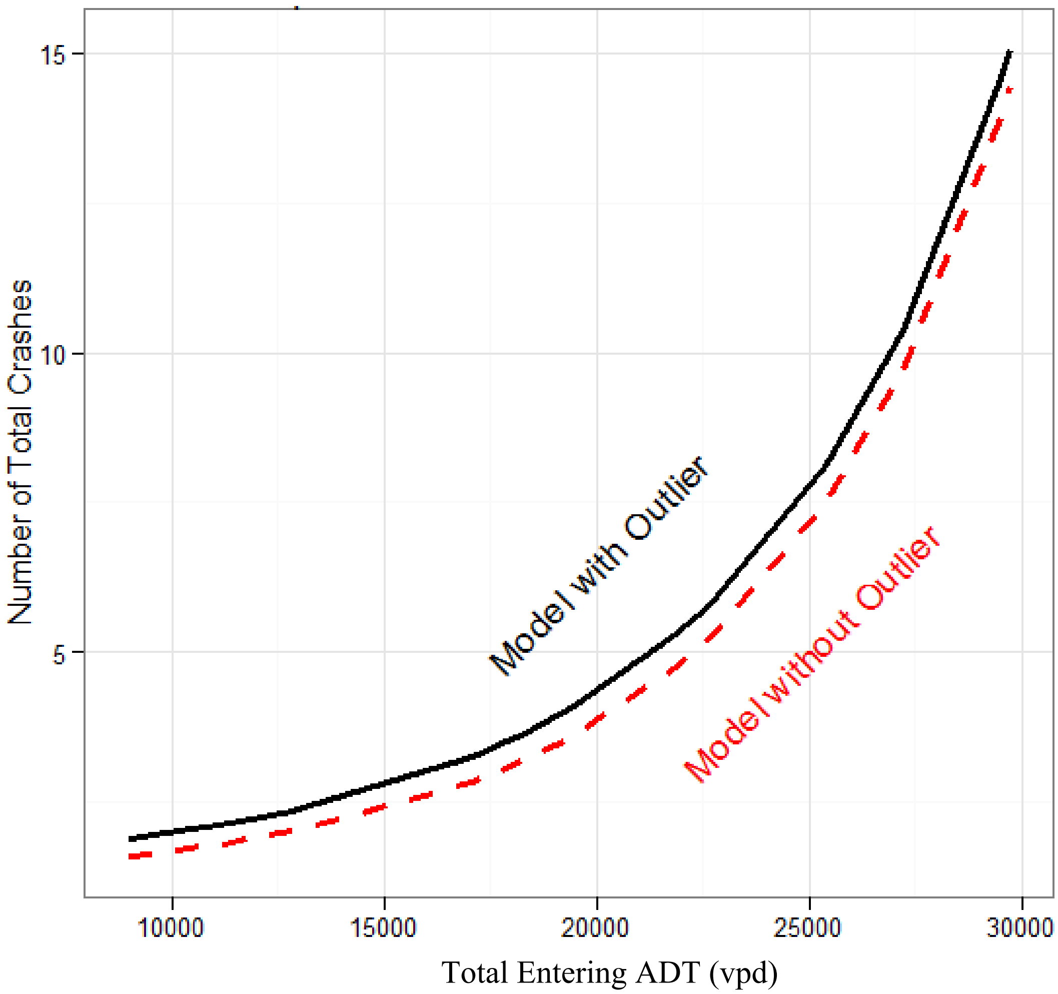


Figure 4.4: Outlier Effect on Model Development

The removal of an outlier from the modeling process can potentially substantially change the predictive capabilities for small sample sizes. To assess this impact, Figure 4.4 demonstrates that, for this total crash model, the difference between the model with and without the outlier is negligible. For example, at an ADT value of 20,000 the model with the outlier slightly over predicts the number of crashes at just above four crashes in a five year period. The final model that excluded the outlier shows just less than four crashes in a five year period. Consequently, when rounding the number of crashes to a whole number, both models predict the same rounded value of four crashes.

4.3 INJURY CRASHES BASELINE MODEL

A scatter plot depicting the number of crashes during the five year analysis period contrasted to the total entering traffic volume is depicted in Figure 4.5. As also shown in Figure 4.1, the sites represented by baseline conditions are contrasted to two sites that did not conform to all baseline characteristics. Though fewer injury crashes occurred than total crashes, the data configuration is similar to that previously observed.

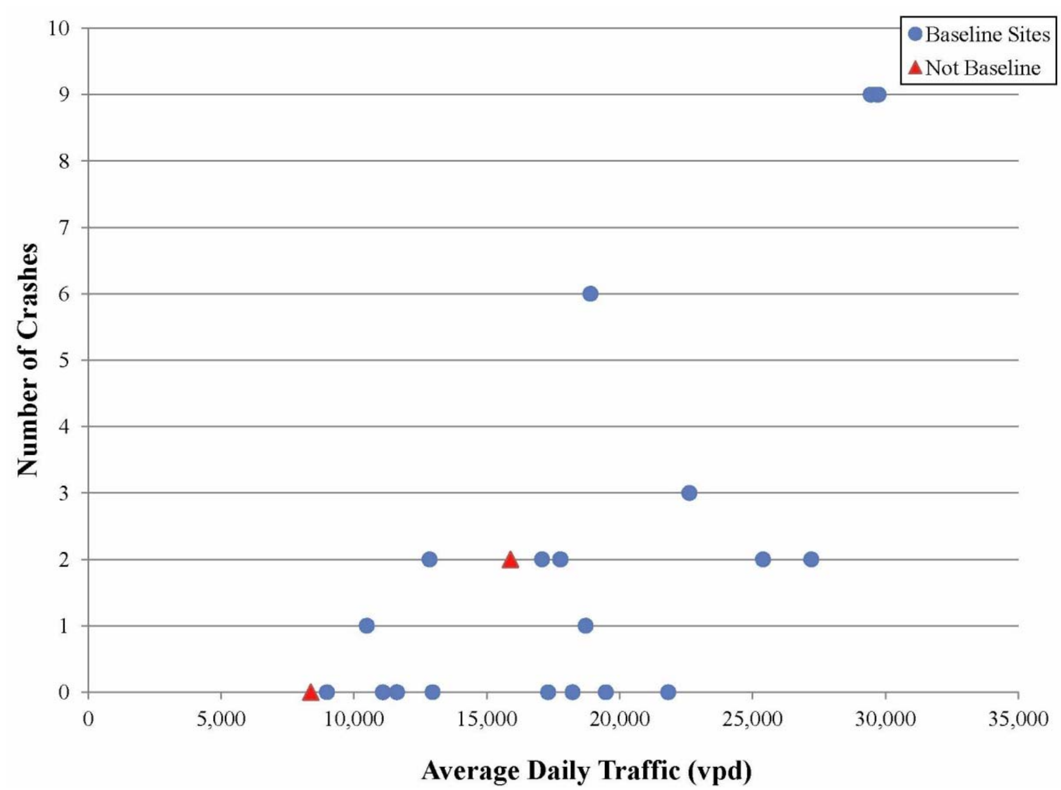


Figure 4.5: Scatter Plot of Injury Crashes against Total Entering Volume (2007 – 2011)

Table 4.2 depicts the Poisson and negative binomial regression models based on the database that contained the outlier. The negative binomial regression model reached its iteration limit when evaluated without the outlier. Since negative binomial regression has an additional over dispersion parameter, the further reduced associated degrees of freedom limited this model development. Figure 4.6 and Figure 4.7 show the Poisson regression line and corresponding cumulative residual plot, respectively for injury crashes based on data that included the outlier.

Table 4.2: Modeling Process Results for Injury Crashes with Outlier

5-year Total Injury Crash Model (with outlier)						
Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = \text{Exp}[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-9.558e-01	3.855e-01	-2.479	0.0132	*
β_2	TOT_ADT^2	3.456e-09	5.473e-10	6.314	2.72e-10	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = \text{Exp}[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-9.219e-01	4.095e-01	-2.251	0.0244	*
β_2	TOT_ADT^2	3.395e-09	6.223e-10	5.455	4.9e-08	***
θ		11.1	36.8			
Over dispersion $1/\theta$		0.09				
		Poisson Regression		Negative Binomial Regression		
AIC		74.98		76.901		
Likelihood Ratio Test (p-valve = 0.778)		Null Hypothesis		Alternative Hypothesis		

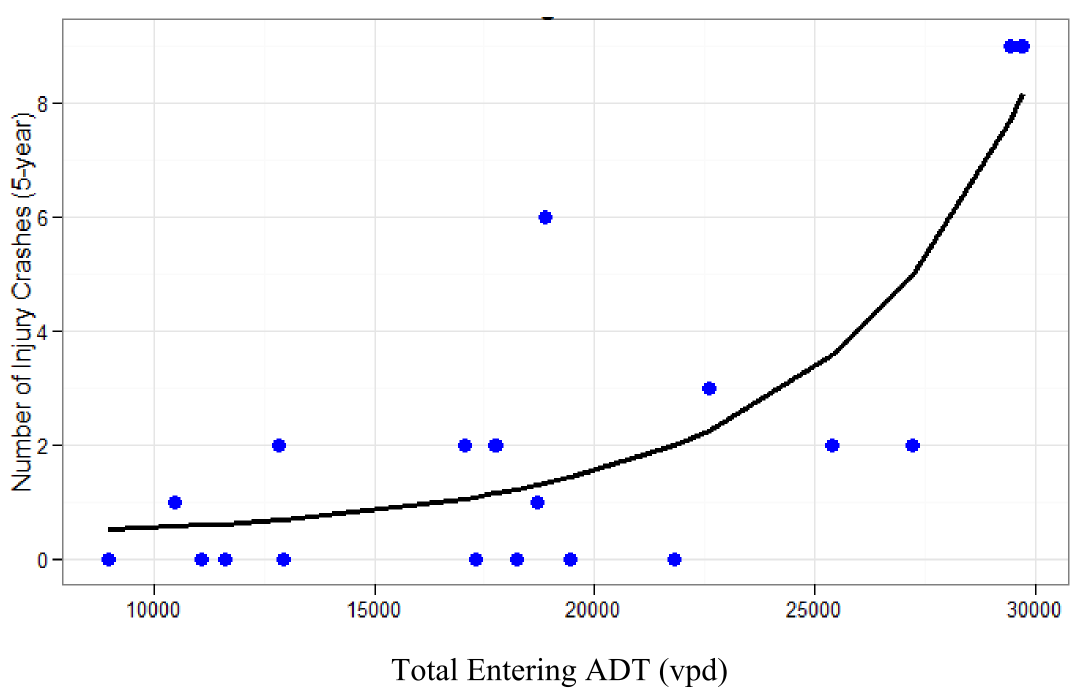


Figure 4.6: Poisson Regression Model for Injury Crashes (data includes outlier)

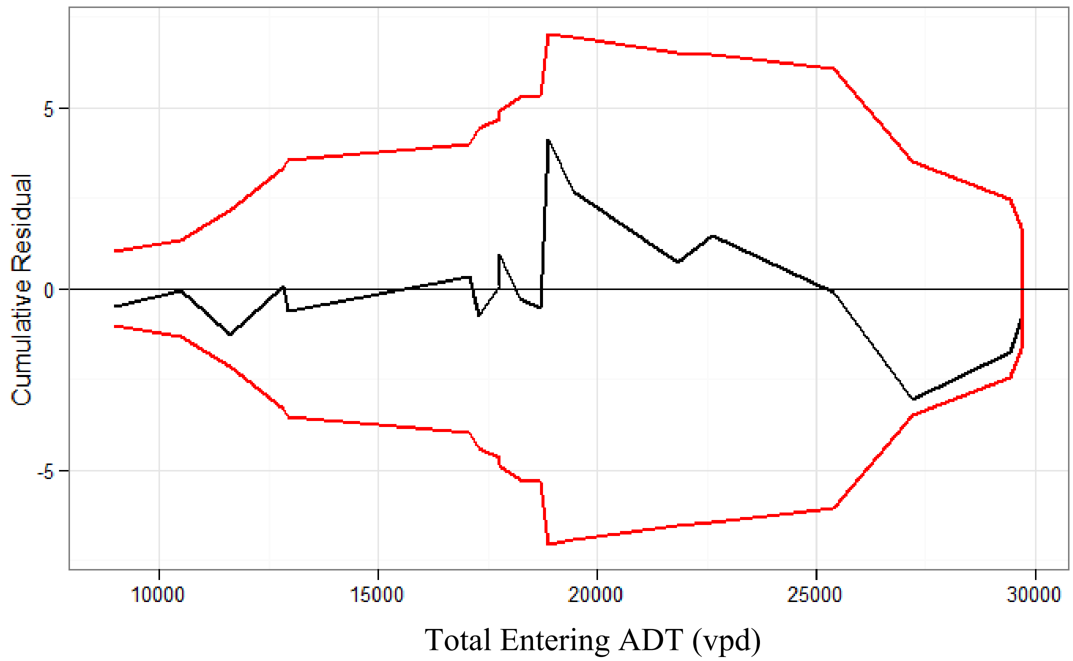


Figure 4.7: CURE Plot for Poisson Distributed Injury Model (data includes outlier)

Since the Poisson model that used the data set with the outlier outperformed the negative binomial regression model, the project team then developed the Poisson injury model based on data that excluded the outlier (see Table 4.3). Figure 4.8 and Figure 4.9 show the Poisson regression line and corresponding CURE plot for injury crashes without the outlier, respectively.

Table 4.3: Modeling Process Results for Injury Crashes (data excludes outlier)

5-year Total Injury Crash Model (without outlier)						
Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-1.41e+00	4.584e-01	-3.080	0.00207	**
β_2	TOT_ADT^2	3.978e-09	6.221e-10	6.395	1.61e-10	***

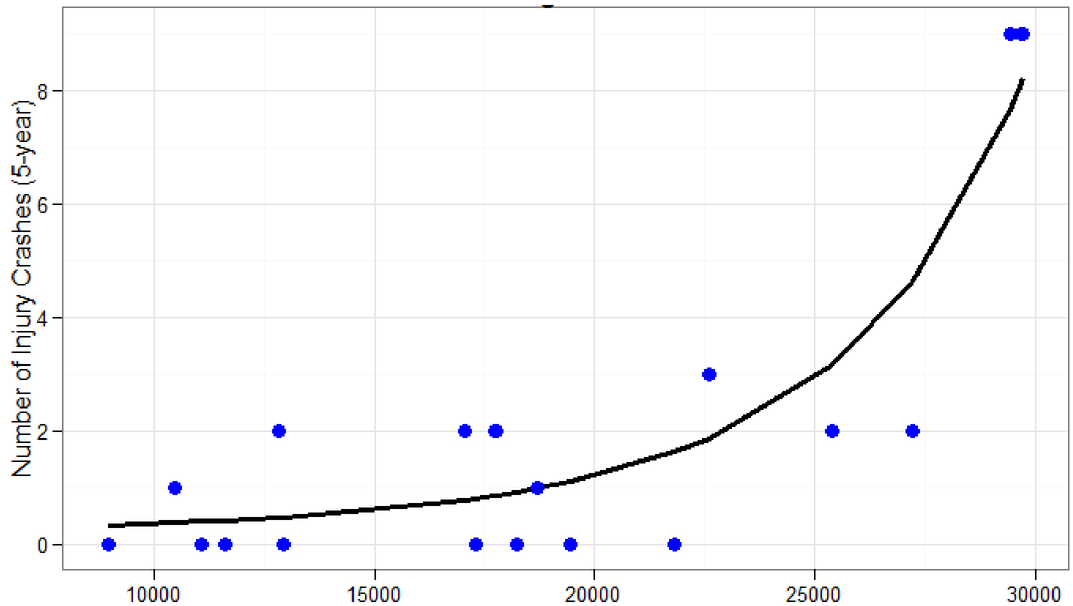


Figure 4.8: Poisson Regression Model for Injury Crashes (data excludes outlier)

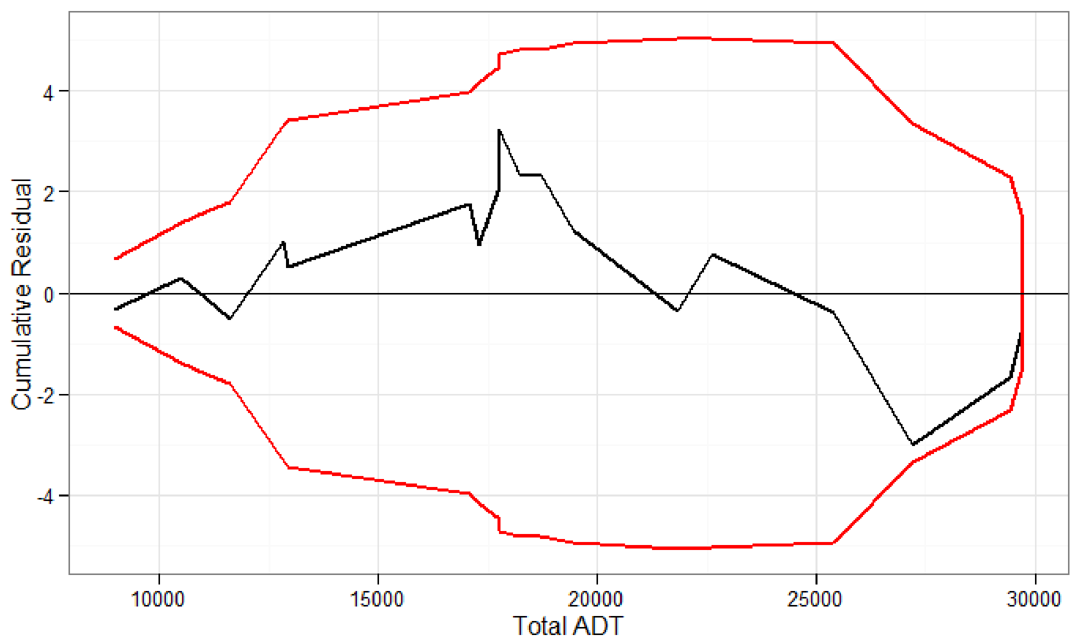


Figure 4.9: CURE Plot for Injury Crash Model (data excludes outlier)

The final Poisson regression model is shown as follows:

$$N_{(5-year)} = e^{[-1.41+(4.0\times10^{-9})(ADT_{total})^{2}]}$$

Where:
N (5-year) = The predicted total number of roundabout crashes that will occur for a similar roundabout during five years, and
ADTtotal = The total entering (major + minor) daily traffic volume, vpd.

To applicable ADT range for total entering vehicles is 8,975 to 29,732 vpd.

The associated annual crash prediction model is:

$$N = \frac{e^{[-1.41+(4.0\times10^{-9})(ADT_{total})^{2}]}}{5}$$

Where:

N = The predicted total annual number of roundabout crashes that will occur for a similar roundabout, and
ADTtotal = The total entering (major + minor) daily traffic volume, vpd.

This model is valid for total entering ADT ranging from 8,975 to 29,732 vpd.

4.4 ROUNDABOUT MODEL APPLICATION

To assess the predicted safety for similar roundabouts, the following procedure can be used. Since this predicted value applies generally to all similar sites, an additional Empirical Bayes (EB) analysis can extend the assessment to site-specific facilities. This additional EB approach is outlined in the HSM, Volume 2 (Part C), Appendix A. An additional enhancement that is recommended as more roundabouts are constructed in Oregon is to develop CMFs for each non-base condition configuration. Currently, there are not enough of these conditions available in Oregon for this extension to the procedure.

This section begins with an overview of the individual steps that should be followed for predicting the number of crashes at a roundabout in Oregon followed by an example application of the technique.

4.4.1 Summary of Steps for Oregon Roundabout Safety Assessment Procedure

Application Note: The following procedure describes how to calculate the **predicted** number of crashes for an Oregon roundabout. The terminology "predicted" is used in a manner consistent with that shown in the HSM and indicates that the procedure calculates an estimated number of crashes for roundabouts with similar conditions at varying traffic volumes. The HSM also uses the term **expected** number of crashes. The use of this term implies that the EB process has been applied so as to weight the predicted number of crashes for a set of site conditions with the observed (historic) crashes at a specific site. As a result, the "expected" number of crashes is location specific. The EB procedure and the associated weighting factors are available in the HSM, Volume 2 (Part C) Appendix A (see page A-19 of the HSM).

Step #1: Check base conditions for the target roundabouts:

- Single lane roundabout,
- Four approach legs,
- Raised central island present,
- Truck apron present,
- No bicycle lane,
- Sidewalk present,
- Splitter island associated with a pedestrian refuge area,
- Lighting system present,
- No bypass lane,
- Center alignment design,
- Circular roundabouts (no ovals),
- Inscribed circle diameter of approximately 135 feet,
- Circulating lane width of approximately 16 to 17 feet, and
- A 15 mph circulating speed limit.

Step #2: Identify the traffic volumes for both the major and the minor streets. Compare traffic volume values to those shown in Table 4.4.

Table 4.4: Valid Traffic Volumes Range for Roundabout SPFs

	Traffic Volume Range (Average Daily Traffic)	
	Minimum (vpd)	**Maximum (vpd)**
Major Street ADT	6,430	19,350
Minor Street ADT	1,400	13,285
Total Entering ADT	8,975	29,732

Step #3: If the base conditions and volume criteria are met, estimate the number of annual total crashes or injury crashes using the roundabout models provided in Table 4.5. Figure 4.10 shows the regression lines for these two models.

Table 4.5: Roundabout Models

Estimate Value	Model	Over Dispersion Parameter
Annual total crashes	$N = \frac{e^{[0.24+(2.7\times10^{-9})(ADT_{total})^{2}]}}{5}$	0.365
Annual total injury crashes	$N = \frac{e^{[-1.41+(4.0\times10^{-9})(ADT_{total})^{2}]}}{5}$	1

Step #4: Report the results in terms of annual total crashes or annual total injury crashes. As previously indicated, these values represent the predicted number of crashes for similar roundabout configurations. To estimate the predicted number of PDO crashes, subtract the number of predicted injury crashes from the total predicted crashes.

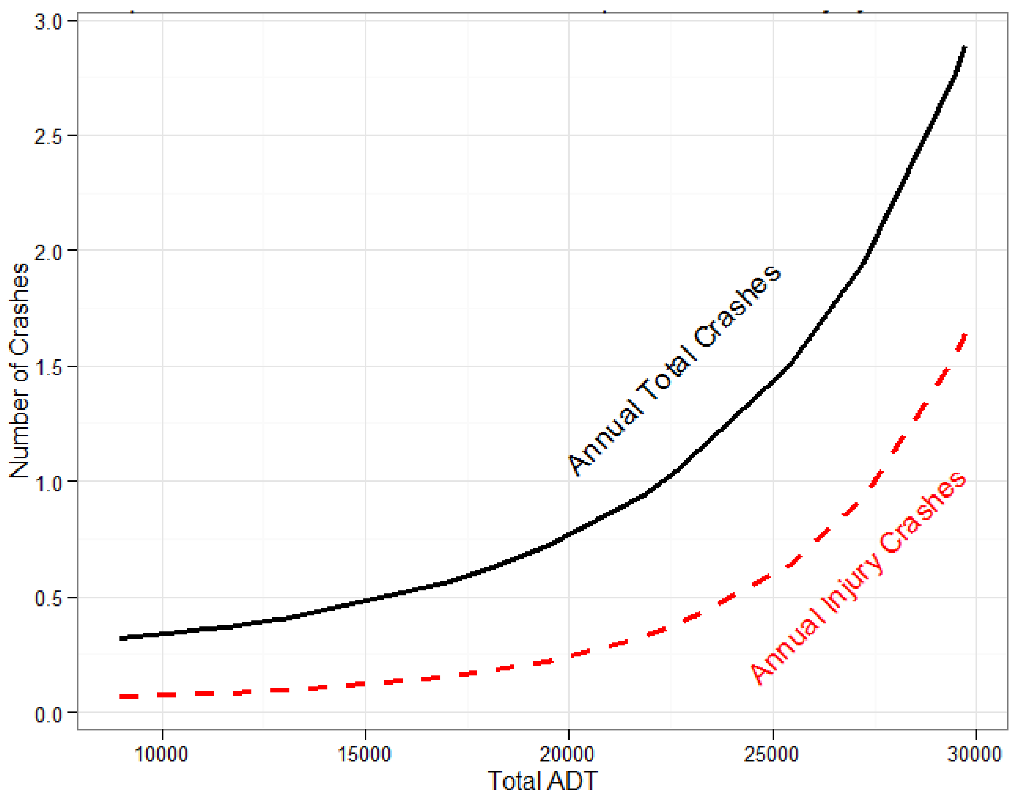


Figure 4.10: Annual Total Crashes and Annual Injury Crashes Regression Lines

4.4.2 Example Application of the Roundabout Models

Given:

An agency wants to evaluate the predicted safety performance for a roundabout with characteristics similar to those summarized in Table 4.6. The year of interest is 2014 so traffic volumes that represent that year should be considered in this analysis.

Table 4.6: Sample Input for Roundabout Safety Assessment

Important Quantitative Feature	Value
Inscribed Circle Diameter	147 ft
Circulating Lane Width	17 ft
Major Traffic Volume (2014)	17,000 vpd
Minor Traffic Volume (2014)	8,200 vpd
Total Entering Volume (2014)	25,200 vpd

Step 1: Check to confirm the roundabout conforms to all baseline conditions. If the site is applicable, proceed to Step 2. If it does not entirely meet base conditions, explore how it differs and determine if it is reasonable representative before proceeding.

Step 2: Check to confirm the traffic volume is within the volume range shown in Table 4.4.
Major traffic volume: 17,000 < 19,350 vpd ← Okay

Minor traffic volume: 8,200 < 13,285 vpd ← Okay

Total entering volume: 25,200 < 29,732 vpd ← Okay

If the total entering volume is not within the volume range, be cautious when using the SPF for an application for which it was not designed.

Step 3: Calculate the predicted number of crashes.

1. Predict the annual total number of crashes based on using the equation from Table 4.5.

$$N_{total} = \frac{e^{[0.84+(1.77\times10^{-9})(ADT_{total})^2]}}{5} = \frac{e^{[0.84+(1.77\times10^{-9})(25,200)^2]}}{5} = 1.42 \text{ crashes per year}$$

2. Predict the annual injury crashes based on using the equation from Table 4.5.

$$N_{injury} = \frac{e^{[-1.41+(4.00\times10^{-9})(ADT_{total})^2]}}{5} = \frac{e^{[-1.41+(4.00\times10^{-9})(25,200)^2]}}{5} = 0.62 \text{ crashes per year}$$

3. Estimate the number of PDO crashes per year by subtracting the number of injury from the total crashes:
$N_{PDO} = N_{total} - N_{injury} = 1.42 - 0.62 = 0.80$ crashes per year

Step 4: Report the results.

A total of 1.42 crashes can be expected to occur at this roundabout site in a one year period. This is equivalent to 7 crashes in a five-year period of which 4 crashes would be property damage only and 3 crashes would be injury related.

4.5 COMPARING ROUNDABOUT AND TRADITIONAL INTERSECTION MODELS

Often a roundabout is recommended as a safer option than a traditional intersection, yet the literature suggests a wide variety of perceived safety expectations based on roundabouts. The project team, therefore, elected to contrast the roundabout models to HSM models as one way of determining relative safety performance.

Since the roundabouts were generally located on lower volume rural or transition regions, the rural two-lane two-way highway can be used for this comparison.

The HSM provides baseline model for two types of rural intersections: stop controlled intersection and signalized intersection. Both of these two models are derived from a negative binomial regression process and are represented as follows:

$$N_{spf4ST} = e^{[-8.56+0.6\ln(AADT_{Major})+0.61\ln(AADT_{minor})]}$$

$$N_{spf4SG} = e^{[-5.13+0.6\ln(AADT_{Major})+0.2\ln(AADT_{minor})]}$$

The variable N_{spf4ST} represents the predicted number of annual total crashes at a stop controlled intersection under baseline conditions. Similarly, N_{spf4SG} represents the predicted number of annual total crashes at a signalized intersection under baseline conditions. The $AADT_{Major}$ and $AADT_{minor}$ variables represent major traffic volume and minor volume, respectively, in units of vehicles per day.

The baseline conditions on which these two models are developed include no skewed intersections, no lighting systems, and no left and right turn lanes. In order to make reasonable comparisons to the roundabout models, the baseline settings should be consistent between these traditional intersection models and the roundabout model.

Since all roundabouts in the data set had street lights, a CMF for the lighting system should be applied (multiplied) to the baseline model for the traditional intersections. The CMF for lighting is shown as follow:

$$CMF_{lighting} = \begin{cases} 4ST: 1 - 0.38 \times 0.244 = 0.90728 \\ 4SG: 1 - 0.38 \times 0.286 = 0.89132 \end{cases}$$

Based on different traffic volume thresholds, the project team calculated the predicted number of annual total crashes for different intersection characteristics under similar baseline conditions. The goal of this calculation was to visualize the difference in trends for the predicted number of crashes for different models so as to see how well roundabouts improve safety performance for an intersection when compared to traditional intersections. As shown in

Figure 4.11, circle dots represent observations of annual total crashes for roundabouts in the data set. Triangles represent the predicted number of annual total crashes for four-leg stop controlled intersections with the same traffic volumes as the corresponding roundabouts. Squares represent the predicted number of annual total crashes for four-leg signalized intersections with the same traffic volumes as the corresponding roundabouts. The regression line represents the predicted trend for number of annual total crashes for roundabouts. As shown in

Figure 4.11, the overall predicted numbers of roundabout crashes are less than the overall predicted numbers of crashes for traditional intersections under similar settings. This figure provides strong evidence that, for highway facilities with ADT values at or below 29,000 vpd, roundabouts can be expected to substantially improve safety performance at intersection locations.

Table 4.7: Total Crash SPFs for Traditional Intersections and Roundabouts

Traditional Intersections	$N_{spf4ST} = CMF_{lighting} \times e^{[-8.86+0.60\ln(AADT_{Major})+0.61\ln(AADT_{minor})]}$	
	$Over\ dispersion = 0.24$	Input Range: $AADT_{Major} = 0 \text{ to } 14{,}700 \text{ vpd}$ $AADT_{minor} = 0 \text{ to } 3{,}500 \text{ vpd}$
	$N_{spf4SG} = CMF_{lighting} \times e^{[-8.13+0.60\ln(AADT_{Major})+0.20\ln(AADT_{minor})]}$	
	$Over\ dispersion = 0.11$	$AADT_{Major} = 0 \text{ to } 25{,}200 \text{ vpd}$ $AADT_{minor} = 0 \text{ to } 12{,}500 \text{ vpd}$
Roundabouts	$N_{roundabout} = \frac{e^{0.24+[(2.7\times10^{-9})(ADT_{total})^{2}]}}{5}$	
	$Over\ dispersion = 0.365$	$AADT_{Total} = 8{,}975 \text{ to } 29{,}732 \text{ vpd}$

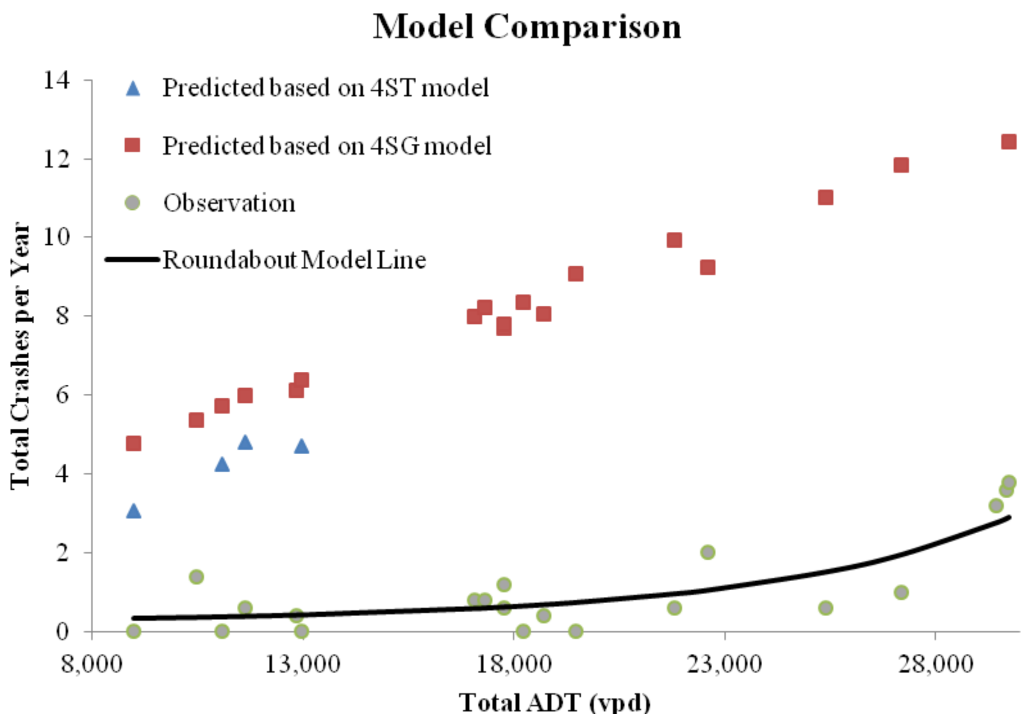


Figure 4.11: Model Comparison between Roundabouts and Traditional Intersections

4.6 SUMMARY MODEL DEVELOPMENT OVERVIEW

The modeling results indicate that the number of crashes has a strong positive relationship with corresponding traffic volumes and the increase in traffic volume will result in the increase for the number of crashes at a roundabout. The project team developed Poisson and negative binomial regression models for total crashes and injury crashes. The final recommended models were then based on the results of AIC index and likelihood ratio test. Model comparison results provide evidence that roundabouts, based on this study, are expected to have fewer crashes than traditional intersections under similar baseline conditions. This section also included an example application of the models developed for this effort.

5.0 SITE IDENTIFICATION AND ANALYSIS OF WASHINGTON ROUNDABOUTS

Due to the relatively small Oregon roundabout sample size for single-lane, four-leg roundabouts, the technical advisory committee (TAC) recommended that the project team explore including similar roundabouts from the neighboring state of Washington. Subsequently, the project team contacted the Washington State Department of Transportation (WSDOT) to determine the availability of roundabout crash data. Staff at the WSDOT indicated that they would extract applicable roundabout crash data and provide when available. Ultimately, the WSDOT staff provided data for 13 of their roundabout sites (see Table 5.1). Appendix E provides summary information for each of these sites (referred to as Site #24 through Site #36).

Unfortunately, only eight of the 13 sites selected by the WSDOT staff adhered to the four-leg configuration as reflected by the shaded lines in Table 5.1. In addition, WSDOT was not able to provide traffic volume information for the study sites so only four of the eight sites include traffic information (obtained from city and county sources). Consequently, Washington information could not be used to enhance the SPF development, so the project team used the Washington data to assess the transferability of the Oregon model to the State of Washington locations.

Table 5.1: Summary of Washington Roundabout Study Sites

Site No.	Site ID	Major Road	Minor Road	County
24	WA-S3-1	N 5th Avenue	Fruitvale Blvd.	Yakima
25	WA-S3-2	SR 903	Bullfrog Rd.	Kittitas
26	WA-S4-3	N Crestline St.	E Lincoln Rd.	Spokane
27	WA-S4-4	SR 206	N Bruce Rd.	Spokane
28	WA-S5-5	US 395	E Hawthorne Ave. / W Glenn Ave.	Stevens
29	WA-S4-6	Borgen Blvd. / 112th St NW	Peacock Hill Ave.	Pierce
30	WA-S4-7	36th St. NW	Point Fosdick Dr. NW	Pierce
31	WA-S4-8	Shoultes Rd.	51st Ave. NE / 108th St. NE	Snohomish
32	WA-S3-9	SR 538 / E College Way	SR 9	Skagit
33	WA-S3-10	Evergreen Pkwy NW	McCann Plaza Dr.	Thurston
34	WA-S4-11	Henderson Blvd. SE	14th Ave. SE	Thurston
35	WA-S4-12	Keene Rd.	Bombing Range Rd.	Benton
36	WA-S4-13	Rainier Rd. SE	SE Balustrade Blvd. / 67th Ave. SE	Thurston

5.1 CONTRASTING OBSERVED CRASHES AT WASHINGTON AND OREGON ROUNDABOUTS

As a first step in assessing the transferability of the Oregon SPFs to similar roundabouts in Washington, Figure 5.1 presents a side-by-side comparison of the total annual crashes per site for Oregon and Washington. The use of the box plots helps to further demonstrate any variations in the overall site data. Assuming similar traffic volume thresholds, Figure 5.1 similarly demonstrates how the total crash model for Oregon appears to be consistent with that observed for Washington.

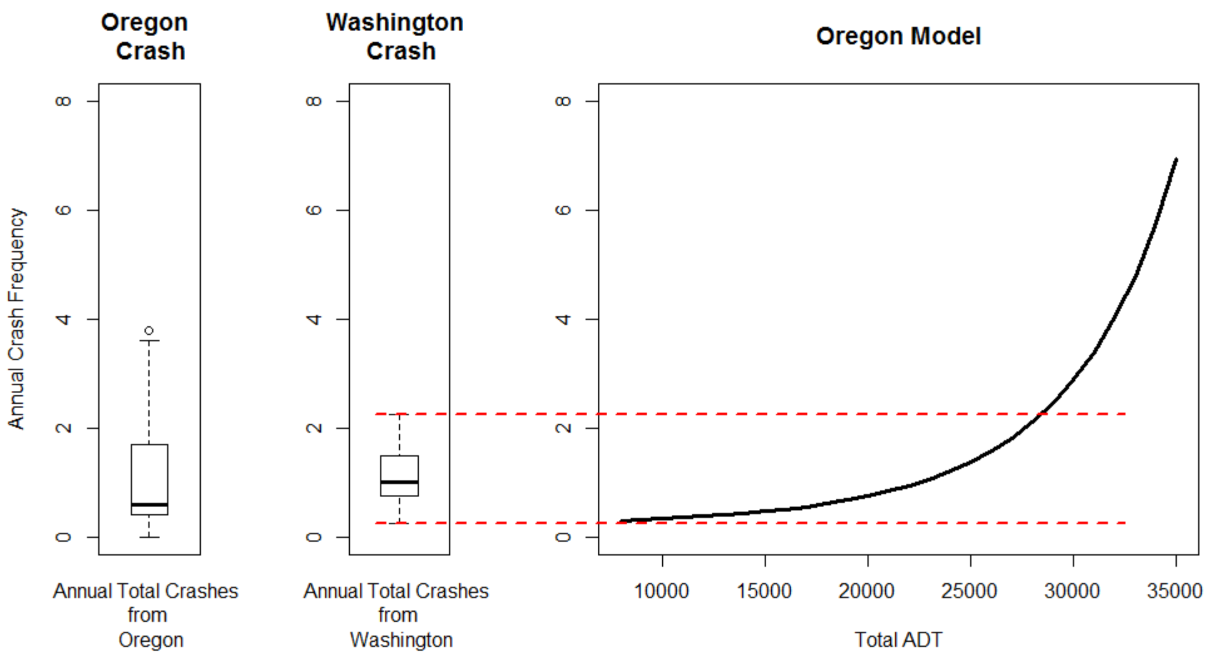


Figure 5.1: Oregon and Washington Data and Model Comparison

The observed annual total crashes at the single lane Washington roundabouts had a range of 0.25 to 2.25 crashes per year, values similar to those observed in Oregon. The larger range of crashes for Oregon (as demonstrated by the extended whiskers for the Oregon box plot) may simply be due to the larger Oregon sample size and potential outliers as represented by points above the end of the box plot whiskers. The thicker line within each box represents the median value while the upper box edge and the lower box edge represent the 75th and the 25th percentile values, respectively. When the median line inside the box is closer to one edge of the box than the other, this means that the data is skewed. The Oregon data appears to have a larger skew then that represented by the Washington crash data. Based on these assessments, the Oregon and Washington data appear to be similar but not quite the same. The median values occur at approximately one crash a year, and the range of crashes for the Washington data fits well within the Oregon model thresholds.

Additional items worth note are the differences in crash data between the two states. Oregon is a self-reporting state with a reporting threshold of $1500 while the State of Washington threshold for reporting a property-damage-only crash is $700. As a result, it is reasonable to expect some differences in the crash levels between states.

Since the total number of annual crashes is generally low, however, and we do not expect to have "partial" crashes, the use of a SPF for relative comparison can be used for fractions of crashes. Ultimately, the estimated number of crashes should be reported as whole numbers. For the Oregon model, the annual total crash SPF equation can be re-written as:

$$5N = e^{0.24 + [(2.7 \times 10^{-9}) \times ADT^2]}$$

This equation can be further reduced by taking the natural log of each side and solving for the ADT value. The resulting equation would then be:

$$ADT = \sqrt{\frac{\ln(5N) - 0.24}{2.7 \times 10^{-9}}}$$

The terms used in both equations are those previously defined. The upper and lower ADT threshold for this equation is 29,732 vpd and 8,975 vpd respectively. Though it may be acceptable to moderately extrapolate values from this equation, the rapidly increasing rate associated with the exponential function would suggest that the use of the model above the maximum observed ADT value should be used with caution. To determine the upper boundary for 1, 2, and 3 crashes per year, insert these values as *N* and solve for ADT. The resulting ADT thresholds are then 22,521 for one crash, 27,639 for two crashes, and 30,234 for three crashes (slightly above the model boundary). The rapidly increasing rate of change in the model is demonstrated, along with these key values, in Table 5.2.

The values shown in Table 5.2 represent the number of predicted crashes (based on the Oregon model), the difference between predicted crashes for every 1000 vpd threshold, and the associated change of rate. The arrows included in the table help to demonstrate how each value has been calculated. The whole number crash values have been included in the table and are shaded so as to depict how the function rapidly begins to increase at the larger ADT values. It is apparent that for the lower volume roundabouts, the number of predicted crashes is expected to be quite low (below 3 to 4 crashes per year). This observation is substantially less than is typically observed for the traditional four-leg intersections with similar traffic volumes.

Table 5.2: Rate of Change for the Oregon Model

Total ADT (vpd)	Predicted Crashes (crashes / year)	Difference in Crashes For 1000 vpd change	Rate of Increase
8,000	0.302	NA	NA
9,000	0.316	0.014	0.046358
10,000	0.333	0.017	0.053797
11,000	0.352	0.019	0.057057
12,000	0.375	0.023	0.065341
13,000	0.401	0.026	0.069333
14,000	0.432	0.031	0.077307
15,000	0.467	0.035	0.081019
16,000	0.508	0.041	0.087794
17,000	0.555	0.047	0.09252
18,000	0.61	0.055	0.099099
19,000	0.674	0.064	0.104918
20,000	0.749	0.075	0.111276
21,000	0.836	0.087	0.116155
22,000	0.939	0.103	0.123206
22,521	1.0	--	--
23,000	1.061	0.122	0.129925
24,000	1.204	0.143	0.134779
25,000	1.374	0.17	0.141196
26,000	1.577	0.203	0.147744
27,000	1.82	0.243	0.15409
27,639	2.0	--	--
28,000	2.111	0.291	0.15989
29,000	2.463	0.352	0.166746
30,000	2.888	0.425	0.172554
30,234	3.0	--	--
31,000	3.405	0.517	0.179017
31,947	4.0	--	--

5.2 CASE STUDIES

This section reviews three of the Washington sites where traffic volume information could be obtained (Sites 26, 30, and 35). Each site is a single-lane, four-leg roundabout with features consistent with those observed for the Oregon roundabouts. The project team used the Oregon model for total crashes and directly applied it to the Washington locations. Of course, calibration of models is recommended when using for locally applicable sites; however, due to the small sample size available for Washington as well as the slow rate of change for lower volume sites, the project team elected to use the SPF directly at the Washington sites. In addition, the HSM includes techniques to estimate both the predicted and the expected number of crashes for a given site. Though these words are sometimes mistakenly used interchangeably, they have a very distinct definition in the HSM. Crashes that are estimated through the use of a SPF and that represent the average number of crashes for a type of facility are referred to as predicted crashes. Estimated crashes that are site-specific and developed using the Empirical Bayes method of weighting the observed and predicted crashes are identified as expected crashes. Table 5.3 shows the predicted and the expected crashes for the three Washington sites. If a location has observed crashes that are greater than the expected crashes, this site may be in need of a safety treatment. Of course, as noted in this case study assessment, the resulting predicted and expected crashes are quite low, so this case study comparison has been included as a way of demonstrating that the Oregon SPF can be reasonably transferred to Washington locations.

Table 5.3: Case Studies for Three Washington Roundabout Sites

Site	Year	ADT (vpd)	5-Year Predicted Crashes	1-Year Predicted Crashes	Observed Crashes Per Year	EB Weighting Factor	1-Year Expected Crashes
26	2006	8,300	1.53	0.31	1		
	2007	9,735	1.64	0.33	2		
	2008	11,170	1.78	0.36	4		
	2009	12,600	1.95	0.39	1		
			Total:	1.38	8	0.66	3.60
30	2006	12,350	1.92	0.38	0		
	2007	11,065	1.77	0.35	1		
	2008	9,775	1.65	0.33	1		
			Total:	1.07	2	0.72	1.33
35	2005	6,500	1.42	0.28	0		
	2006	6,570	1.43	0.29	0		
	2007	6,631	1.43	0.29	3		
			Total:	0.86	3	0.75	1.37

If the predicted and expected crashes are rounded to whole numbers, and partial crashes are always rounded up, the values in Table 5.3 can be re-organized and summarized as shown in Table 5.4. For the three case study locations, the expected number of crashes for Sites 30 and 35 closely matched the observed (historic) crashes at these sites. For Site 26, the number of observed crashes for the study period was twice that of the expected. This difference may be an indication that a site inspection and detailed crash analysis is appropriate for this location. By inspection of the crash data, five of the eight crashes observed at this particular site were in some way linked to the entry of the vehicle into the roundabout. This could be due to sunlight glare or geometric characteristics unique to this site. The purpose of this case study example is not to diagnose potential issues associated with this particular roundabout, but rather to demonstrate one way the SPFs, complimented with EB analysis, can then be used to identify sites that may merit additional consideration.

Table 5.4: Summary of the Three Washington Case Studies

Site	Predicted (Rounded) Crashes for Study Period	Expected (Rounded) Crashes for Study Period	Observed Crashes for Study Period
26	2	4	8
30	2	2	2
35	1	2	3

5.3 SUMMARY OF THE WASHINGTON APPLICATION OVERVIEW

The initial goal of including data from the State of Washington was to increase the sample size and ultimately develop a more robust model for the States of Oregon and Washington. Though the limited Washington data that was provided did not enable this type of assessment, the project team was able to determine if safety associated with the Washington roundabouts generally conformed to that observed for Oregon roundabouts. Since the findings were similar, this chapter then also included three example case studies to demonstrate how the SPFs, expanded to site-specific applications using the EB analysis, could be used to further evaluate unique roundabout safety characteristics.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This research effort used cross-sectional modeling to develop a statistical model that represents the predicted number of crashes at an Oregon roundabout. The initial expectations of the project team were that geometric features such as the width of the circulating lane or the radius of the inscribed circle would appear as variables in the crash prediction model; however, these geometric features ultimately were not statistically significant for the Oregon sites. It is likely that the similarity of the Oregon roundabouts contributed to this finding as this would reduce variability of the geometric features in the data set. Section 4.0 of this report, accompanied by Appendix D, summarizes the final crash prediction models for Oregon single-lane, four-leg roundabouts. Table 4.4 identifies the applicable traffic volume ranges and Table 4.5 defines the resulting SPFs. Step-by-step instructions for applying these SPFs are provided in Section 4.4.

As a way of comparing roundabouts to traditional intersections, the project team contrasted the roundabout SPFs to the HSM crash prediction SPFs for rural four-leg STOP-controlled and rural four-leg signalized-control traditional intersections (see

Figure 4.11). This figure clearly demonstrates that the predicted number of crashes is substantially lower for roundabouts than for traditional intersections with the same total entering ADT. Since the SPF for total crashes, as depicted in this figure, has an exponential form, it is feasible to expect that an increase in exposure may ultimately result in the roundabout SPF converging on the traditional intersection SPF. For the sites studied, however, the safety benefits of the roundabouts are dramatic.

An extension of the Oregon roundabout SPFs to Washington sites (see Chapter 5.0) further demonstrates that the Oregon single-lane, four-leg roundabout SPFs are reasonably transferable to similar sites in the State of Washington.

In conclusion, the project team would recommend that it is suitable to construct roundabouts in places that have low and moderate traffic exposure levels (less than 30,000 vpd). Caution should be exercised when constructing single-lane roundabouts in conjunction with high traffic volume locations as these configurations were not included in this study and the SPF shape would indicate that as exposure increases, the expected safety benefits may diminish.

The TAC selected the single-lane, four-leg roundabout intersection configurations studied for this research effort because these were the most common roundabouts constructed in Oregon. Future research efforts could compare the resulting SPFs for Oregon to those of other states. In addition, as roundabouts become more common, SPFs for alternative roundabout configurations such as three- or five-leg, as well as partial- or multiple-lane configurations should be developed.

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APPENDIX A:
ABBREVIATIONS AND ACRONYM DEFINITIONS

Abbreviations and Acronym Definitions

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
CMF	Crash Modification Factor (or Function)
CURE	Cumulative Residual
EB	Empirical Bayes
HSM	Highway Safety Manual
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
SPF	Safety Performance Function
TAC	Technical Advisory Committee

APPENDIX B:
SUMMARY OF OREGON ROUNDABOUT INVENTORY DATA

Geometric Inventory Data

Site Number	Site ID	Raised Central Island	Truck Apron	Sidewalk	Pedestrian Refuge Area	Lighting
1	OR-S4-1	X	X	X	X	X
2	OR-S4-2	X	X	X	X	X
3	OR-S4-3	X	X	X	X	X
4	OR-S4-4	X	X	X	X	X
5	OR-S4-5	X	X	X	X	X
6	OR-S4-6	X	X	X	X	X
7	OR-S4-7	X	X	X	X	X
8	OR-S4-8	X	X	X	X	X
9	OR-S4-9	X	X	X	X	X
10	OR-S4-10	X	X	X	X	X
11	OR-S4-11	X	X	X	X	X
12	OR-S4-12	X	X	X	X	X
13	OR-S4-13	X	X	X	X	X
14	OR-S4-14	X	X	X	X	X
15	OR-S4-15	X	X	X	X	X
16	OR-S4-16	X	X	X	X	X
17	OR-S4-17	X	X	X	X	X
18	OR-S4-18	X	X	X	X	X
19	OR-S4-19	X	X	X	X	X
20	OR-S4-20	X	X	X	X	X
21	OR-S4-21	X		X		X
22	OR-S4-22	X	X	X	X	X
23	OR-S4-23	X	X	X	X	X

Projected Traffic Volume Information for Each Approach Leg

Site No.	Site ID	Street Name	Location of Leg	Volume Type	AADT/ADT (vpd)
1	OR-S4-1	SE Stevens Rd.	N	ADT	6,250
		Monterey Ave.	E	ADT	1,400
		SE Stevens Rd.	S	ADT	7,575
		Monterey Ave.	W	ADT	412
2	OR-S4-2	SW Century Dr.	N	ADT	8,982
		SW Colorado Ave.	E	ADT	9,730
		SW Century Dr.	S	ADT	8,654
		SW Colorado Ave.	W	ADT	6,325
3	OR-S4-3	Mt. Washington Dr.	N	ADT	9,088
		Skyliners Rd.	E	ADT	2,272
		Mt. Washington Dr.	S	ADT	9,215
		Skyliners Rd.	W	ADT	2,395
4	OR-S4-4	Mt. Washington Dr.	N	ADT	5,379
		NW Shevlin Park Rd.	E	ADT	7,160
		Mt. Washington Dr.	S	ADT	7,150
		NW Shevlin Park Rd.	W	ADT	5,675
5	OR-S4-5	Mt. Washington Dr.	N	ADT	7,150
		NW Crossing Dr.	E	ADT	843
		Mt. Washington Dr.	S	ADT	9,088
		NW Crossing Dr.	W	ADT	1,992
6	OR-S4-6	SW Century Dr.	N	ADT	8,654
		SE Reed Market Rd.	E	ADT	10,837
		SW Century Dr.	S	ADT	8,054
		Mt. Washington Dr.	W	ADT	6,628
7	OR-S4-7	SW 14th St.	N	ADT	16,402
		SW Simpson Ave.	E	ADT	10,604
		SW Century Dr.	S	ADT	8,982
		SW Simpson Ave.	W	ADT	3,908
8	OR-S4-8	NW 14th St.	N	ADT	13,285
		NW Galveston Ave.	E	ADT	16,402
		NW 14th St.	S	ADT	13,261
		NW Galveston Ave.	W	ADT	4,980
9	OR-S4-9	NW 14th St.	N	ADT	215
		NW Newport Ave.	E	ADT	13,410
		NW 14th St.	S	ADT	13,156
		NW Newport Ave.	W	ADT	16,283

Projected Traffic Volume Information for Each Approach Leg (continued)

Site No.	Site ID	Street Name	Location of Leg	Volume Type	AADT/ADT (vpd)
10	OR-S4-10	NW 9th St.	N	ADT	7,850
		NW Newport Ave.	E	ADT	16,014
		NW Nashville Ave.	S	ADT	--
		NW Newport Ave.	W	ADT	19,350
11	OR-S4-11	SW Terwilliger Blvd.	N	ADT	12,125
		Parking lot entry	E	ADT	5,863
		SW Terwilliger Blvd.	S	ADT	5,174
		SW Palater Rd.	W	ADT	3,611
12	OR-S4-12	Carman Dr.	N	ADT	9,150
		Quarry Rd.	E	ADT	4,885
		Carman Dr.	S	ADT	8,790
		Meadows Rd.	W	ADT	8,602
13	OR-S4-13	SW Colorado Ave.	N	ADT	15,869
		SW Simpson Ave.	E	ADT	1,673
		SW Colorado Ave.	S	ADT	5,949
		SW Simpson Ave.	W	ADT	9,625
14	OR-S4-14	NE 8th St.	N	ADT	11,266
		NE Franklin Ave.	E	ADT	9,077
		NE 8th St.	S	ADT	11,412
		NE Franklin Ave.	W	ADT	11,201
15	OR-S4-15	SW Bond St.	N	ADT	11,041
		SW Reed Mkt. Rd.	E	ADT	18,748
		Brookswood Blvd.	S	ADT	10,984
		SW Reed Mkt. Rd.	W	ADT	10,837
16	OR-S4-16	Century Dr.	N	ADT	6,233
		SW Reed Mkt. Rd.	E	ADT	10,837
		Century Dr.	S	ADT	3,800
		SW Reed Mkt. Rd.	W	ADT	10,837
17	OR-S4-17	58th St.	N	ADT	6,430
		Thurston Rd.	E	ADT	5,863
		58th St.	S	ADT	4,045
		Thurston Rd.	W	ADT	--
18	OR-S4-18	SW Stafford Rd.	N	ADT	10,570
		Rosemont Rd.	E	ADT	6,914
		SW Stafford Rd.	S	ADT	11,305
		Atherton Dr.	W	ADT	333

Projected Traffic Volume Information for Each Approach Leg (continued)

Site No.	Site ID	Street Name	Location of Leg	Volume Type	AADT/ADT (vpd)
19	OR-S4-19	NW Marsh Rd.	N	ADT	204
		NW Verboort Rd.	E	ADT	14,488
		NW Martin Rd.	S	ADT	6,333
		NW Verboort Rd.	W	ADT	4,982
20	OR-S4-20	SE 15th St.	N	ADT	8,859
		NE Bear Crk. Rd.	E	ADT	8,281
		SE 15th St.	S	ADT	9,487
		NE Bear Crk. Rd.	W	ADT	4,922
21	OR-S4-21	SW Juniper Terr.	N	ADT	1,525
		SW Hart Rd.	E	ADT	6,846
		SW Hart Rd.	S	ADT	6,846
		SW Sorrento Rd.	W	ADT	1,000
22	OR-S4-22	Highland Dr.	N	ADT	6,595
		Siskiyou Blvd.	E	ADT	5,268
		Highland Dr.	S	ADT	9,288
		Siskiyou Blvd.	W	ADT	7,537
23	OR-S4-23	SW Roshak Rd.	N	ADT	1,531
		SW Barrows Rd.	E	ADT	11,006
		SW Roshak Rd.	S	ADT	1,946
		SW Barrows Rd.	W	ADT	11,006

Projected Traffic Volume Data used for Modeling

Site Number	Site ID	Major ADT (vpd)	Minor ADT (vpd)	Total ADT (vpd)
1	OR-S4-1	7,575	1,400	8,975
2	OR-S4-2	9,730	8,982	18,712
3	OR-S4-3	9,215	2,395	11,610
4	OR-S4-4	7,160	5,675	12,835
5	OR-S4-5	9,088	1,992	11,080
6	OR-S4-6	10,837	8,054	18,891
7	OR-S4-7	16,402	8,982	25,384
8	OR-S4-8	16,402	13,285	29,687
9	OR-S4-9	16,283	13,156	29,439
10	OR-S4-10	19,350	7,850	27,200
11	OR-S4-11	12,125	5,174	17,299
12	OR-S4-12	9,150	8,602	17,752
13	OR-S4-13	15,869	5,949	21,818
14	OR-S4-14	11,412	11,201	22,613
15	OR-S4-15	18,748	10,984	29,732
16	OR-S4-16	10,837	6,233	17,070
17	OR-S4-17	6,430	4,045	10,475
18	OR-S4-18	11,305	6,914	18,219
19	OR-S4-19	14,488	4,982	19,470
20	OR-S4-20	9,487	8,281	17,768
21	OR-S4-21	6,846	1,525	8,371
22	OR-S4-22	9,288	6,595	15,883
23	OR-S4-23	11,006	1,946	12,952

Crash Summary per Oregon Site

Site Number	Site ID	Crashes (2007 - 2011)			
		Fatal	Injury	PDO	Total
1	OR-S4-1	0	0	0	0
2	OR-S4-2	0	1	1	2
3	OR-S4-3	0	0	3	3
4	OR-S4-4	0	2	0	2
5	OR-S4-5	0	0	0	0
6	OR-S4-6	0	6	6	12
7	OR-S4-7	0	2	1	3
8	OR-S4-8	0	9	9	18
9	OR-S4-9	0	9	7	16
10	OR-S4-10	0	2	3	5
11	OR-S4-11	0	0	4	4
12	OR-S4-12	0	2	1	3
13	OR-S4-13	0	0	3	3
14	OR-S4-14	0	3	7	10
15	OR-S4-15	0	9	10	19
16	OR-S4-16	0	2	2	4
17	OR-S4-17	0	1	6	7
18	OR-S4-18	0	0	0	0
19	OR-S4-19	0	0	0	0
20	OR-S4-20	0	2	4	6
21	OR-S4-21	0	0	2	2
22	OR-S4-22	0	2	10	12
23	OR-S4-23	0	0	0	0
	Total:	0	52	79	131

APPENDIX C:
INDIVIDUAL SITE SUMMARIES

SITE #1: Monterey Ave. at SE Stevens Rd., Clackamas County [OR-S4-1]

Source: Google Maps

Basic Information			
Intersecting Approaches		Monterey Ave.	
		SE Stevens Rd.	
County		Clackamas	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2006	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	140	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	5
Central Island Diameter (ft)	100	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	19	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	6	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #1: Monterey Ave. at SE Stevens Rd., Clackamas County [OR-S4-1] (continued)

Traffic Volume Information (2012)

Street	Location of Leg	Direction	Volume Type	AADT/ADT
SE Stevens Rd.	N	Both	ADT	6,250
Monterey Ave.	E	Both	ADT	1,400
SE Stevens Rd.	S	Both	ADT	7,575
Monterey Ave.	W	Both	ADT	412

Major ADT	7,575
Minor ADT	1,400
Total ADT	8,975

Crash Distribution by Severity Level and Collision Type (2007-2011)

Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	0	0

Crash Distribution by Year

Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
Total Crashes (2007-2011)	0	0	0

SITE #2: SW Century Dr. at SW Colorado Ave., Deschutes County [OR-S4-2]

Source: Google Maps

Basic Information			
Intersecting Approaches		SW Century Dr. SW Colorado Ave.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		1999	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	183	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	9
Central Island Diameter (ft)	150	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	16	Minimum Angle between Legs (degrees)	66
Bicycle Lane/Path Width (ft)	10	Number of Crosswalks	4
Sidewalk Width (ft)	10	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #2: SW Century Dr. at SW Colorado Ave., Deschutes County [OR-S4-2] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Century Dr.	N	Both	ADT	8,982
SW Colorado Ave.	E	Both	ADT	9,730
SW Century Dr.	S	Both	ADT	8,654
SW Colorado Ave.	W	Both	ADT	6,325

Major ADT	9,730
Minor ADT	8,982
Total ADT	18,712

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	1	1
Fix Object or Other Object	1	0	1
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	1	1	2

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	1	0	1
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	1	1
Total Crashes (2007-2011)	1	1	2

SITE #3: Mt. Washington Dr. at Skyliners Rd., Deschutes County [OR-S4-3]

Source: Google Maps

Basic Information			
Intersecting Approaches		Mt. Washington Dr.	
		Skyliners Rd.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2005	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	132	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	7
Central Island Diameter (ft)	98	Entry Alignment	Center
Truck Apron Width (ft)	18	Offset Alignment	0
Minimum Lane Width (ft)	19	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	11	Number of Crosswalks	4
Sidewalk Width (ft)	11	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	0		

SITE #3: Mt. Washington Dr. at Skyliners Rd., Deschutes County [OR-S4-3] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
Mt. Washington Dr.	N	Both	ADT	9,088
Skyliners Rd.	E	Both	ADT	2,272
Mt. Washington Dr.	S	Both	ADT	9,215
Skyliners Rd.	W	Both	ADT	2,395
Major ADT		9,215		
Minor ADT		2,395		
Total ADT		11,610		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	1	1
Fix Object or Other Object	0	1	1
Rear-end Collision	0	1	1
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	3	3

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	1	1
2009	0	0	0
2010	0	2	2
2011	0	0	0
Total Crashes (2007-2011)	0	3	3

SITE #4: Mt. Washington Dr. at NW Shevlin Park Rd., Deschutes County [OR-S4-4]

Source: Google Maps

Basic Information			
Intersecting Approaches		Mt. Washington Dr.	
		NW Shevlin Park Rd.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2000	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	127	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	8
Central Island Diameter (ft)	106	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	10	Minimum Angle between Legs (degrees)	75
Bicycle Lane/Path Width (ft)	6	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #4: Mt. Washington Dr. at NW Shevlin Park Rd., Deschutes County [OR-S4-4] (continued)

Traffic Volume Information (2012)

Street	Location of Leg	Direction	Volume Type	AADT/ADT
Mt. Washington Dr.	N	Both	ADT	5,379
NW Shevlin Park Rd.	E	Both	ADT	7,160
Mt. Washington Dr.	S	Both	ADT	7,150
NW Shevlin Park Rd.	W	Both	ADT	5,675

Major ADT	7,160
Minor ADT	5,675
Total ADT	12,835

Crash Distribution by Severity Level and Collision Type (2007-2011)

Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	2	0	2
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	2	0	2

Crash Distribution by Year

Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	1	0	1
2011	1	0	1
Total Crashes (2007-2011)	2	0	2

SITE #5: Mt. Washington Dr. at NW Crossing Dr., Deschutes County [OR-S4-5]

Source: Google Maps

Basic Information			
Intersecting Approaches		Mt. Washington Dr.	
		NW Crossing Dr.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2000	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	120	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	22
Central Island Diameter (ft)	80	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	20	Minimum Angle between Legs (degrees)	77
Bicycle Lane/Path Width (ft)	13	Number of Crosswalks	4
Sidewalk Width (ft)	13	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #5: Mt. Washington Dr. at NW Crossing Dr., Deschutes County [OR-S4-5] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
Mt. Washington Dr.	N	Both	ADT	7,150
NW Crossing Dr.	E	Both	ADT	843
Mt. Washington Dr.	S	Both	ADT	9,088
NW Crossing Dr.	W	Both	ADT	1,992

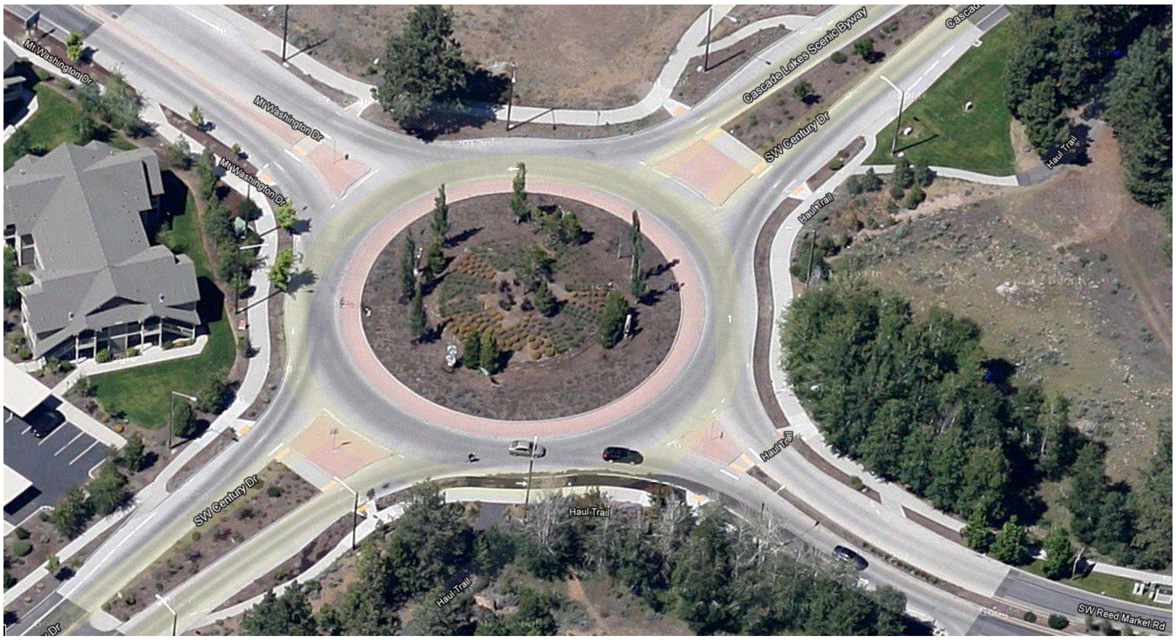
Major ADT	9,088
Minor ADT	1,992
Total ADT	11,080

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	0	0

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
Total Crashes (2007-2011)	0	0	0

NOTES: Unusual sidewalk design directs pedestrians and cyclists far away from circulation lane, thereby improving safety.

SITE #6: SW Century Dr. at Mt. Washington Dr. / SW Reed Market Rd., Deschutes County [OR-S4-6]



Source: Google Maps

Basic Information			
Intersecting Approaches		SW Century Dr.	
		Mt. Washington Dr. / SW Reed Market Rd.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2001	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	190	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	7
Central Island Diameter (ft)	150	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	20	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	9	Number of Crosswalks	4
Sidewalk Width (ft)	9	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	0		

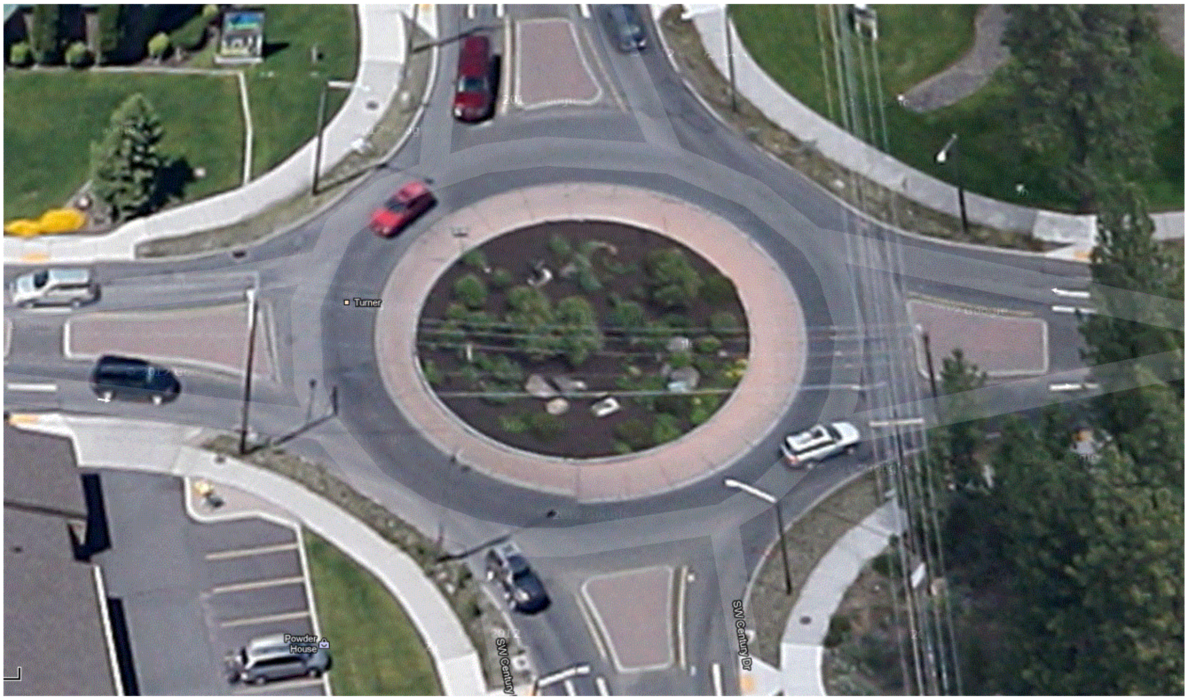
SITE #6: SW Century Dr. at Mt. Washington Dr. / SW Reed Market Rd., Deschutes County [OR-S4-6] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Century Dr.	N	Both	ADT	8,654
SE Reed Market Rd.	E	Both	ADT	10,837
SW Century Dr.	S	Both	ADT	8,054
Mt. Washington Dr.	W	Both	ADT	6,628
Major ADT		10,837		
Minor ADT		8,054		
Total ADT		18,891		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	1	1
Fix Object or Other Object	0	0	0
Rear-end Collision	5	1	6
Miscellaneous	1	0	1
Turning Movement	0	3	3
Sideswipe - Meeting	0	1	1
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	6	6	12

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	2	1	3
2008	1	4	5
2009	1	0	1
2010	2	1	3
2011	0	0	0
Total Crashes (2007-2011)	6	6	12

SITE #7: SW Century Dr. / SW 14th St. at SW Simpson Ave., Deschutes County [OR-S4-7]



Source: Google Maps

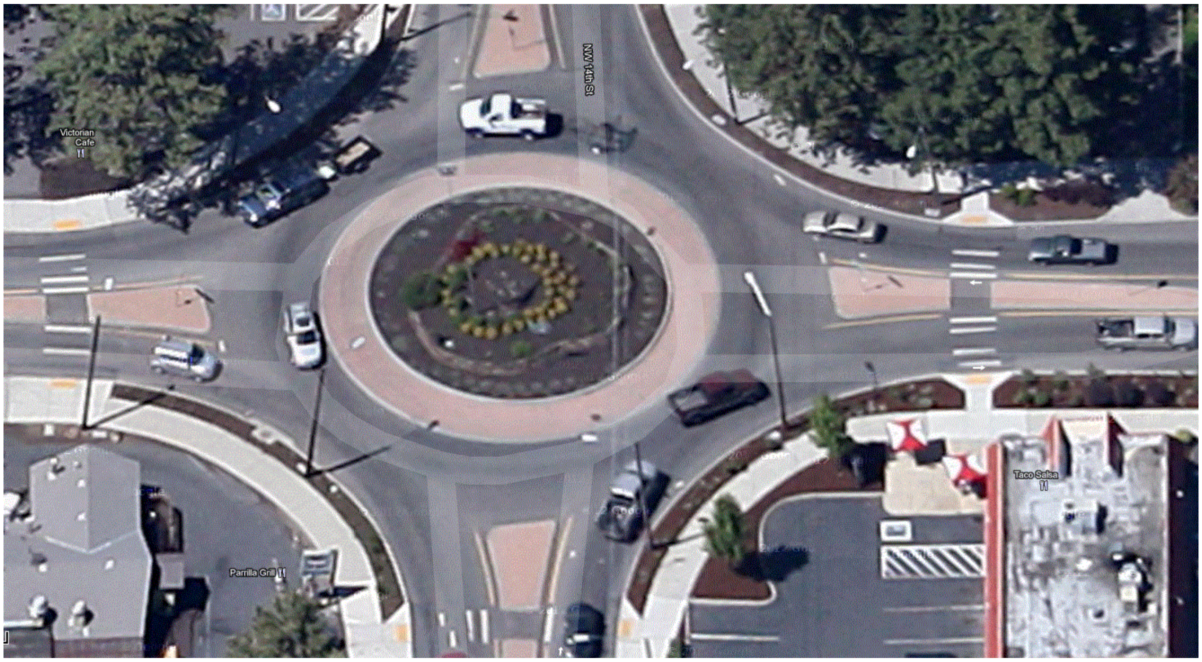
Basic Information			
Intersecting Approaches		SW Century Dr. / SW 14th St.	
		SW Simpson Ave.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2002	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	116	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	8
Central Island Diameter (ft)	85	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	15	Minimum Angle between Legs (degrees)	85
Bicycle Lane/Path Width (ft)	8	Number of Crosswalks	4
Sidewalk Width (ft)	8	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #7: SW Century Dr. / SW 14th St. at SW Simpson Ave., Deschutes County [OR-S4-7] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW 14th St.	N	Both	ADT	16,402
SW Simpson Ave.	E	Both	ADT	10,604
SW Century Dr.	S	Both	ADT	8,982
SW Simpson Ave.	W	Both	ADT	3,908
Major ADT		16,402		
Minor ADT		8,982		
Total ADT		25,384		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	2	1	3
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	2	1	3
Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	1	0	1
2011	1	1	2
Total Crashes (2007-2011)	2	1	3

SITE #8: NW 14th St. at NW Galveston Ave., Deschutes County [OR-S4-8]



Source: Google Maps

Basic Information			
Intersecting Approaches		NW 14th St.	
		NW Galveston Ave.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2002	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	120	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	4
Central Island Diameter (ft)	80	Entry Alignment	Center
Truck Apron Width (ft)	12	Offset Alignment	0
Minimum Lane Width (ft)	20	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	10	Number of Crosswalks	4
Sidewalk Width (ft)	10	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

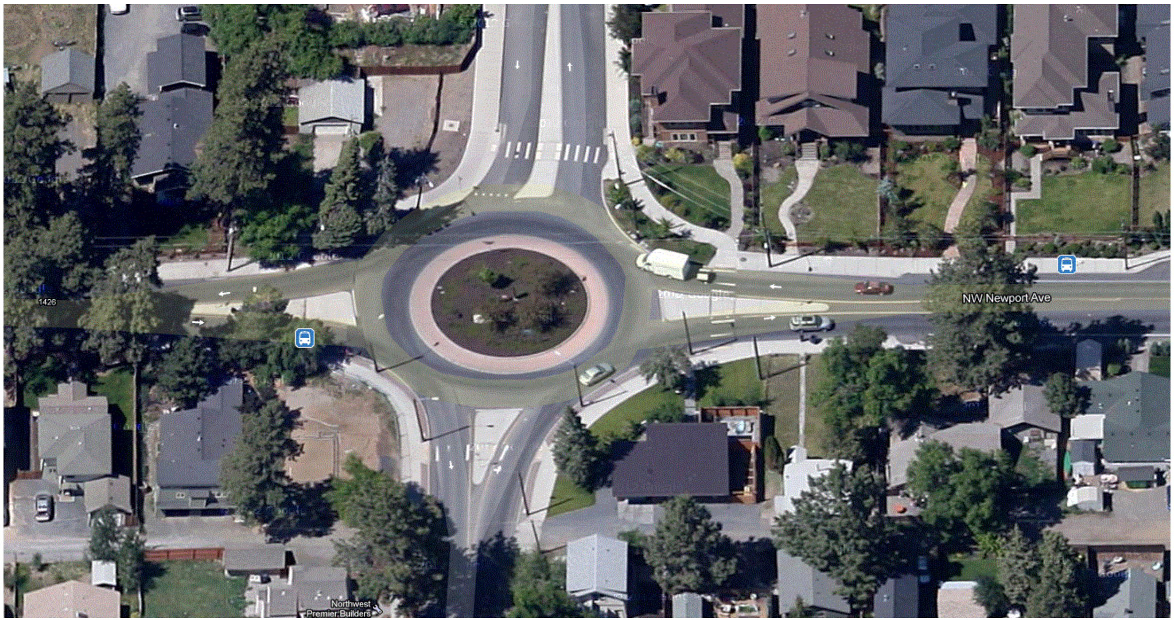
SITE #8: NW 14th St. at NW Galveston Ave., Deschutes County [OR-S4-8] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
NW 14th St.	N	Both	ADT	13,285
NW Galveston Ave.	E	Both	ADT	16,402
NW 14th St.	S	Both	ADT	13,261
NW Galveston Ave.	W	Both	ADT	4,980
Major ADT	16,402			
Minor ADT	13,285			
Total ADT	29,687			

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	1	1	2
Fix Object or Other Object	1	0	1
Rear-end Collision	5	8	13
Miscellaneous	0	0	0
Turning Movement	2	0	2
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	9	9	18

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	3	0	3
2008	1	3	4
2009	0	1	1
2010	1	3	4
2011	4	2	6
Total Crashes (2007-2011)	9	9	18

SITE #9: NW 14th St. at NW Newport Ave., Deschutes County [OR-S4-9]



Source: Google Maps

Basic Information	
Intersecting Approaches	NW 14th St.
	NW Newport Ave.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

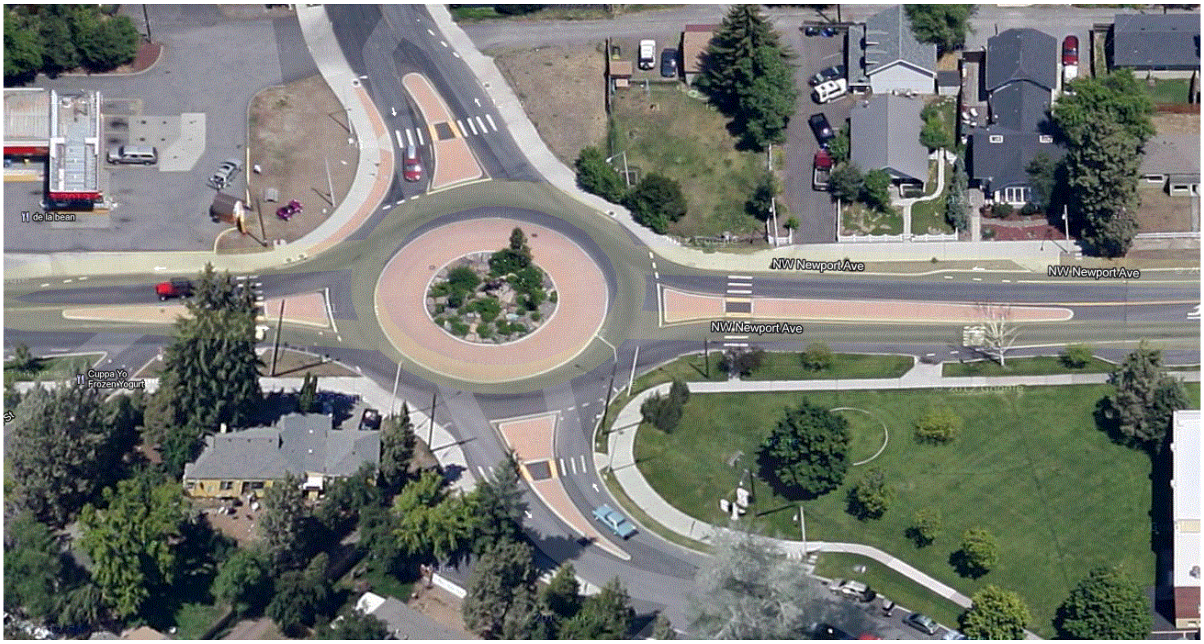
Geometric Design Information			
Inscribed Circle Diameter (ft)	115	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	4
Central Island Diameter (ft)	80	Entry Alignment	Center
Truck Apron Width (ft)	9	Offset Alignment	0
Minimum Lane Width (ft)	15	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	8	Number of Crosswalks	3
Sidewalk Width (ft)	8	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #9: NW 14th St. at NW Newport Ave., Deschutes County [OR-S4-9] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
NW 14th St.	N	Both	ADT	215
NW Newport Ave.	E	Both	ADT	13,410
NW 14th St.	S	Both	ADT	13,156
NW Newport Ave.	W	Both	ADT	16,283
Major ADT		16,283		
Minor ADT		13,156		
Total ADT		29,439		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	2	1	3
Fix Object or Other Object	0	0	0
Rear-end Collision	5	6	11
Miscellaneous	0	0	0
Turning Movement	1	0	1
Sideswipe - Meeting	0	0	0
Backing Movement	1	0	1
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	9	7	16
Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	3	3
2008	5	0	5
2009	1	1	2
2010	0	3	3
2011	3	0	3
Total Crashes (2007-2011)	9	7	16

SITE #10: NW Newport Ave. at NW Nashville Ave. / NW 9th St., Deschutes County [OR-S4-10]



Source: Google Maps

Basic Information			
Intersecting Approaches		NW Newport Ave.	
		NW Nashville Ave. / NW 9th St.	
County		Deschutes	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2005	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		
Geometric Design Information			
Inscribed Circle Diameter (ft)	127	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	5
Central Island Diameter (ft)	90	Entry Alignment	Center
Truck Apron Width (ft)	20	Offset Alignment	0
Minimum Lane Width (ft)	18	Minimum Angle between Legs (degrees)	76
Bicycle Lane/Path Width (ft)	9	Number of Crosswalks	4
Sidewalk Width (ft)	9	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #10: NW Newport Ave. at NW Nashville Ave. / NW 9th St., Deschutes County [OR-S4-10] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
NW 9th St.	N	Both	ADT	7,850
NW Newport Ave.	E	Both	ADT	16,014
NW Nashville Ave.	S	Both	ADT	--
NW Newport Ave.	W	Both	ADT	19,350

Major ADT	19,350
Minor ADT	7,850
Total ADT	27,200

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	2	2	4
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	1	1
Total Crashes (2007-2011)	2	3	5

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	1	0	1
2008	0	2	2
2009	0	1	1
2010	0	0	0
2011	1	0	1
Total Crashes (2007-2011)	2	3	5

SITE #11: SW Terwilliger Blvd. at SW Palater Rd., Multnomah County [OR-S4-11]

Source: Google Maps

Basic Information			
Intersecting Approaches		SW Terwilliger Blvd.	
		SW Palater Rd.	
County		Multnomah	
State		OR	
Type		Single	
Number of Legs		4	
Year of Completion		2002	
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		
Geometric Design Information			
Inscribed Circle Diameter (ft)	121	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	88	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	15	Minimum Angle between Legs (degrees)	74
Bicycle Lane/Path Width (ft)	7	Number of Crosswalks	4
Sidewalk Width (ft)	7	Number of Approach Curves	4
Number of Approach with Bypass for Right Turn	0		

SITE #11: SW Terwilliger Blvd. at SW Palater Rd., Multnomah County [OR-S4-11] (continued)

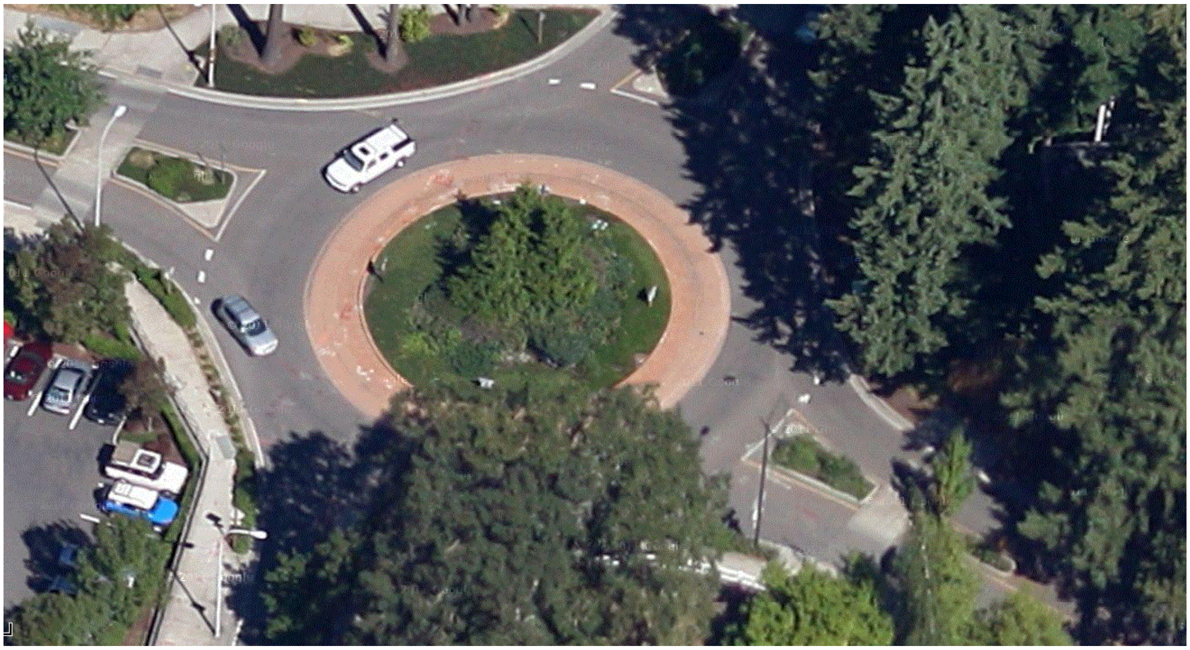
Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Terwilliger Blvd.	N	Both	ADT	12,125
Parking lot entry	E	Both	ADT	5,863
SW Terwilliger Blvd.	S	Both	ADT	5,174
SW Palater Rd.	W	Both	ADT	3,611
Major ADT	12,125			
Minor ADT	5,174			
Total ADT	17,299			

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	0	4	4
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	4	4

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	1	1
2008	0	1	1
2009	0	1	1
2010	0	1	1
2011	0	0	0
Total Crashes (2007-2011)	0	4	4

NOTES: Southwest approach is an exit from a parking lot.

SITE #12: Carman Dr. at Meadows Rd. / Quarry Rd., Clackamas County [OR-S4-12]



Source: Google Maps

Basic Information	
Intersecting Approaches	Carman Dr.
	Meadows Rd./Quarry Rd.
County	Clackamas
State	OR
Type	Single
Number of Legs	4
Year of Completion	2003

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	120	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	4
Central Island Diameter (ft)	81	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	16	Minimum Angle between Legs (degrees)	76
Bicycle Lane/Path Width (ft)	7	Number of Crosswalks	4
Sidewalk Width (ft)	7	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

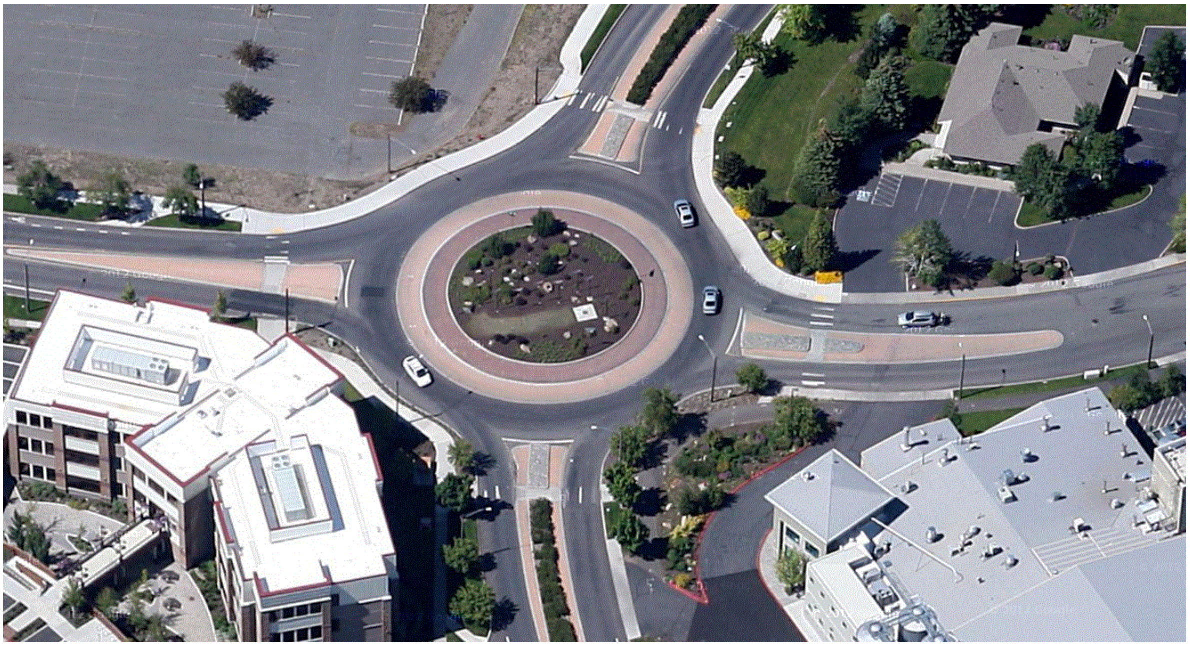
SITE #12: Carman Dr. at Meadows Rd. / Quarry Rd., Clackamas County [OR-S4-12] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
Carman Dr.	N	Both	ADT	9,150
Quarry Rd.	E	Both	ADT	4,885
Carman Dr.	S	Both	ADT	8,790
Meadows Rd.	W	Both	ADT	8,602
Major ADT		9,150		
Minor ADT		8,602		
Total ADT		17,752		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	1	1
Fix Object or Other Object	0	0	0
Rear-end Collision	2	0	2
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	2	1	3

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	1	0	1
2008	0	1	1
2009	0	0	0
2010	0	0	0
2011	1	0	1
Total Crashes (2007-2011)	2	1	3

SITE #13: SW Colorado Ave. at SW Simpson Ave., Deschutes County [OR-S4-13]



Source: Google Maps

Basic Information	
Intersecting Approaches	SW Colorado Ave.
	SW Simpson Ave.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2001

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	141	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	10
Central Island Diameter (ft)	120	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	12	Minimum Angle between Legs (degrees)	77
Bicycle Lane/Path Width (ft)	9	Number of Crosswalks	4
Sidewalk Width (ft)	9	Number of Approach Curves	3
Number of Approach with Bypass for Right Turn	0		

SITE #13: SW Colorado Ave. at SW Simpson Ave., Deschutes County [OR-S4-13] (continued)

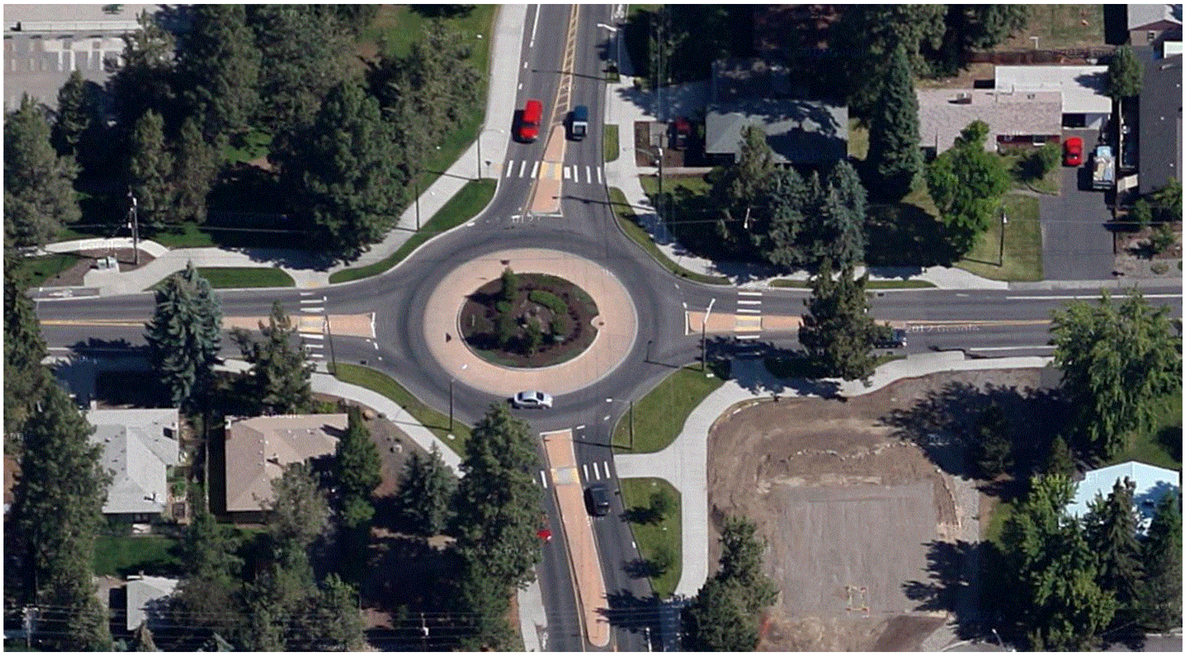
Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Colorado Ave.	N	Both	ADT	15,869
SW Simpson Ave.	E	Both	ADT	1,673
SW Colorado Ave.	S	Both	ADT	5,949
SW Simpson Ave.	W	Both	ADT	9,625
Major ADT		15,869		
Minor ADT		5,949		
Total ADT		21,818		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	1	1
Fix Object or Other Object	0	1	1
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	1	1
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head - on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	3	3

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	2	2
2008	0	1	1
2009	0	0	0
2010	0	0	0
2011	0	0	0
Total Crashes (2007-2011)	0	3	3

NOTES: The sidewalk and bicycle lane do not have a connecting ramp as commonly expected.

SITE #14: NE 8th St. at NE Franklin Ave., Deschutes County [OR-S4-14]



Source: Google Maps

Basic Information	
Intersecting Approaches	NE 8th St.
	NE Franklin Ave.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2004

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	125	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	7
Central Island Diameter (ft)	82	Entry Alignment	Center
Truck Apron Width (ft)	15	Offset Alignment	0
Minimum Lane Width (ft)	20	Minimum Angle between Legs (degrees)	81
Bicycle Lane/Path Width (ft)	10	Number of Crosswalks	4
Sidewalk Width (ft)	10	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

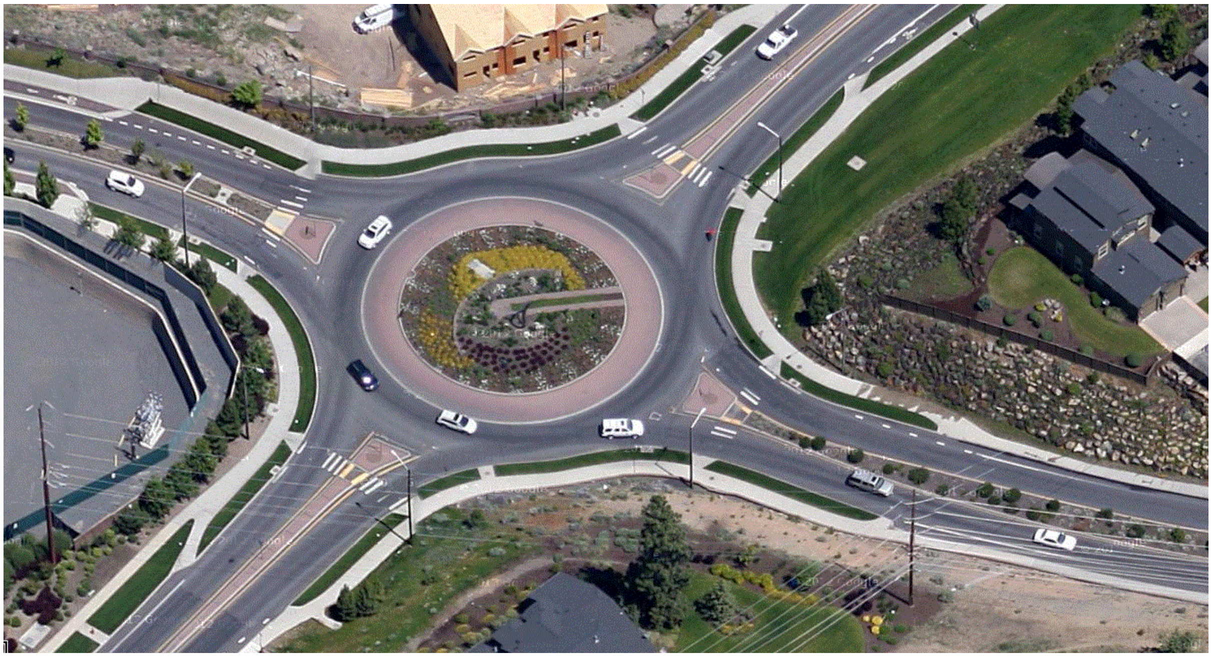
SITE #14: NE 8th St. at NE Franklin Ave., Deschutes County [OR-S4-14] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
NE 8th St.	N	Both	ADT	11,266
NE Franklin Ave.	E	Both	ADT	9,077
NE 8th St.	S	Both	ADT	11,412
NE Franklin Ave.	W	Both	ADT	11,201
Major ADT		11,412		
Minor ADT		11,201		
Total ADT		22,613		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	4	4
Fix Object or Other Object	1	2	3
Rear-end Collision	1	1	2
Miscellaneous	1	0	1
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	3	7	10

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	1	1	2
2008	0	2	2
2009	1	2	3
2010	1	1	2
2011	0	1	1
Total Crashes (2007-2011)	3	7	10

SITE #15: SW Bond St. / Brookswood Blvd. at SW Reed Market Rd., Deschutes County [OR-S4-15]



Source: Google Maps

Basic Information	
Intersecting Approaches	SW Bond St./Brookswood Blvd.
	SW Reed Market Rd.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2003

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	157	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	7
Central Island Diameter (ft)	120	Entry Alignment	Center
Truck Apron Width (ft)	15	Offset Alignment	0
Minimum Lane Width (ft)	20	Minimum Angle between Legs (degrees)	85
Bicycle Lane/Path Width (ft)	9	Number of Crosswalks	4
Sidewalk Width (ft)	9	Number of Approach Curves	3
Number of Approach with Bypass for Right Turn	0		

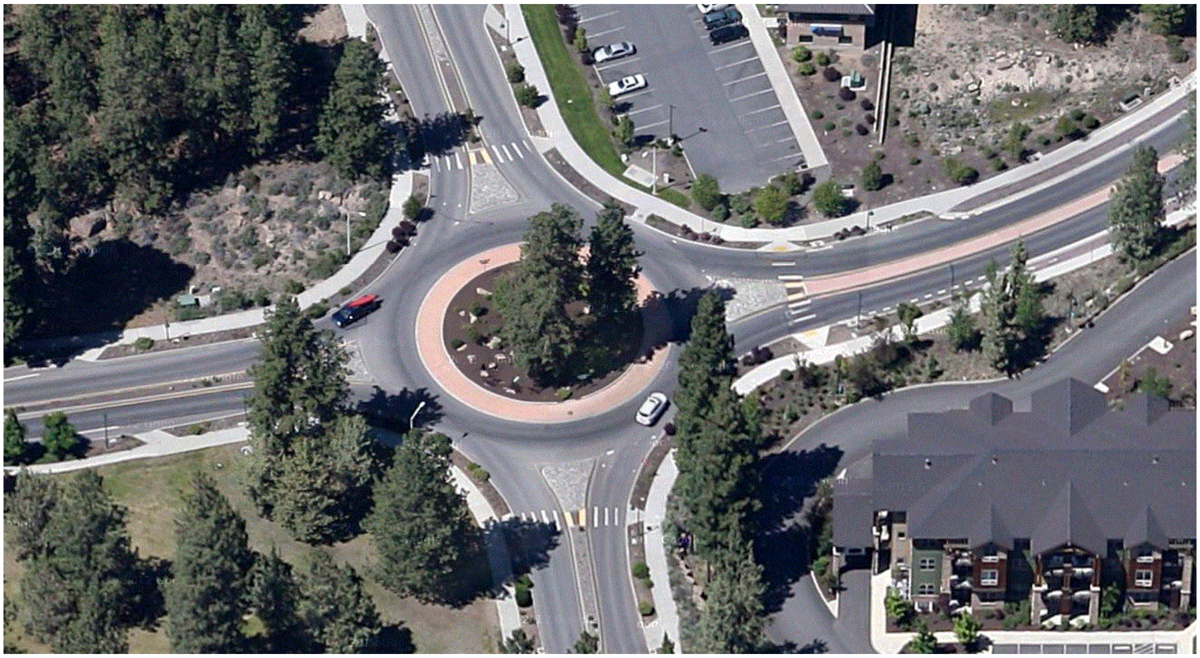
SITE #15: SW Bond St. / Brookswood Blvd. at SW Reed Market Rd., Deschutes County [OR-S4-15] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Bond St.	N	Both	ADT	11,041
SW Reed Mkt. Rd.	E	Both	ADT	18,748
Brookswood Blvd.	S	Both	ADT	10,984
SW Reed Mkt. Rd.	W	Both	ADT	10,837
Major ADT			18,748	
Minor ADT			10,984	
Total ADT			29,732	

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	2	0	2
Rear-end Collision	3	8	11
Miscellaneous	0	0	0
Turning Movement	1	0	1
Sideswipe - Meeting	0	1	1
Backing Movement	0	0	0
Collision with Pedestrian	2	0	2
Non - Collision	1	0	1
Head-on Collision	0	1	1
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	9	10	19

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	5	2	7
2008	1	3	4
2009	1	2	3
2010	1	1	2
2011	1	2	3
Total Crashes (2007-2011)	9	10	19

SITE #16: SW Reed Market Rd. at Century Dr., Deschutes County [OR-S4-16]



Source: Google Maps

Basic Information	
Intersecting Approaches	SW Reed Market Rd.
	Century Dr.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2002

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	138	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	6
Central Island Diameter (ft)	101	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	17	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	9	Number of Crosswalks	4
Sidewalk Width (ft)	9	Number of Approach Curves	4
Number of Approach with Bypass for Right Turn	0		

SITE #16: SW Reed Market Rd. at Century Dr., Deschutes County [OR-S4-16] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
Century Dr.	N	Both	ADT	6,233
SW Reed Mkt. Rd.	E	Both	ADT	10,837
Century Dr.	S	Both	ADT	3,800
SW Reed Mkt. Rd.	W	Both	ADT	10,837
Major ADT		10,837		
Minor ADT		6,233		
Total ADT		17,070		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	1	1	2
Rear-end Collision	1	0	1
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	1	1
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	2	2	4

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	1	0	1
2009	1	1	2
2010	0	1	1
2011	0	0	0
Total Crashes (2007-2011)	2	2	4

SITE #17: 58th St. at Thurston Rd., Lane County [OR-S4-17]

Source: Google Maps

Basic Information	
Intersecting Approaches	58th St.
	Thurston Rd.
County	Lane
State	OR
Type	Single
Number of Legs	4
Year of Completion	2001

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	104	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	6
Central Island Diameter (ft)	70	Entry Alignment	Center
Truck Apron Width (ft)	15	Offset Alignment	0
Minimum Lane Width (ft)	15	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	6	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	0		

SITE #17: 58th St. at Thurston Rd., Lane County [OR-S4-17] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
58th St.	N	Both	ADT	6,430
Thurston Rd.	E	Both	ADT	5,863
58th St.	S	Both	ADT	4,045
Thurston Rd.	W	Both	ADT	--
Major ADT		6,430		
Minor ADT		4,045		
Total ADT		10,475		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	2	2
Fix Object or Other Object	0	1	1
Rear-end Collision	1	0	1
Miscellaneous	0	0	0
Turning Movement	0	2	2
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	1	1
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	1	6	7

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	2	2
2008	0	0	0
2009	0	0	0
2010	0	1	1
2011	1	3	4
Total Crashes (2007-2011)	1	6	7

SITE #18: SW Stafford Rd. at Atherton Dr. / Rosemont Rd., Clackamas County [OR-S4-18]

Source: Google Maps

Basic Information	
Intersecting Approaches	SW Stafford Rd.
	Rosemont Rd. / Atherton Dr.
County	Clackamas
State	OR
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	160	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	4
Central Island Diameter (ft)	120	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	17	Minimum Angle between Legs (degrees)	79
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	0		

SITE #18: SW Stafford Rd. at Atherton Dr. / Rosemont Rd., Clackamas County [OR-S4-18] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Stafford Rd.	N	Both	ADT	10,570
Rosemont Rd.	E	Both	ADT	6,914
SW Stafford Rd.	S	Both	ADT	11,305
Atherton Dr.	W	Both	ADT	333
Major ADT		11,305		
Minor ADT		6,914		
Total ADT		18,219		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	0	0

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
Total Crashes (2007-2011)	0	0	0

SITE #19: NW Verboort Rd. at NW Marsh Rd. / NW Martin Rd., Washington County [OR-S4-19]

Source: Google Maps

Basic Information	
Intersecting Approaches	NW Verboort Rd.
	NW Marsh Rd. / NW Martin Rd.
County	Washington
State	OR
Type	Single
Number of Legs	4
Year of Completion	2003

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	0
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	192	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	165	Entry Alignment	Center
Truck Apron Width (ft)	19	Offset Alignment	0
Minimum Lane Width (ft)	13	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	4
Sidewalk Width (ft)	8	Number of Approach Curves	3
Number of Approach with Bypass for Right Turn	0		

SITE #19: NW Verboort Rd. at NW Marsh Rd. / NW Martin Rd., Washington County [OR-S4-19] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
NW Marsh Rd.	N	Both	ADT	204
NW Verboort Rd.	E	Both	ADT	14,488
NW Martin Rd.	S	Both	ADT	6,333
NW Verboort Rd.	W	Both	ADT	4,982
Major ADT		14,488		
Minor ADT		4,982		
Total ADT		19,470		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	0	0

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
Total Crashes (2007-2011)	0	0	0

SITE #20: SE 15th St. at NE Bear Creek Rd., Deschutes County [OR-S4-20]

Source: Google Maps

Basic Information	
Intersecting Approaches	SE 15th St.
	NE Bear Creek Rd.
County	Deschutes
State	OR
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	118	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	6
Central Island Diameter (ft)	85	Entry Alignment	Center
Truck Apron Width (ft)*	Variable	Offset Alignment	0
Minimum Lane Width (ft)	17	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	11	Number of Crosswalks	4
Sidewalk Width (ft)	11	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #20: SE 15th St. at NE Bear Creek Rd., Deschutes County [OR-S4-20] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SE 15th St.	N	Both	ADT	8,859
NE Bear Creek Rd.	E	Both	ADT	8,281
SE 15th St.	S	Both	ADT	9,487
NE Bear Creek Rd.	W	Both	ADT	4,922

Major ADT	9,487
Minor ADT	8,281
Total ADT	17,768

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	1	1
Fix Object or Other Object	2	2	4
Rear-end Collision	0	1	1
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	2	4	6

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	1	1
2009	0	0	0
2010	0	3	3
2011	2	0	2
Total Crashes (2007-2011)	2	4	6

*NOTE: The truck apron has a width that varies in size. Minimum width is approximately 11' so this is the value used in the summary statistics.

SITE #21: SW Hart Rd. / SW Juniper Terrace at SW Sorrento Rd., Washington County [OR-S4-21]

Source: Google Maps

Basic Information	
Intersecting Approaches	SW Hart Rd. / SW Juniper Terrace
	SW Sorrento Rd.
County	Washington
State	OR
Type	Single
Number of Legs	4
Year of Completion	1980

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	0
Truck Apron	0	Pedestrian Refuge Area	0
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	113	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	71	Entry Alignment	Center
Truck Apron Width (ft)	0	Offset Alignment	0
Minimum Lane Width (ft)	18	Minimum Angle between Legs (degrees)	70
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	0
Sidewalk Width (ft)	3	Number of Approach Curves	4
Number of Approach with Bypass for Right Turn	0		

SITE #21: SW Hart Rd. / SW Juniper Terrace at SW Sorrento Rd., Washington County [OR-S4-21] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Juniper Terrace	N	Both	ADT	1,525
SW Hart Rd.	E	Both	ADT	6,846
SW Hart Rd.	S	Both	ADT	6,846
SW Sorrento Rd.	W	Both	ADT	1,000
Major ADT		6,846		
Minor ADT		1,525		
Total ADT		8,371		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	1	1
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	1	1
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	2	2

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	1	1
2009	0	0	0
2010	0	1	1
2011	0	0	0
Total Crashes (2007-2011)	0	2	2

NOTES: This roundabout is located in a residential area and the roundabout configuration is atypical as it does not have a truck apron, pedestrian refuge area, or bicycle accomodations.

SITE #22: Highland Dr. at Siskiyou Blvd., Jackson County [OR-S4-22]

Source: Google Maps

Basic Information	
Intersecting Approaches	Highland Dr.
	Siskiyou Blvd.
County	Jackson
State	OR
Type	Single
Number of Legs	4
Year of Completion	2006

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	124	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	91	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	16	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	14	Number of Crosswalks	4
Sidewalk Width (ft)	14	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

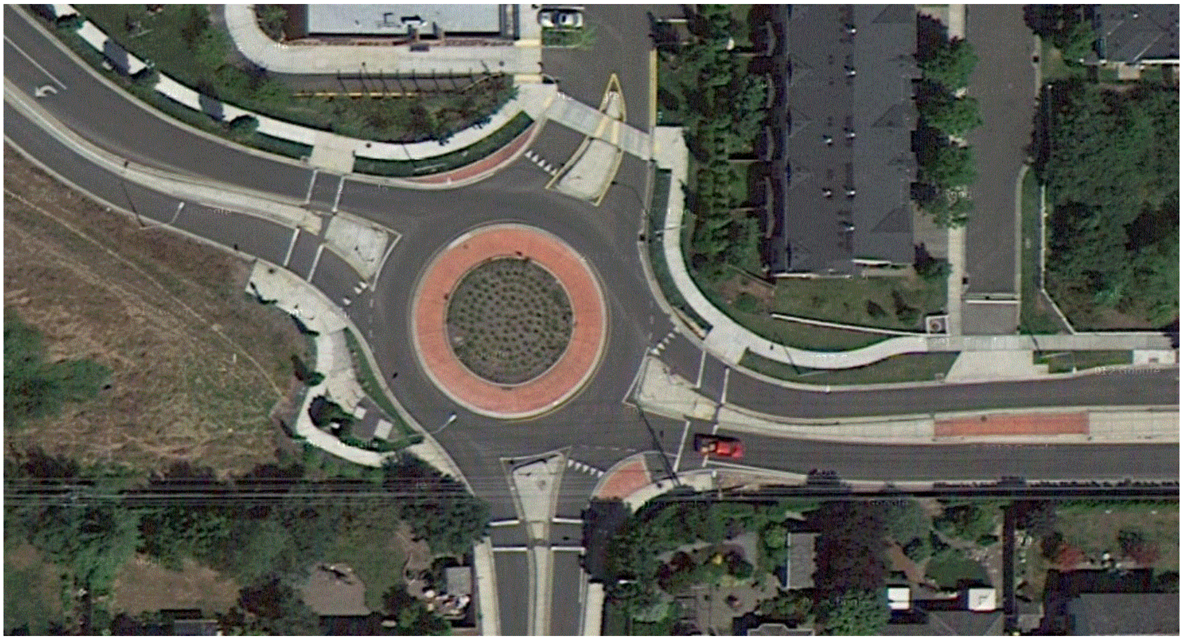
SITE #22: Highland Dr. at Siskiyou Blvd., Jackson County [OR-S4-22] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
Highland Dr.	N	Both	ADT	6,595
Siskiyou Blvd.	E	Both	ADT	5,268
Highland Dr.	S	Both	ADT	9,288
Siskiyou Blvd.	W	Both	ADT	7,537
Major ADT		9,288		
Minor ADT		6,595		
Total ADT		15,883		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	1	0	1
Fix Object or Other Object	0	2	2
Rear-end Collision	0	5	5
Miscellaneous	0	0	0
Turning Movement	0	3	3
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	1	0	1
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	2	10	12

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	4	4
2008	1	0	1
2009	0	1	1
2010	1	3	4
2011	0	2	2
Total Crashes (2007-2011)	2	10	12

SITE #23: SW Barrows Rd. at SW Roshak Rd., Washington County [OR-S4-23]



Source: Google Maps

Basic Information	
Intersecting Approaches	SW Barrows Rd.
	SW Roshak Rd.
County	Washington
State	OR
Type	Single
Number of Legs	4
Year of Completion	2008

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	108	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	9
Central Island Diameter (ft)	78	Entry Alignment	Center
Truck Apron Width (ft)	14	Offset Alignment	0
Minimum Lane Width (ft)	14	Minimum Angle between Legs (degrees)	58
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	3
Number of Approach with Bypass for Right Turn	0		

SITE #23: SW Barrows Rd. at SW Roshak Rd., Washington County [OR-S4-23] (continued)

Traffic Volume Information (2012)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
SW Roshak Rd.	N	Both	ADT	1,531
SW Barrows Rd.	E	Both	ADT	11,006
SW Roshak Rd.	S	Both	ADT	1,946
SW Barrows Rd.	W	Both	ADT	11,006
Major ADT		11,006		
Minor ADT		1,946		
Total ADT		12,952		

Crash Distribution by Severity Level and Collision Type (2007-2011)			
Collision Type	Injury	PDO	Total
Angle Collision	0	0	0
Fix Object or Other Object	0	0	0
Rear-end Collision	0	0	0
Miscellaneous	0	0	0
Turning Movement	0	0	0
Sideswipe - Meeting	0	0	0
Backing Movement	0	0	0
Collision with Pedestrian	0	0	0
Non - Collision	0	0	0
Head-on Collision	0	0	0
Parking Maneuver	0	0	0
Total Crashes (2007-2011)	0	0	0

Crash Distribution by Year			
Year	Injury	PDO	Total
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
Total Crashes (2007-2011)	0	0	0

NOTES: First two years for crash data extend across construction period.

APPENDIX D:
MODEL DEVELOPMENT

This section shows statistical efforts executed by the project team for model development and selection. Four different candidate model configurations, based on two different data sets, are addressed. The geometric characteristics were considered during the modeling process but, due to the lack of variation between sites, geometric variables proved to be inconclusive (not statistically significant for the available thresholds).

Overview Attempts for Modeling Total Crashes

Models of Total Crash		
Model	Data	
	Include outlier	Exclude outlier
$ln(crash) \sim TOT\_ADT$	***Section 0***	***Section 0***
$ln(crash) \sim TOT\_ADT + TOT\_ADT^2$	***Section 0***	***Section 0***
$ln(crash) \sim TOT\_ADT^2$	***Section 0***	***Section 0***
Reference Model		
$ln(crash) \sim ln(TOT\_ADT)$	***Section 0***	***Section 0***

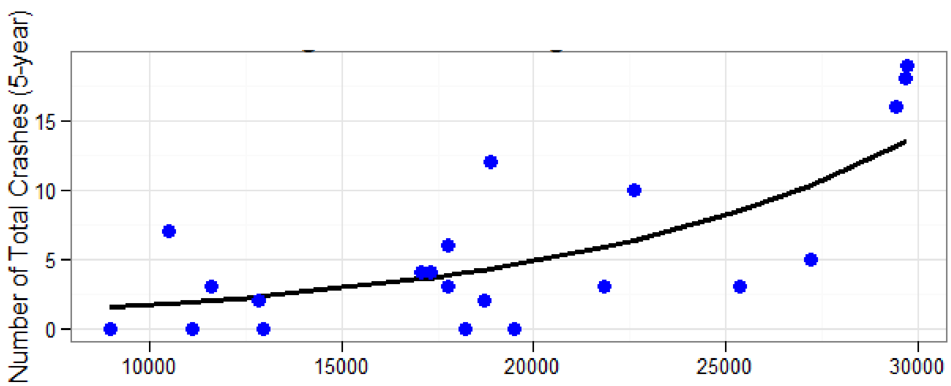
Overview Attempts for Modeling Injury Crashes

Models of Injury Crash		
Model	Data	
	Include outlier	Exclude outlier
$ln(inj\ crash) \sim TOT\_ADT$	***Section 0***	***Section 0***
$ln(inj\ crash) \sim TOT\_ADT \mid TOT\_ADT^2$	***Section 0***	***Section 0***
$ln(inj\ crash) \sim TOT\_ADT^2$	***Section 0***	***Section 0***
Reference Model		
$ln(inj\ crash) \sim ln(TOT\_ADT)$	***Section 0***	***Section 0***

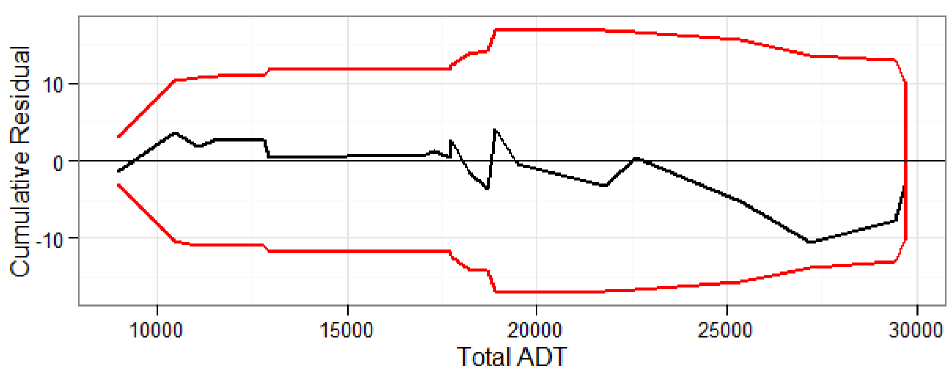
TOTAL CRASHES FOR TOT_ADT (INCLUDES OUTLIER)

Total Crash Model with TOT_ADT (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp(\beta_1 + \beta_2 Total\ Entering\ ADT)$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-7.649e-01	3.752e-01	-2.039	0.0415	*
β_2	TOT_ADT	1.162e-04	1.536e-05	7.560	4.02e-14	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ of\ Crash\ (5\ years) = Exp(\beta_1 + \beta_2 Total\ Entering\ ADT)$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-5.474e-01	6.460e-01	-0.847	0.396781	
β_2	TOT_ADT	1.060e-04	3.048e-05	3.479	0.000503	***
θ		1.90	1.05			
Over dispersion 1/θ		0.526				



Regression Model for TOT_ADT (includes outlier)

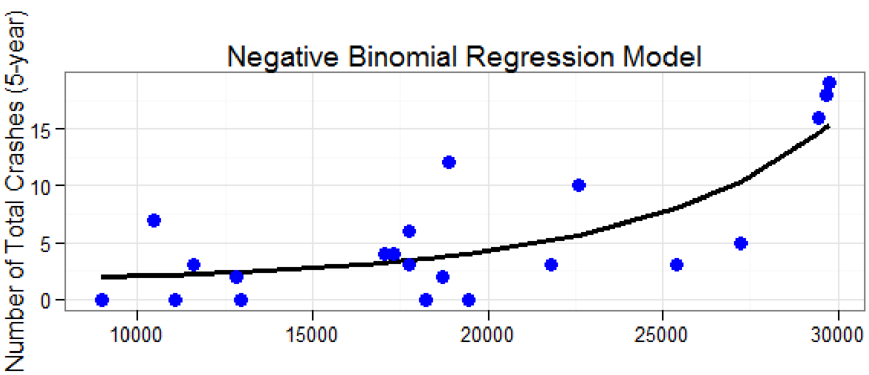


CURE Plot for TOT_ADT (includes outlier)

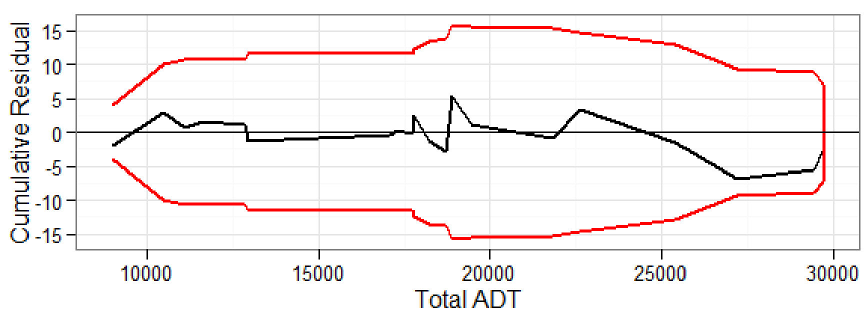
TOTAL CRASHES FOR TOT_ADT+TOT_ADT^2 (INCLUDES OUTLIER)

Total Crash Model with TOT_ADT+TOT_ADT^2 (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 Total\ Entering\ ADT + \beta_3 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	1.152e+00	1.156e+00	0.996	0.3190	
β_2	TOT_ADT	-7.840e-05	1.149e-04	-0.682	0.4950	
β_3	TOT_ADT2	4.487e-09	2.654e-09	1.691	0.0909	.
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 Total\ Entering\ ADT + \beta_3 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	6.131e-01	1.907e+00	0.321	0.748	
β_2	TOT_ADT	-1.901e-05	1.983e-04	-0.096	0.924	
β_3	TOT_ADT2	3.030e-09	4.805e-09	0.631	0.528	
θ		2.00	1.14			
Over dispersion 1/θ		0.5				



Regression Model for TOT_ADT + TOT_ADT^2 (includes outlier)

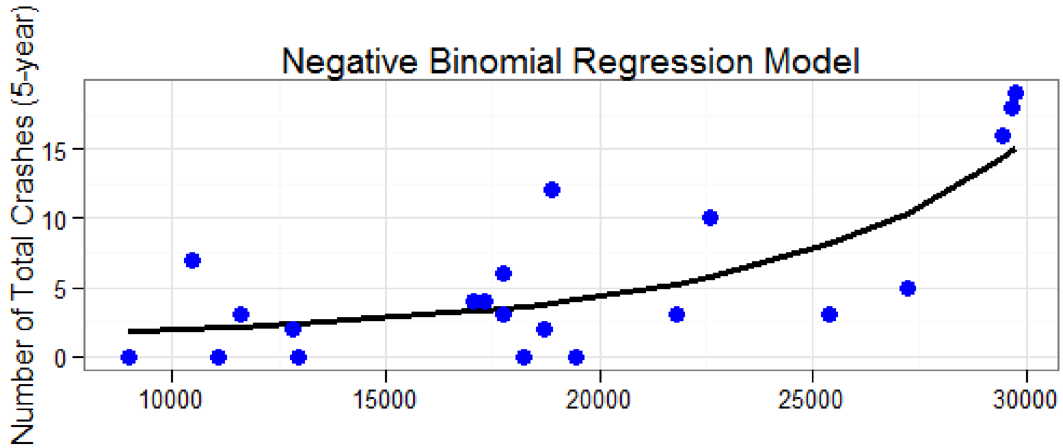


CURE Plot for TOT_ADT + TOT_ADT^2 (includes outlier)

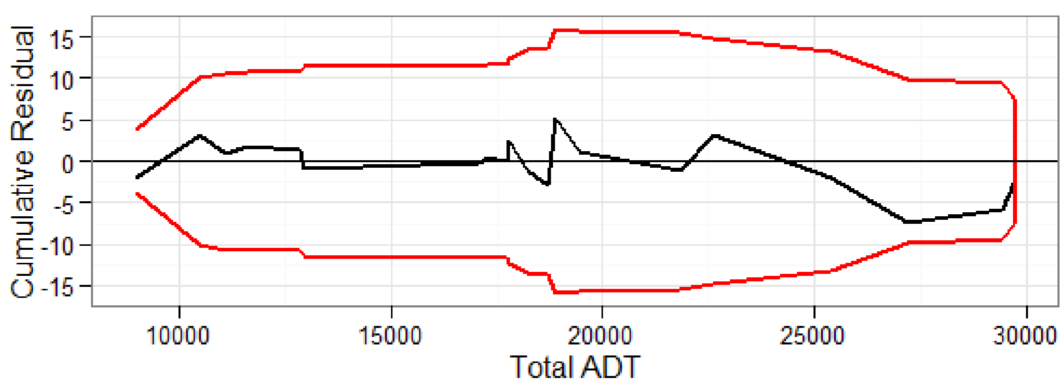
TOTAL CRASHES FOR TOT_ADT^2 (INCLUDES OUTLIER)

Total Crash Model with TOT_ADT^2 (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	3.712e-01	2.239e-01	1.657	0.0975	.
β_2	TOT_ADT^2	2.698e-09	3.391e-10	7.957	1.76e-15	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	4.320e-01	3.720e-01	1.161	0.245483	
β_2	TOT_ADT^2	2.579e-09	7.135e-10	3.614	0.000301	***
θ		2.00	1.14			
Over dispersion 1/θ		0.5				



Regression Model for TOT_ADT^2 (includes outlier)

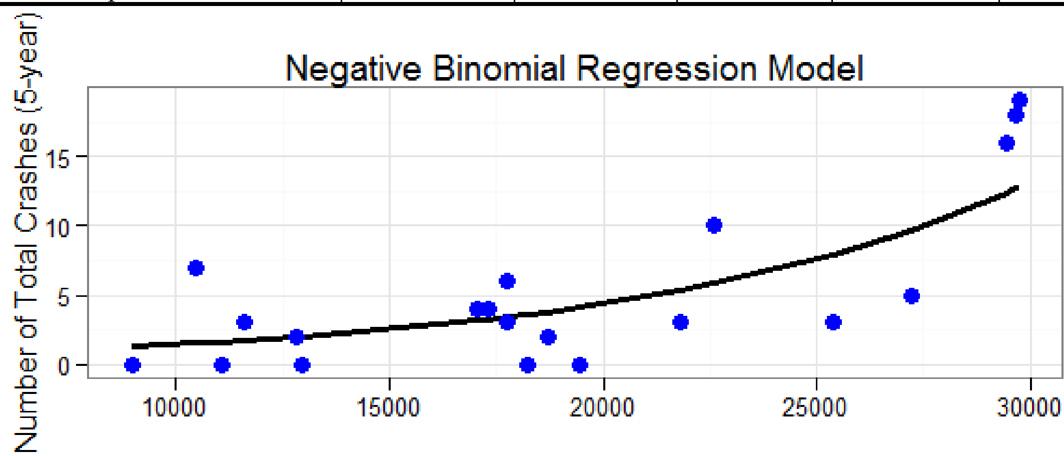


CURE Plot for TOT_ADT^2 (includes outlier)

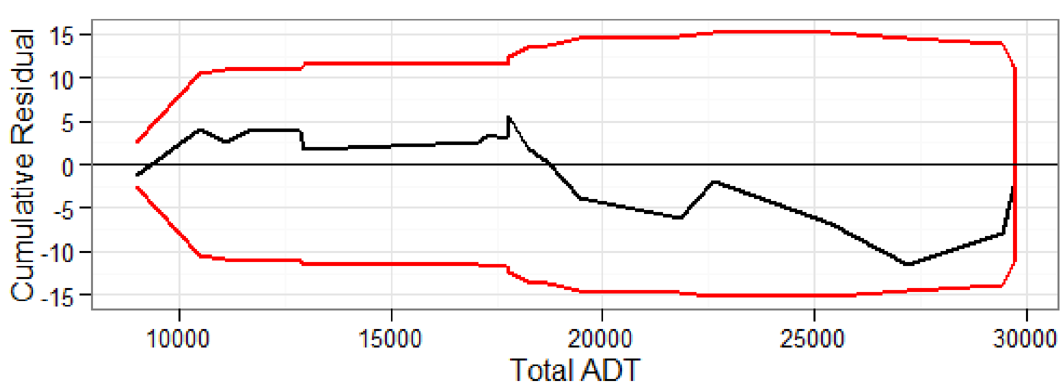
TOTAL CRASHES FOR TOT_ADT (EXCLUDES OUTLIER)

Total Crash Model for TOT_ADT (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp(\beta_1 + \beta_2 Total\ Entering\ ADT)$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-1.08e+00	4.107e-01	-2.639	0.00831	**
β_2	TOT_ADT	1.264e-04	1.647e-05	7.675	1.66e-14	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ of\ Crash\ (5\ years) = Exp(\beta_1 + \beta_2 Total\ Entering\ ADT)$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-7.314e-01	6.323e-01	-1.157	0.247419	
β_2	TOT_ADT	1.102e-04	2.927e-05	3.765	0.000167	***
θ		2.28	1.47			
Over dispersion 1/θ		0.439				



Regression Model for TOT_ADT (excludes outlier)

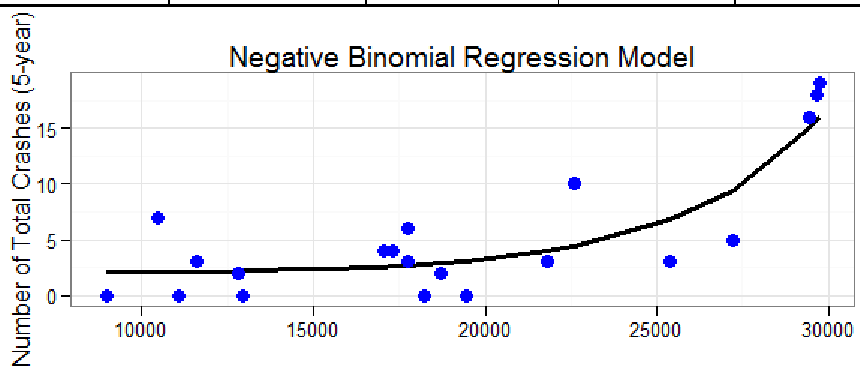


CURE Plot for TOT_ADT (excludes outlier)

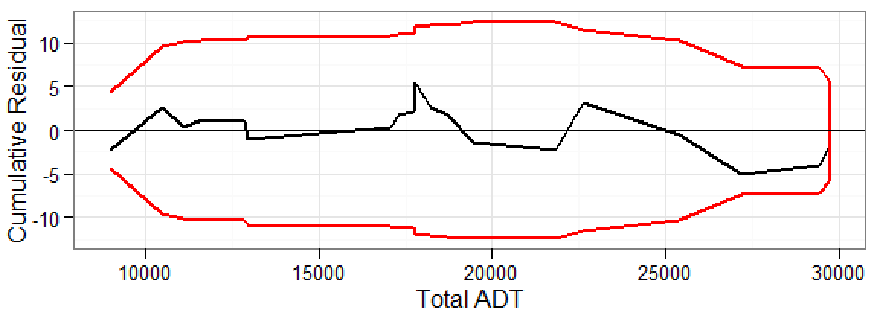
TOTAL CRASH MODEL FOR TOT_ADT+TOT_ADT^2 (EXCLUDES OUTLIER)

Total Crash Model with TOT_ADT+TOT_ADT^2 (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 Total\ Entering\ ADT + \beta_3 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	2.002e+00	1.202e+00	1.666	0.0956	.
β_2	TOT_ADT	-1.901e-04	1.221e-04	-1.558	0.1193	
β_3	TOT_ADT^2	7.323e-09	2.846e-09	2.573	0.0101	*
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 Total\ Entering\ ADT + \beta_3 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	1.628e+00	1.732e+00	0.940	0.347	
β_2	TOT_ADT	-1.468e-04	1.815e-04	-0.809	0.419	
β_3	TOT_ADT^2	6.232e-09	4.386e-09	1.421	0.155	
θ		3.09	2.42			
Over dispersion 1/θ		0.324				



Regression Model for TOT_ADT + TOT_ADT^2 (excludes outlier)

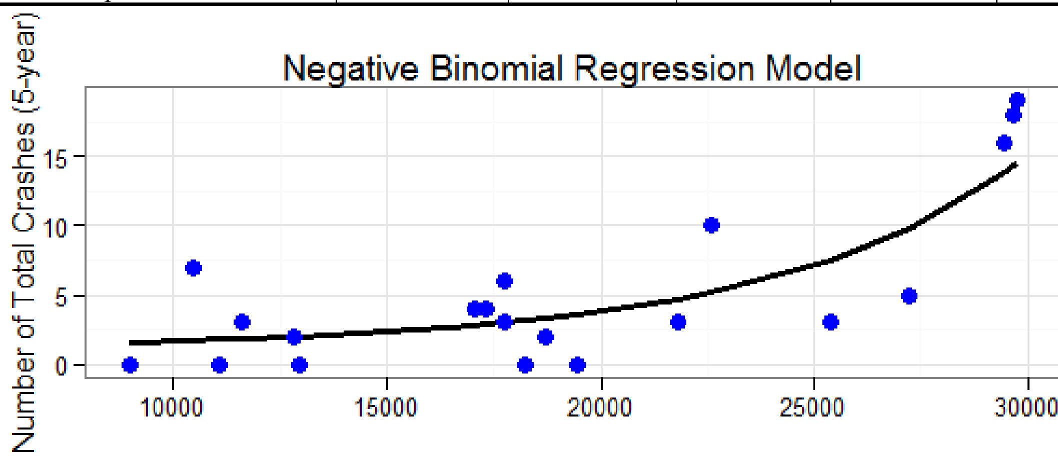


CURE Plot for TOT_ADT + TOT_ADT^2 (excludes outlier)

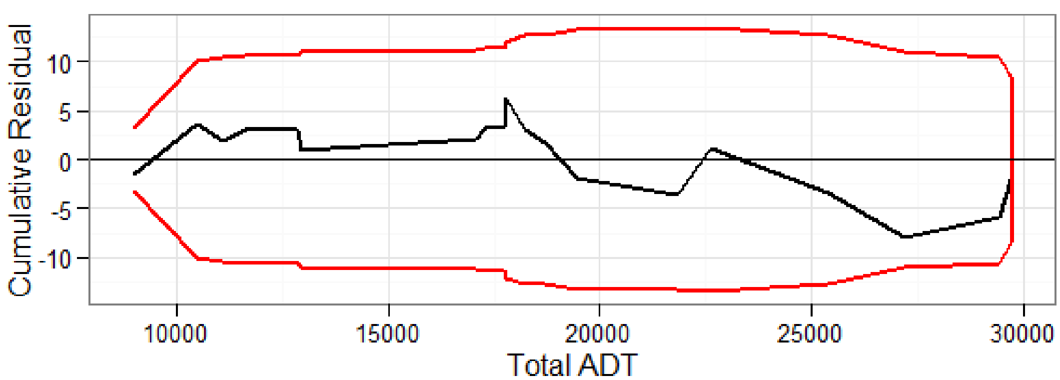
TOTAL CRASH MODEL WITH TOT_ADT^2 (EXCLUDES OUTLIER)

Total Crash Model with TOT_ADT^2 (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	1.292e-01	2.488e-01	0.519	0.604	
β_2	TOT_ADT^2	2.967e-09	3.635e-10	8.161	3.31e-16	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2(Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	2.447e-01	3.577e-01	0.684	0.494	
β_2	TOT_ADT^2	2.744e-09	6.536e-10	4.198	2.69e-05	***
θ		2.74	1.98			
Over dispersion 1/θ		0.365				



Regression Model for TOT_ADT^2 (excludes outlier)

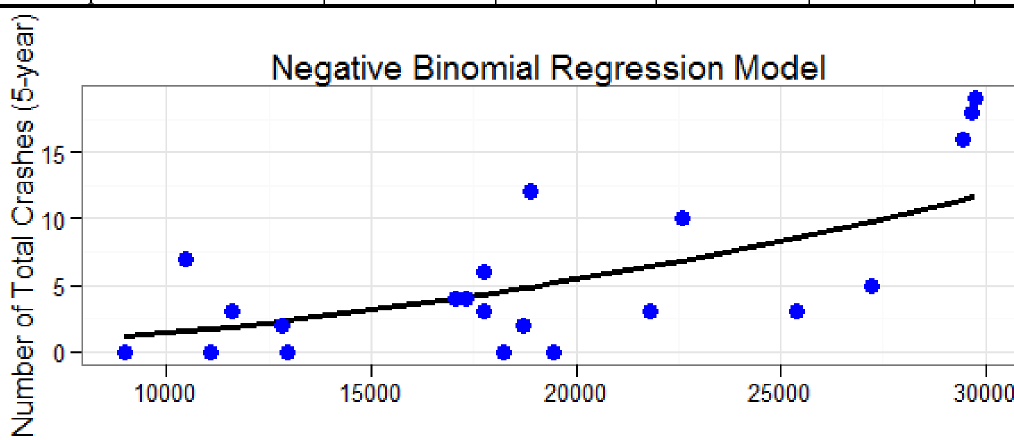


CURE Plot for TOT_ADT^2 (excludes outlier)

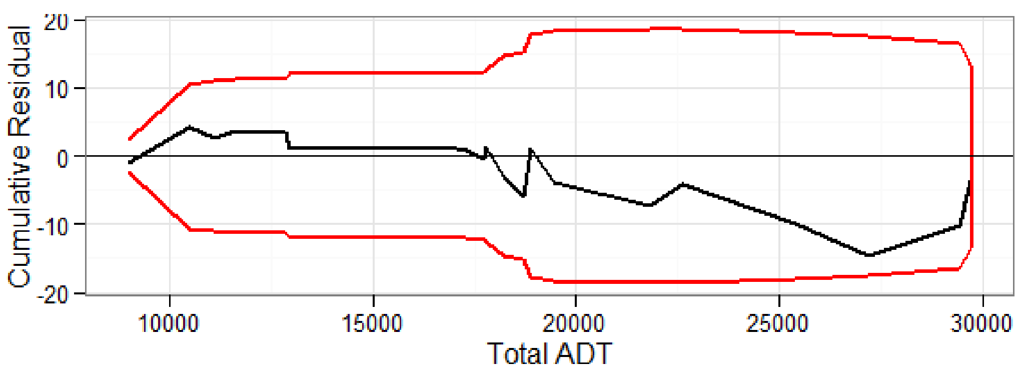
TOTAL CRASH MODEL WITH [LN(TOT_ADT)] (INCLUDES OUTLIER)

Total Crash Model with [ln(TOT_ADT)] (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp(\beta_1) \times (Total\ Entering\ ADT)^{\beta_2}$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-20.9527	3.3096	-6.331	2.44e-10	***
β_2	log(cd$TOT_ADT)	2.2856	0.3299	6.927	4.29e-12	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ of\ Crash\ (5\ years) = Exp(\beta_1) \times (Total\ Entering\ ADT)^{\beta_2}$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-17.434	5.969	-2.921	0.00349	**
β_2	log(cd$TOT_ADT)	1.931	0.605	3.192	0.00141	**
θ		1.709	0.893			
Over dispersion 1/θ		0.585				



Regression Model for [ln(TOT_ADT)] (includes outlier)

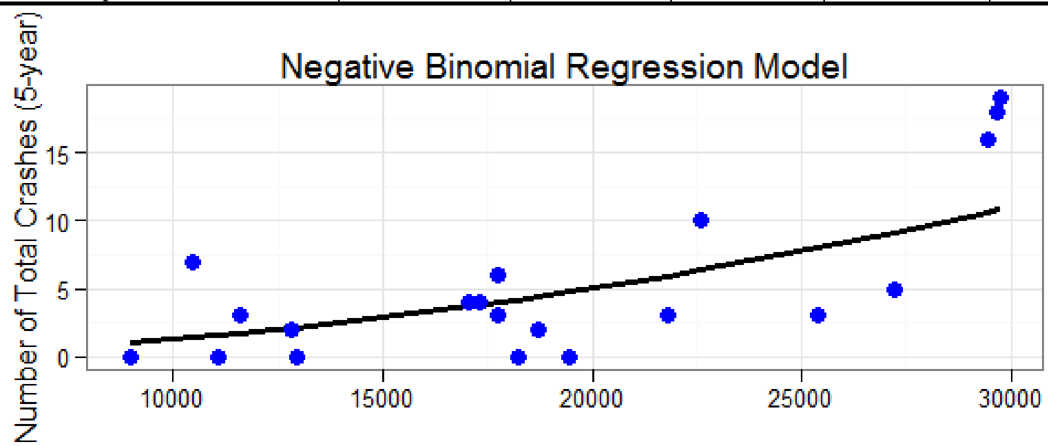


CURE Plot for [ln(TOT_ADT)] (includes outlier)

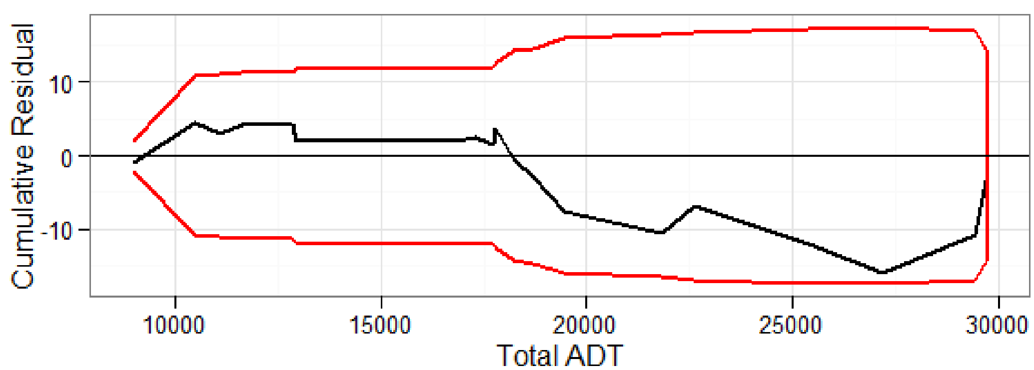
TOTAL CRASH MODEL WITH [LN(TOT_ADT)] (EXCLUDES OUTLIER)

Total Crash Model with [ln(TOT_ADT)] (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ Crash\ (5\ years) = Exp(\beta_1) \times (Total\ Entering\ ADT)^{\beta_2}$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-22.6864	3.5453	-6.399	1.56e-10	***
β_2	log(cd$TOT_ADT)	2.4516	0.3527	6.951	3.64e-12	***
Model:	Negative Binomial Regression Model					
Equation:	$Total\ Number\ of\ Crash\ (5\ years) = Exp(\beta_1) \times (Total\ Entering\ ADT)^{\beta_2}$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-17.7570	5.9565	-2.981	0.00287	**
β_2	log(cd$TOT_ADT)	1.9555	0.6032	3.242	0.00119	**
θ		1.82	1.03			
Over dispersion 1/θ		0.549				



Regression Model for [ln(TOT_ADT)] (excludes outlier)

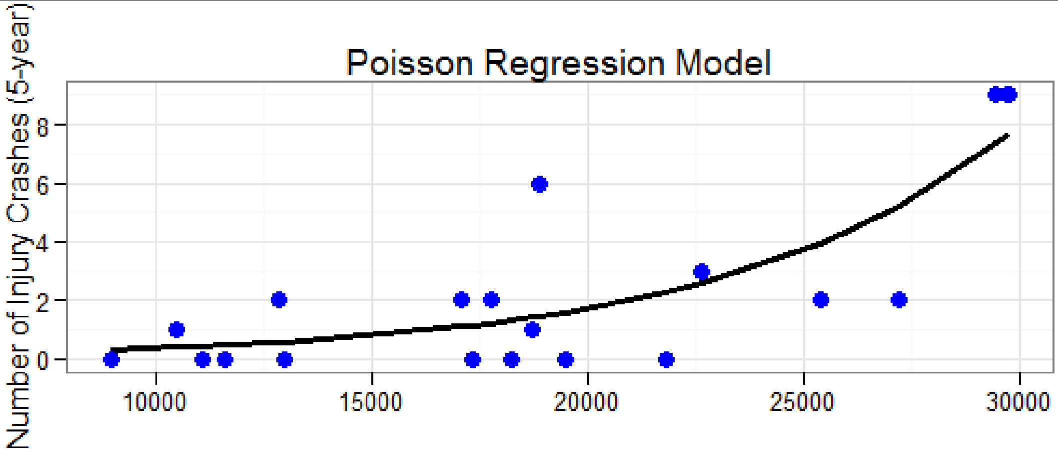


CURE Plot for [ln(TOT_ADT)] (excludes outlier)

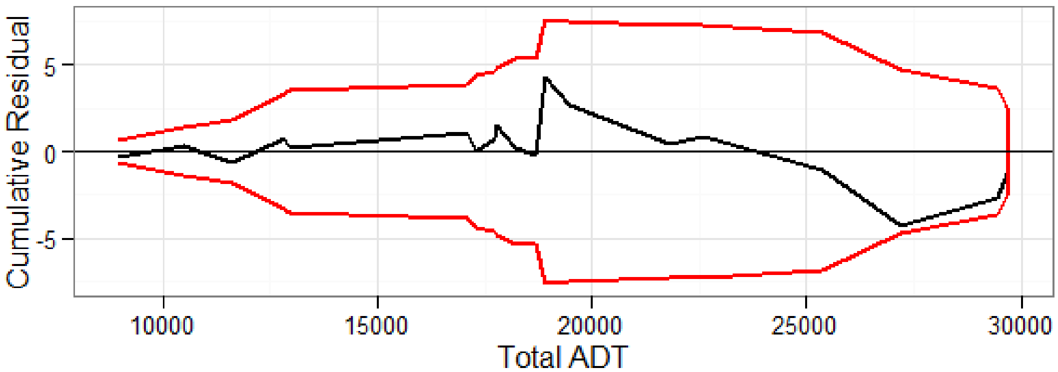
INJURY MODEL WITH TOT_ADT (INCLUDES OUTLIER)

Injury Crash Model with TOT_ADT (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp(\beta_1 + \beta_2 Total\ Entering\ ADT)$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-2.52e+00	6.504e-01	-3.877	0.000106	***
β_2	TOT_ADT	1.534e-04	2.547e-05	6.024	1.7e-09	***



Injury Regression Model for TOT_ADT (includes outlier)

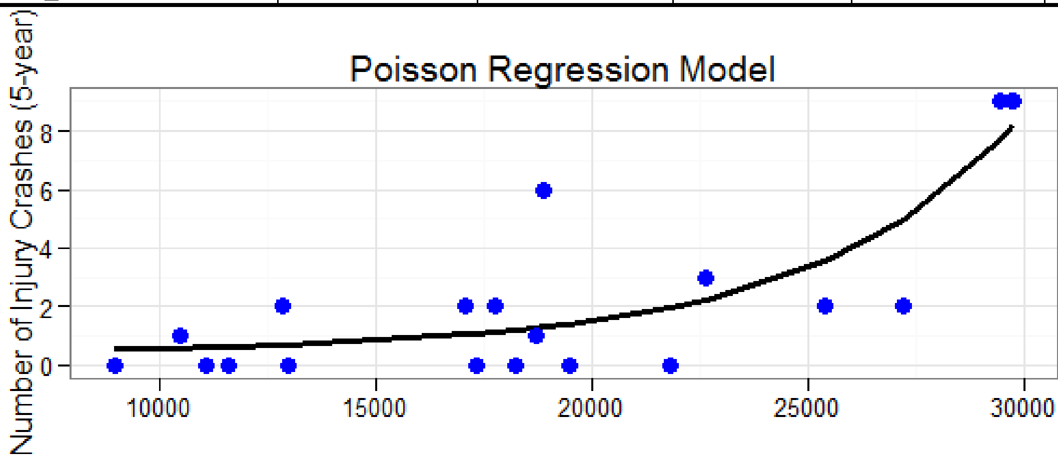


Injury Model CURE Plot for TOT_ADT (includes outlier)

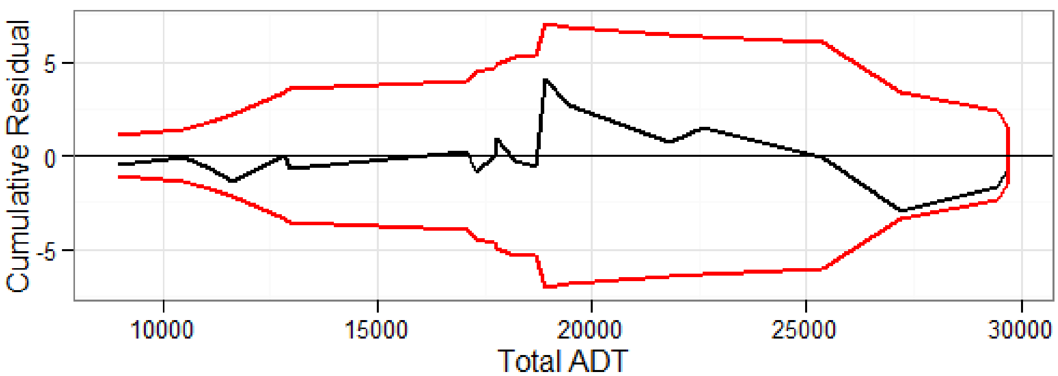
INJURY MODEL WITH TOT_ADT+TOT_ADT^2 (INCLUDES OUTLIER)

Injury Crash Model with TOT_ADT+TOT_ADT^2 (includes outlier)

Model:	Poisson Regression Model					
Equation:	$\text{Total Number of Injury Crash (5 years)} = \text{Exp}[\beta_1 + \beta_2 \text{Total Entering ADT} + \beta_3 (\text{Total Entering ADT})^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-8.054e-01	2.120e+00	-0.380	0.704	
β_2	TOT_ADT	-1.464e-05	2.034e-04	-0.072	0.943	
β_3	TOT_ADT2	3.784e-09	4.587e-09	0.825	0.410	



Injury Regression Model for TOT_ADT + TOT_ADT^2 (includes outlier)

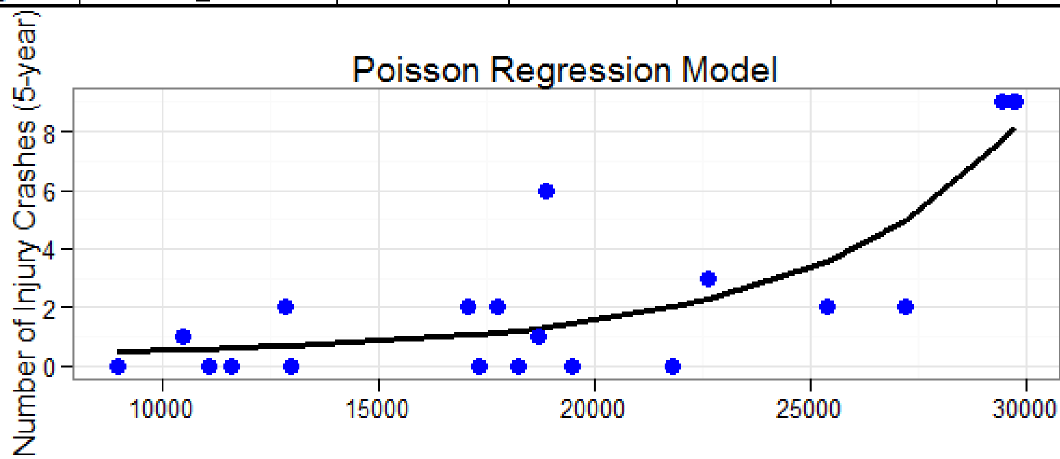


Injury Model CURE Plot for TOT_ADT + TOT_ADT^2 (includes outlier)

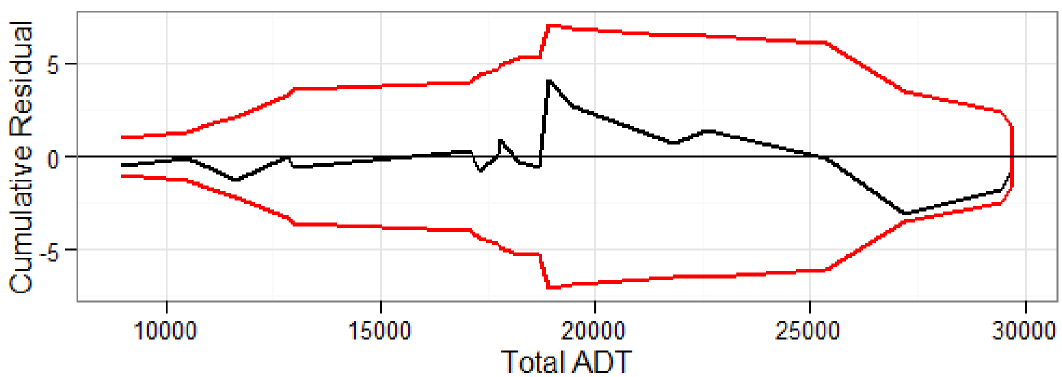
INJURY MODEL WITH TOT_ADT^2 (INCLUDES OUTLIER)

Injury Crash Model with TOT_ADT^2 (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-9.558e-01	3.855e-01	-2.479	0.0132	*
β_2	TOT_ADT^2	3.456e-09	5.473e-10	6.314	2.72e-10	***



Injury Regression Model with TOT_ADT^2 (includes outlier)

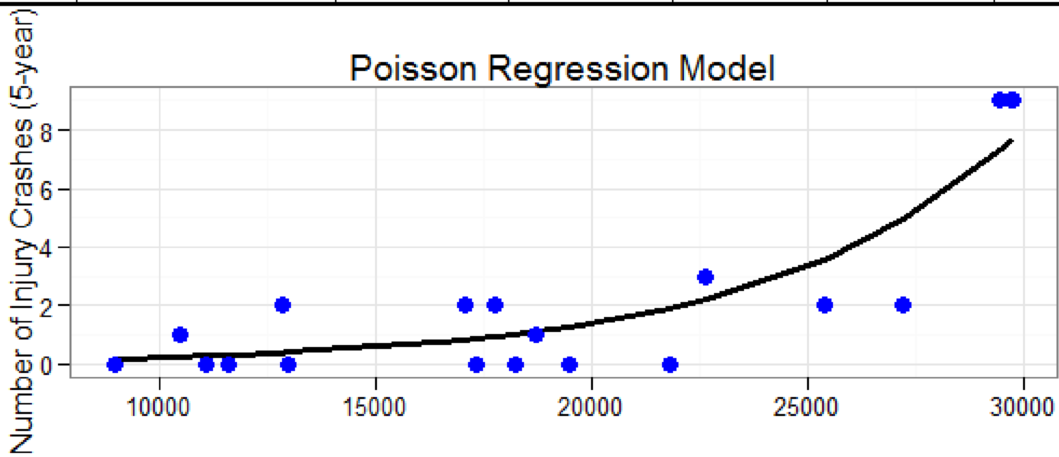


Injury Model CURE Plot with TOT_ADT^2 (includes outlier)

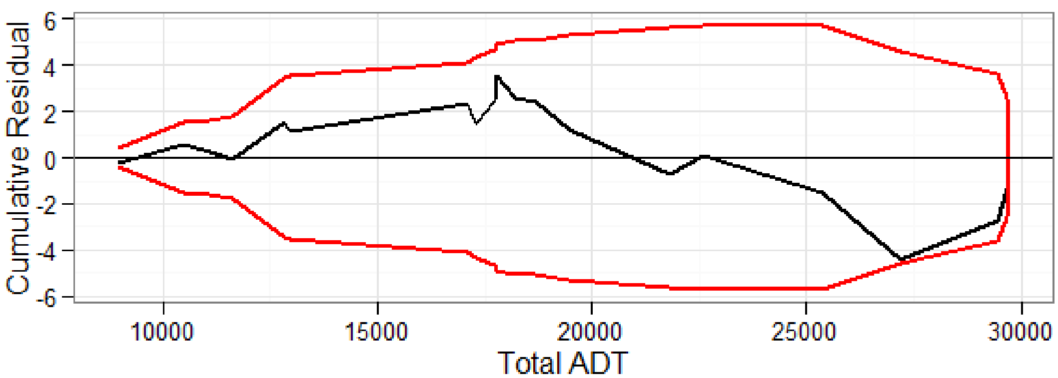
INJURY MODEL WITH TOT_ADT (EXCLUDES OUTLIER)

Injury Crash Model with TOT_ADT (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp(\beta_1 + \beta_2 Total\ Entering\ ADT)$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-3.187729	0.7641033	-4.172	3.02e-05	***
β_2	TOT_ADT	0.0001758	0.0000291	6.041	1.53e-09	***



Injury Regression Model with TOT_ADT (excludes outlier)

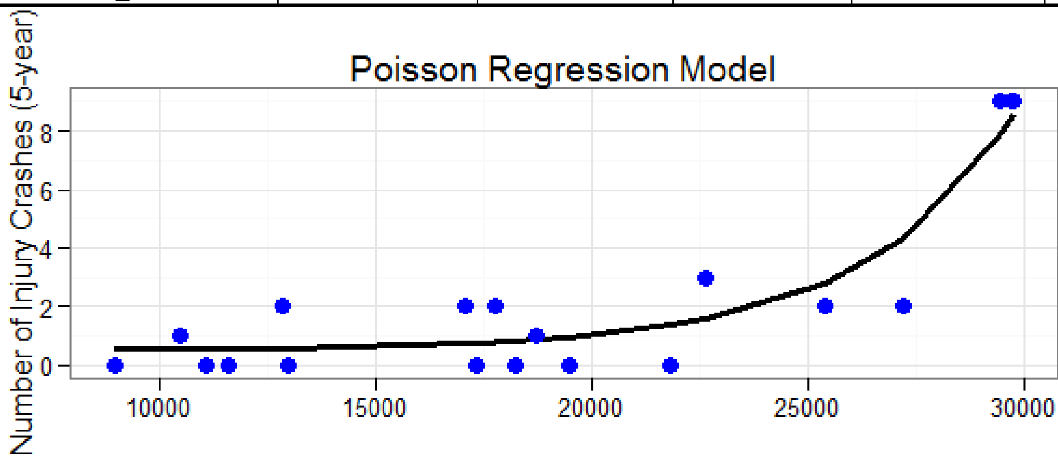


Injury Model CURE Plot with TOT_ADT (excludes outlier)

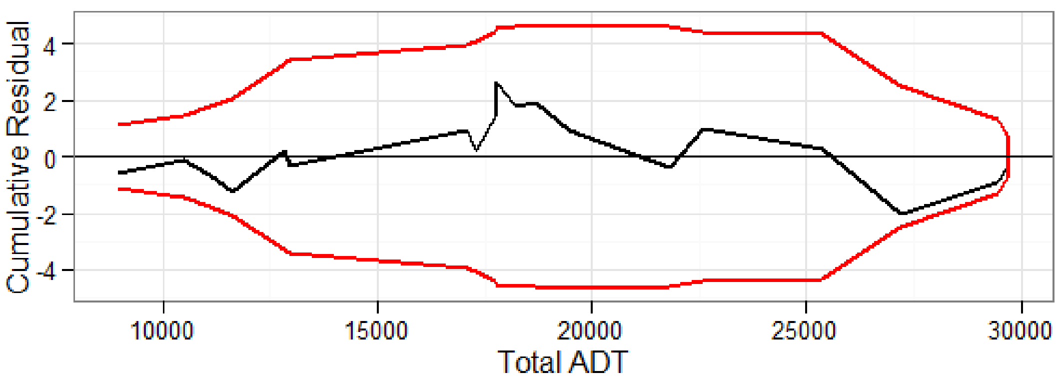
INJURY MODEL WITH TOT_ADT+TOT_ADT^2 (EXCLUDES OUTLIER)

Injury Crash Model with TOT_ADT+TOT_ADT^2 (excludes outliers)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 Total\ Entering\ ADT + \beta_3 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	3.769e-01	2.252e+00	0.167	0.867	
β_2	TOT_ADT	-1.756e-04	2.212e-04	-0.794	0.427	
β_3	TOT_ADT^2	7.914e-09	5.044e-09	1.569	0.117	



Injury Regression Model for TOT_ADT + TOT_ADT^2 (excludes outliers)

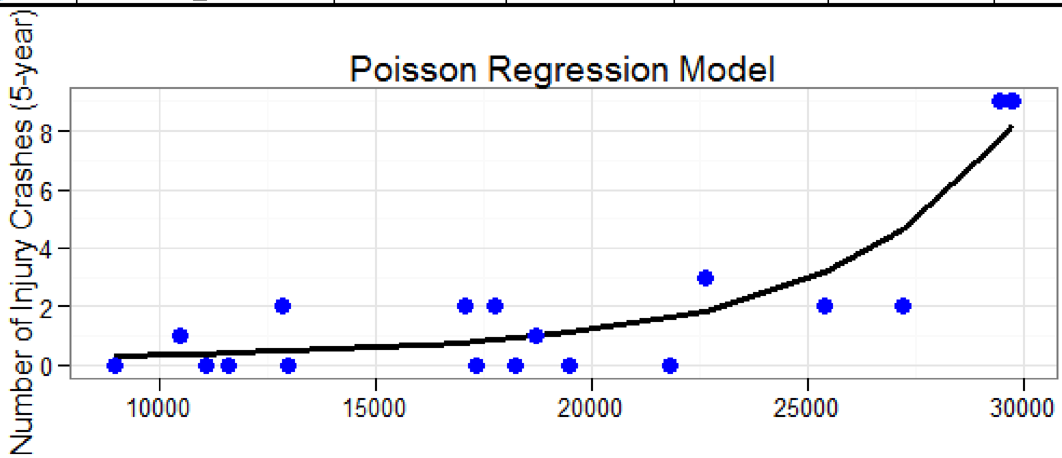


Injury Model CURE Plot for TOT_ADT + TOT_ADT^2 (excludes outliers)

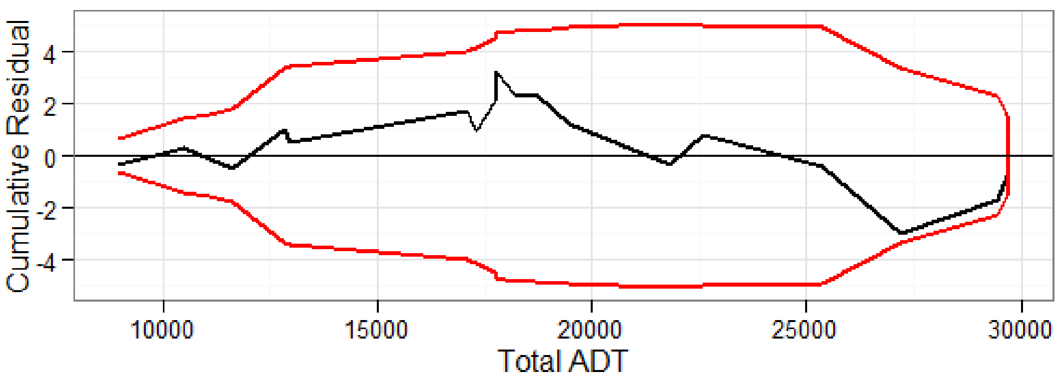
INJURY MODEL WITH TOT_ADT^2 (EXCLUDES OUTLIER)

Injury Crash Model with TOT_ADT^2 (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp[\beta_1 + \beta_2 (Total\ Entering\ ADT)^2]$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-1.41e+00	4.584e-01	-3.080	0.00207	**
β_2	TOT_ADT^2	3.978e-09	6.221e-10	6.395	1.61e-10	***



Injury Regression Model for TOT_ADT^2 (excludes outlier)

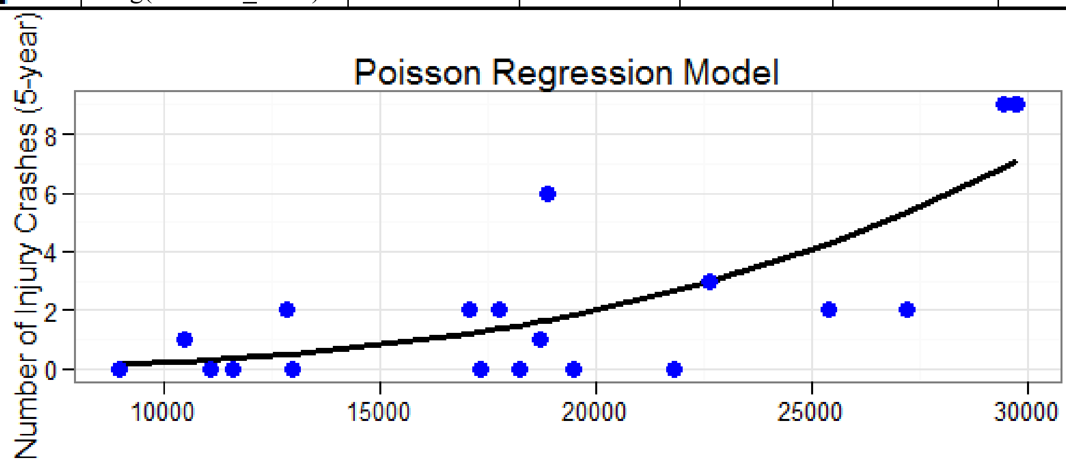


Injury CURE Plot for TOT_ADT^2 (excludes outlier)

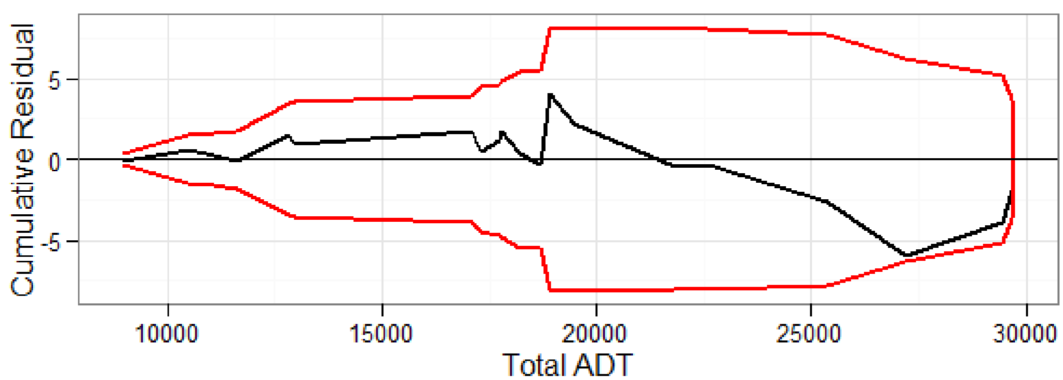
INJURY REFERENCE MODEL WITH [LN(TOT_ADT)] (INCLUDES OUTLIER)

Injury Crash Reference Model with [ln(TOT_ADT)] (includes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp(\beta_1) \times (Total\ Entering\ ADT)^{\beta_2}$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-30.979	5.793	-5.347	8.93e-08	***
β_2	log(cd$TOT_ADT)	3.198	0.574	5.571	2.53e-08	***



Injury Regression Reference Model with [ln(TOT_ADT)] (includes outlier)

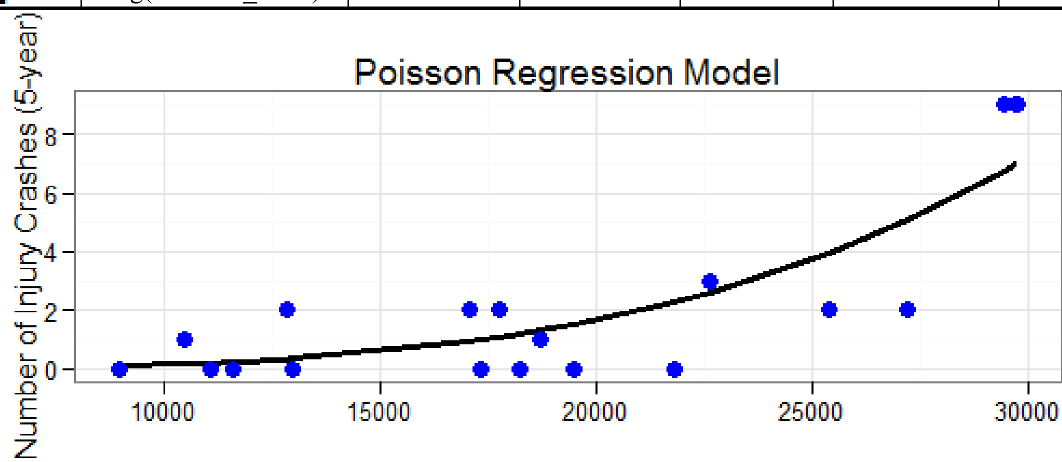


Injury Reference Model CURE Plot with [ln(TOT_ADT)] (includes outlier)

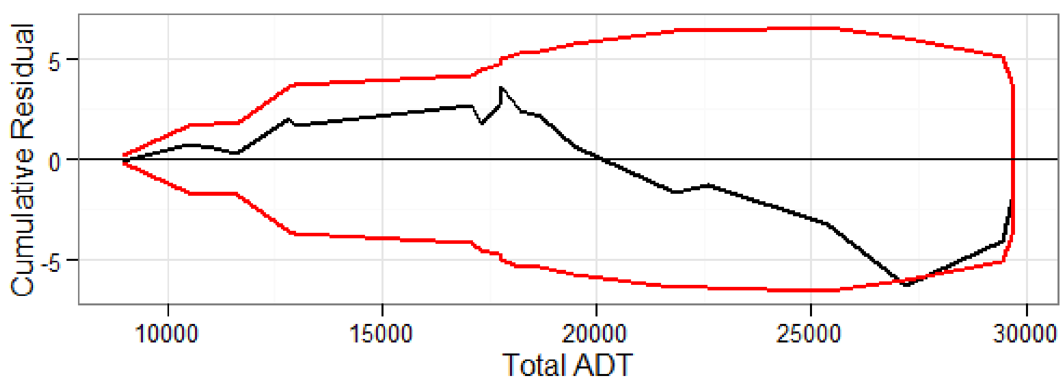
INJURY REFERENCE MODEL WITH [LN(TOT_ADT)] (EXCLUDES OUTLIER)

Injury Reference Model with [ln(TOT_ADT)] (excludes outlier)

Model:	Poisson Regression Model					
Equation:	$Total\ Number\ of\ Injury\ Crash\ (5\ years) = Exp(\beta_1) \times (Total\ Entering\ ADT)^{\beta_2}$					
Coefficients	Input Variable	Estimate	Std. Error	z value	Pr(>|z|)	Significance
β_1	(Intercept)	-35.5153	6.6570	-5.335	9.55e-08	***
β_2	log(cd$TOT_ADT)	3.6371	0.6574	5.532	3.16e-08	***



Injury Regression Reference Model for [ln(TOT_ADT)] (excludes outlier)



Injury Reference Model CURE Plot for [ln(TOT_ADT)] (excludes outlier)

APPENDIX E:
INDIVIDUAL WASHINGTON SITE SUMMARIES

SITE #24: N. 5th Ave. at Fruitvale Blvd., Yakima County [WA-S3-1]

Source: Google Maps

Basic Information	
Intersecting Approaches	N. 5th Ave.
	Fruitvale Blvd.
County	Yakima
State	WA
Type	Single
Number of Legs	3
Year of Completion	2004

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	127	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	83	Entry Alignment	Center
Truck Apron Width (ft)	14	Offset Alignment	0
Minimum Lane Width (ft)	22	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	8	Number of Crosswalks	3
Sidewalk Width (ft)	8	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #24: N. 5th Ave. at Fruitvale Blvd., Yakima County [WA-S3-1] (continued)

Crash Distribution by Year after the Construction of Roundabout (2004 – 2007)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2004	0	0	0	1	1	1	2
2005	0	0	0	1	1	1	2
2006	0	0	1	0	0	1	1
2007	0	0	0	0	1	0	1
Total Crashes (2004 – 2007)	0	0	1	2	3	3	6

SITE 25: SR 903 at Bullfrog Rd., Kittitas County [WA-S3-2]

Source: Google Maps

Basic Information	
Intersecting Approaches	SR 903
	Bullfrog Rd.
County	Kittitas
State	WA
Type	Single
Number of Legs	3
Year of Completion	2005

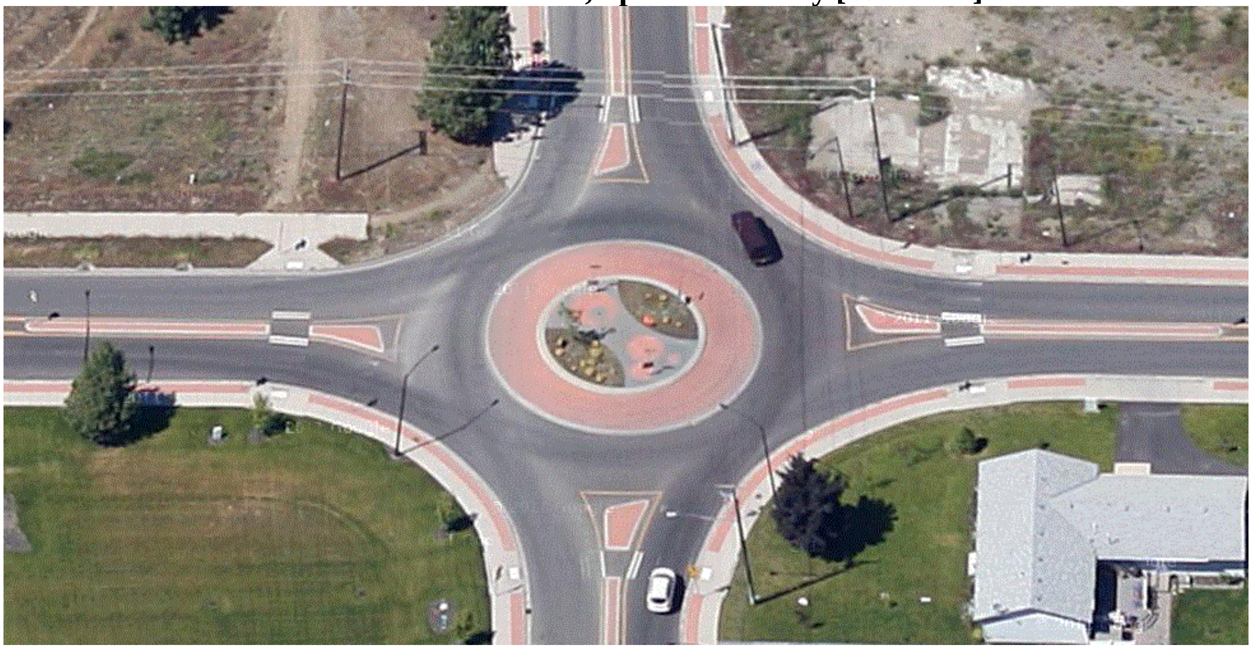
Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	136	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	8
Central Island Diameter (ft)	104	Entry Alignment	Center
Truck Apron Width (ft)	16	Offset Alignment	0
Minimum Lane Width (ft)	17	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	13	Number of Crosswalks	3
Sidewalk Width (ft)	13	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #25: SR 903 at Bullfrog Rd., Kittitas County [WA-S3-2] (continued)

Crash Distribution by Year after the Construction of Roundabout (2005 – 2008)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2007	0	0	0	0	1	0	1
2008	0	0	0	0	2	0	2
Total Crashes (2005 – 2008)	0	0	0	0	3	0	3

SITE #26: N Crestline St. at E Lincoln Rd., Spokane County [WA-S4-3]



Source: Google Maps

Basic Information	
Intersecting Approaches	N Crestline St.
	E Lincoln Rd.
County	Spokane
State	WA
Type	Single
Number of Legs	3
Year of Completion	2006

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	114	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	70	Entry Alignment	Center
Truck Apron Width (ft)	14	Offset Alignment	0
Minimum Lane Width (ft)	22	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	10	Number of Crosswalks	4
Sidewalk Width (ft)	10	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #26: N Crestline St. at E Lincoln Rd., Spokane County [WA-S4-3] (continued)

Crash Distribution by Year after the Construction of Roundabout (2006 – 2009)

Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2006	0	0	0	0	1	0	1
2007	0	0	1	0	1	1	2
2008	0	0	0	0	4	0	4
2009	0	0	0	0	1	0	1
Total Crashes (2006 – 2009)	0	0	1	0	7	1	8

Traffic Volume Information (2006-2007, 2009-2010)

Street	Location of Leg	Direction	Volume Type	AADT/ADT
N. Crestline St.	N	Both	ADT	4200, 4500
E. Lincoln Rd.	E	Both	ADT	---, 3537
N. Crestline St.	S	Both	ADT	6500, 7600
E. Lincoln Rd.	W	Both	ADT	1800, 5000
Major ADT			6500 (2006-2007), 7600 (2009-2010)	
Minor ADT			1800 (2006-2007), 5000 (2009-2010)	
Total ADT			8300 (2006-2007), 12600 (2009-2010)	

SITE #27: SR 206 at N Bruce Rd., Spokane County [WA-S4-4]

Source: Google Maps

Basic Information	
Intersecting Approaches	SR 206 / E Mt. Spokane Park Dr.
	N Bruce Rd.
County	Spokane
State	WA
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	0
Truck Apron	1	Pedestrian Refuge Area	0
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	0	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	130	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	90	Entry Alignment	Center
Truck Apron Width (ft)	15	Offset Alignment	0
Minimum Lane Width (ft)	18	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	0
Sidewalk Width (ft)	0	Number of Approach Curves	4
Number of Approach with Bypass for Right Turn	0		

SITE #27: SR 206 at N Bruce Rd., Spokane County [WA-S4-4] (continued)

Crash Distribution by Year after the Construction of Roundabout (2005 – 2008)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2005	0	0	0	0	2	0	2
2006	0	0	0	0	1	0	1
2008	0	0	0	0	1	0	1
Total Crashes (2005 – 2008)	0	0	0	0	4	0	4

SITE #28: US 395 at Hawthorne Ave./W. Glenn Ave., Stevens County [WA-S5-5]

Source: Google Maps

Basic Information	
Intersecting Approaches	US 395 / S. Main St.
	E. Hawthorne Ave. / W Glenn Ave.
County	Stevens
State	WA
Type	Single
Number of Legs	5
Year of Completion	2003

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	0
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	NA	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	NA	Entry Alignment	NA
Truck Apron Width (ft)	11	Offset Alignment	NA
Minimum Lane Width (ft)	26	Minimum Angle between Legs (degrees)	NA
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	5
Sidewalk Width (ft)	5	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #28: US 395 at Hawthorne Ave./W. Glenn Ave., Stevens County [WA-S5-5] (continued)

Crash Distribution by Year after the Construction of Roundabout (2003 – 2006)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2004	0	0	0	0	1	0	1
Total Crashes (2003 – 2006)	0	0	0	0	1	0	1

SITE #29: Borgen Blvd./112th St. NW at Peacock Hill Ave. NW, Pierce County [WA-S4-6]

Source: Google Maps

Basic Information	
Intersecting Approaches	Borgen Blvd. / 112th St. NW
	Peacock Hill Ave. NW
County	Pierce
State	WA
Type	Single
Number of Legs	4
Year of Completion	2006

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	97	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	70	Entry Alignment	Center
Truck Apron Width (ft)	10	Offset Alignment	0
Minimum Lane Width (ft)	14	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	3
Sidewalk Width (ft)	10	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #29: Borgen Blvd./112th St. NW at Peacock Hill Ave. NW, Pierce County [WA-S4-6] (continued)

Crash Distribution by Year after the Construction of Roundabout (2006 – 2008)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2006	0	0	0	0	2	0	2
2007	0	0	0	0	1	0	1
2008	0	0	0	0	1	0	1
Total Crashes (2006 – 2008)	0	0	0	0	4	0	4

SITE #30: 36th St. NW at Point Fosdick Dr. NW, Pierce County [WA-S4-7]

Source: Google Maps

Basic Information	
Intersecting Approaches	36th St. NW
	Point Fosdick Dr. NW
County	Pierce
State	WA
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	96	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	68	Entry Alignment	Center
Truck Apron Width (ft)	8	Offset Alignment	0
Minimum Lane Width (ft)	12	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	4
Sidewalk Width (ft)	10	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #30: 36th St. NW at Point Fosdick Dr. NW, Pierce County [WA-S4-7] (continued)

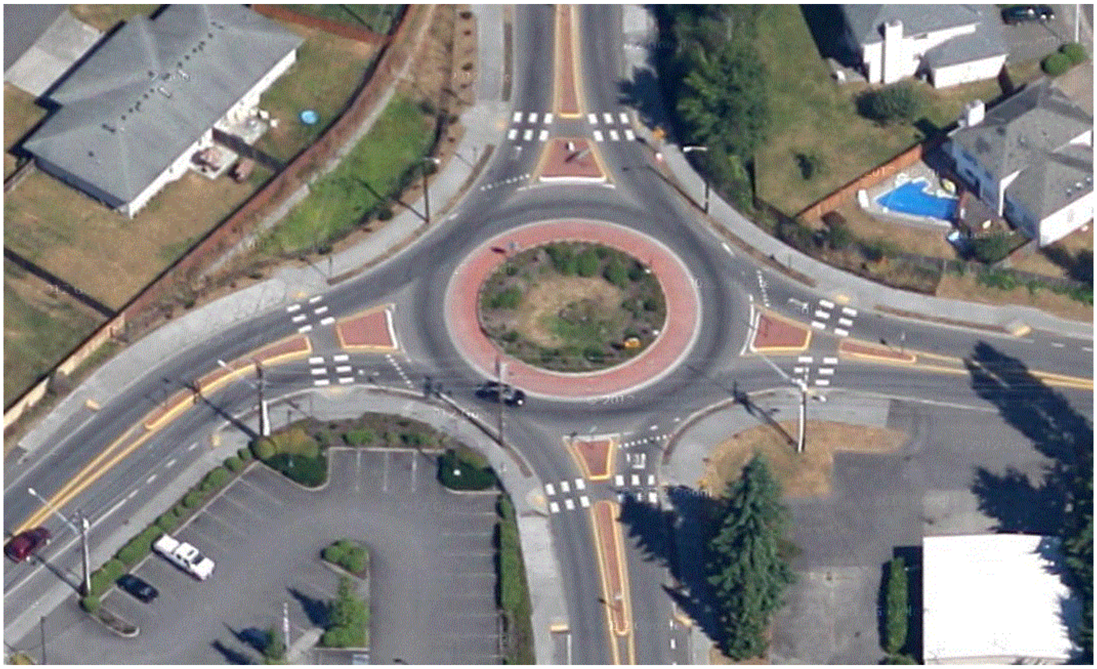
Crash Distribution by Year after the Construction of Roundabout (2006 – 2008)

Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2007	0	0	1	0	0	1	1
2008	0	0	0	0	1	0	1
Total Crashes (2006 – 2008)	0	0	1	0	1	1	2

Traffic Volume Information (2006, 2008)

Street	Location of Leg	Direction	Volume Type	AADT/ADT
Point Fosdick Dr. NW	N	Both	ADT	---, ---
36th St. NW	E	Both	ADT	8100, 5950
Point Fosdick Dr. NW	S	Both	ADT	4250, 3825
36th St. NW	W	Both	ADT	---, ---
Major ADT		8100, 5950		
Minor ADT		4250, 3825		
Total ADT		12350, 9775		

SITE #31: Shoultes Rd. at 51st Ave. NE / 108th St. NE, Snohomish County [WA-S4-8]



Source: Google Maps

Basic Information	
Intersecting Approaches	Shoultes Rd. / 108th St. NE
	51st Ave. NE / Shoultes Rd.
County	Snohomish
State	WA
Type	Single
Number of Legs	4
Year of Completion	2006

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	114	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	5
Central Island Diameter (ft)	83	Entry Alignment	Center
Truck Apron Width (ft)	11	Offset Alignment	0
Minimum Lane Width (ft)	15	Minimum Angle between Legs (degrees)	73
Bicycle Lane/Path Width (ft)	8	Number of Crosswalks	4
Sidewalk Width (ft)	8	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	0		

SITE #31: Shoultes Rd. at 51st Ave. NE / 108th St. NE, Snohomish County [WA-S4-8] (continued)

Crash Distribution by Year after the Construction of Roundabout (2005 – 2008)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2005	0	1	1	0	1	2	3
2006	0	0	0	0	3	0	3
2007	0	0	0	1	0	1	1
2008	0	0	1	0	1	1	2
Total Crashes (2005 – 2008)	0	1	2	1	5	4	9

SITE #32: SR 538 / E College Way at SR 9, Skagit County [WA-S3-9]

Source: Google Maps

Basic Information	
Intersecting Approaches	SR 538 / E College Way
	SR 9
County	Skagit
State	WA
Type	Single
Number of Legs	3
Year of Completion	2007

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	136	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	104	Entry Alignment	Center
Truck Apron Width (ft)	14	Offset Alignment	0
Minimum Lane Width (ft)	18	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	2
Sidewalk Width (ft)	7	Number of Approach Curves	2
Number of Approach with Bypass for Right Turn	0		

SITE #32: SR 538 / E College Way at SR 9, Skagit County [WA-S3-9] (continued)

Crash Distribution by Year after the Construction of Roundabout (2007 – 2010)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2009	0	0	0	0	1	0	1
2010	0	0	0	0	1	0	1
Total Crashes (2007 – 2010)	0	0	0	0	2	0	2

SITE #33: Evergreen Pkwy. NW at McCann Plaza Dr, Thurston County [WA-S3-10]

Source: Google Maps

Basic Information	
Intersecting Approaches	Evergreen Pkwy. NW
	McCann Plaza Dr
County	Thurston
State	WA
Type	Single
Number of Legs	3
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	NA	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	NA	Entry Alignment	Center
Truck Apron Width (ft)	9	Offset Alignment	0
Minimum Lane Width (ft)	18	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	3
Sidewalk Width (ft)	9	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #33: Evergreen Pkwy. NW at McCann Plaza Dr, Thurston County [WA-S3-10] (continued)

Crash Distribution by Year after the Construction of Roundabout (2005 – 2008)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2006	0	0	0	0	1	0	1
2008	0	0	0	1	2	1	3
Total Crashes (2005 – 2008)	0	0	0	1	3	1	4

SITE #34: Henderson Blvd. SE at 14th Ave. SE, Thurston County [WA-S4-11]

Source: Google Maps

Basic Information	
Intersecting Approaches	14th Ave. SE
	Henderson Blvd. SE
County	Thurston
State	WA
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	0	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	0		

Geometric Design Information			
Inscribed Circle Diameter (ft)	125	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	86	Entry Alignment	Center
Truck Apron Width (ft)	13	Offset Alignment	0
Minimum Lane Width (ft)	19	Minimum Angle between Legs (degrees)	90
Bicycle Lane/Path Width (ft)	0	Number of Crosswalks	2
Sidewalk Width (ft)	15	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	1		

SITE #34: Henderson Blvd. SE at 14th Ave. SE, Thurston County [WA-S4-11] (continued)

Crash Distribution by Year after the Construction of Roundabout (2005 – 2008)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2006	0	0	0	0	2	0	2
2008	0	0	0	0	1	0	1
Total Crashes (2005 – 2008)	0	0	0	0	3	0	3

Traffic Volume Information (2011)

Street	Location of Leg	Direction	Volume Type	AADT/ADT
Henderson Blvd.	N	Both	ADT	10,820
14th Ave.	E	Both	ADT	6,829
Henderson Blvd.	S	Both	ADT	7,695
14th Ave.	W	Both	ADT	---
Major ADT			10,820 vpd	
Minor ADT			6,829 vpd	
Total ADT			17,649 vpd	

SITE #35: Keene Rd. at Bombing Range Rd., Benton County [WA-S4-12]

Source: Google Maps

Basic Information	
Intersecting Approaches	Keene Rd.
	Bombing Range Rd.
County	Benton
State	WA
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	148	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	0
Central Island Diameter (ft)	111	Entry Alignment	Center
Truck Apron Width (ft)	12	Offset Alignment	0
Minimum Lane Width (ft)	20	Minimum Angle between Legs (degrees)	80
Bicycle Lane/Path Width (ft)	6	Number of Crosswalks	4
Sidewalk Width (ft)	6	Number of Approach Curves	1
Number of Approach with Bypass for Right Turn	1		

SITE #35: Keene Rd. at Bombing Range Rd., Benton County [WA-S4-12] (continued)

Crash Distribution by Year after the Construction of Roundabout (2005 – 2007)

Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2007	0	0	0	1	2	1	3
Total Crashes (2005 – 2007)	0	0	0	1	2	1	3

Traffic Volume Information (2007)

Street	Location of Leg	Direction	Volume Type	AADT/ADT
Bombing Range Rd.	N	Both	ADT	---
Keene Rd.	E	Both	ADT	3915
Bombing Range Rd.	S	Both	ADT	2716
Keene Rd.	W	Both	ADT	1799
Major ADT		3915 vpd		
Minor ADT		2716 vpd		
Total ADT		6631 vpd		

SITE #36: Rainier Rd. SE at SE Balustrade Blvd. / 67th Ave. SE, Thurston County [WA-S4-13]

Source: Google Maps

Basic Information	
Intersecting Approaches	Rainier Rd. SE
	SE Balustrade Blvd. / 67th Ave. SE
County	Thurston
State	WA
Type	Single
Number of Legs	4
Year of Completion	2005

Inventory of Presence (1=presence; 0=absence)			
Raised Central Island	1	Marked Crosswalk	1
Truck Apron	1	Pedestrian Refuge Area	1
Bicycle Lane	0	Splitter Island	1
Bicycle Path	1	Signal Control	0
Sidewalk	1	Lighting	1
Combination of Sidewalk and Bicycle Path	1		

Geometric Design Information			
Inscribed Circle Diameter (ft)	147	Minimum Distance between Sidewalk and Curb of Inscribed Circle (ft)	5
Central Island Diameter (ft)	111	Entry Alignment	Center
Truck Apron Width (ft)	13	Offset Alignment	0
Minimum Lane Width (ft)	18	Minimum Angle between Legs (degrees)	80
Bicycle Lane/Path Width (ft)	10	Number of Crosswalks	4
Sidewalk Width (ft)	10	Number of Approach Curves	0
Number of Approach with Bypass for Right Turn	0		

SITE #36: Rainier Rd. SE at SE Balustrade Blvd. / 67th Ave. SE, Thurston County [WA-S4-13] (continued)

Crash Distribution by Year after the Construction of Roundabout (2006 – 2009)							
Year	Fatal	Serious Injury	Evident Injury	Possible Injury	PDO	Injury	Total
2006	0	0	0	0	2	0	2
2007	0	0	0	1	1	1	2
2009	0	0	1	0	1	1	2
Total Crashes (2006 – 2009)	0	0	1	1	4	2	6

Traffic Volume Information (2006)				
Street	Location of Leg	Direction	Volume Type	AADT/ADT
Ranier Rd. SE	N	Both	ADT	8532
SE Balustrade Blvd	E	Both	ADT	---
Ranier Rd. SE	S	Both	ADT	---
67th Ave. SE	W	Both	ADT	---
Major ADT		8532 vpd		
Minor ADT		---		
Total ADT		---		