EVALUATING SAFETY AND OPERATIONS OF HIGH-SPEED SIGNALIZED INTERSECTIONS

Final Report

SPR 660

Oregon Department of Transportation

EVALUATING SAFETY AND OPERATION OF HIGH-SPEED INTERSECTIONS

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by

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16. Abstract

This *Final Report* reviews a research effort to evaluate the safety and operations of high-speed intersections in the State of Oregon. In particular, this research effort focuses on four-leg, signalized intersections with speed limits of 45 mph or greater where the intersections are not in the immediate vicinity of other signalized intersections. This report includes a literature review of high-speed intersection safety treatment strategies, a description of the research methodology used in this project, and a summary of final results. The final results include crash conditions at these high-speed intersections, a format for evaluating safety at these and similar intersections, a hierarchy of safety treatment options, and a demonstration of the use of these tools through example analyses of eight Oregon intersections.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

*SI is the symbol for the International System of Measurement

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DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1.0 INTRODUCTION

Many rural intersections occur at locations with approaching operating speeds of 45 mph or greater. These locations often occur on rural or urbanized two-lane or multi-lane highways. When such an intersection is placed under signalized control, it is common for less alert drivers to be forced to execute rapid decelerations. This unexpected deceleration can result in a high number of rear-end or angle crashes. In the United States and Oregon, crashes at high-speed signalized intersections are a significant safety concern. For example, in the Oregon Department of Transportation (ODOT) 2006 Amendment One for the "Oregon Transportation Safety Action Plan" these high-speed signalized intersection crashes are specifically cited as key safety emphasis areas. ODOT continues to examine efforts to improve the transition between low and high-speed sections of State highways. Visibility, management, and decision zone requirements for high-speed intersections are natural complements to these current efforts.

The objective of this research is to study effective means for improving safety at isolated, high-speed, signalized intersections (sites with posted speed limits of 45 mph or greater and at least one approach isolated by one mile or greater, hereafter referred to as IHSSIs). The research seeks to answer questions about how decision makers can determine incremental measures that can enhance intersection safety. These measures include improved advanced signing, extended amber or all-red clearance intervals, modified decision zones based on alternative reaction times, enhanced signal visibility, and other technologies that can further increase safe vehicle operations at these high-crash locations.

To evaluate and improve current safety conditions, the Technical Advisory Committee (TAC), in conjunction with the research team, established four project main goals. First, this research provides average expected percentages and companion crash rates for four-leg IHSSIs. These expected values can be used to quickly detect an overrepresentation of crash types at a given intersection. Second, this project establishes a hierarchy of diagnosis strategies to treat a given overrepresentation of crash types. Third, the research team combined the expected crash values with other essential information for evaluating the safety and operations of these types of intersections into a logical reporting format. This format, referred to as the 'general template,' allows for more efficient future diagnosis and guidance mitigation. Finally, this report contains example applications of this procedure for eight sample intersections.

This report demonstrates the results of the research efforts to evaluate high-speed signalized intersections in Oregon. Chapter 2.0 summarizes the published literature for common and innovative treatments at high-speed signalized intersections. Chapter 3.0 then describes the research methodology used in this project. Chapter 4.0 provides research results and Chapter 5.0 discusses project conclusions. Chapter 6.0 specifically identifies the references cited in this document. Finally, the Appendices in this report contain tables, figures, and other information referenced throughout the report.

2.0 LITERATURE REVIEW

2.1 BACKGROUND

Intersections with approaching operating speeds of 45-mph or greater are often located on two-lane or multi-lane highways in rural areas. A survey of state departments (27 responses) by Jones and Sisiopiku (*2007*) revealed safety and operational concerns related to these intersections. The main safety concerns were red-light running, rear-end crashes, safe stopping of heavy vehicles, and right-angled crashes. The survey also listed operational concerns to include the wear on vehicular breaks and on the pavement surface at these intersection approaches as well as difficulty for heavy vehicles to accelerate at upgrade locations.

The sections that follow will present findings from a literature review covering the human, operational, and physical safety characteristics at high-speed intersections and identify a variety of candidate safety treatments that may be suitable for these locations. The review is limited to high-speed (45 mph or greater) signalized rural intersections when feasible.

2.2 DILEMMA AND DECISION ZONES AT HIGH-SPEED INTERSECTIONS

High-speed signalized intersections are often characterized by abrupt stops (by less alert drivers) and vehicular acceleration during the yellow signal indication. When considering stopping and deceleration behavior at traffic signals, dilemma zones and decision zones are of particular relevance.

Drivers are faced with a dilemma zone when it is not possible to execute a safe stop behind the stop bar or legally enter the intersection. When signal settings and site conditions create such a dilemma zone, the driver will be unable to make a safe decision. It is for this reason that site specific conditions such as cross-street width and approach speeds are considered when setting the yellow and all-red times for a signal (*Mannering, Washburn, & Kilareski 2009*).

The decision zone, also known as the Type II dilemma zone, refers to the distance and corresponding time that drivers have available to make a correct decision when approaching the intersection. The drivers must decide whether they can stop behind the stop bar or proceed safely through the intersection before the red indication. Urbanik and Koonce (*2007*) describe this zone as an “indecision” or “option” zone.

Research results regarding determining the specific boundaries of the decision zone varies. Zegeer (*1977*) initially quantified the zone as a static time duration based on approach operating speeds. He defined the time a vehicle occupies this zone as 4.2 to 5.2 seconds long and defined the start of the Type II dilemma zone as the point at which 90-percent of drivers would stop when presented with a yellow indication. He further defined the end of the Type II dilemma zone as the point at which only 10-percent of drivers would stop if presented with a yellow indication.

Liu et al. (*2007*) determined that this dilemma zone is in fact dynamic and depends on a number of factors: driving population, approaching speed, reaction time, acceleration/deceleration rates, and duration of the yellow interval. Rakha, El-Shawarby and Setti (*2007*), on the other hand, defined the decision zone as a function of driver age. They determined that the decision zone for older drivers 70 years of age or older is much shorter (1.5 seconds up to 3.2 seconds) than for drivers in the 20 to 30 year old range (1.85 seconds up to 3.9 seconds). They based their estimation on experimental results that defined the boundaries of the zone as a range between 10-percent and 90-percent probability of stopping (measured as vehicle time to intersection.

When developing the signal settings for an intersection, the *ITE Traffic Engineering Handbook* (*Pline ed. 1999*) provides a general formula shown as equation (2-1) that can be used to eliminate the dilemma zone. The yellow and clearance interval should be equal to or greater than the non-dilemma change period. However, this equation provides adequate yellow and clearance interval time based on an assumed perception-reaction time and so does not directly address challenges presented by the decision zone where drivers may have a variable perception-reaction time (PRT) value or vehicles on the intersection approach have a variety of approach speeds.

$$CP = t + \frac{v}{2a \pm 64.4\,g} + \frac{W\,L}{v}$$

(2-1)

Where

CP = non-dilemma change period (s)
t = perception-reaction time (usually 1 sec)
V = approach speed (ft/s)

g = percent grade (+ for upgrade, - for downgrade)

a = deceleration rate (ft/s^2)
W = width of intersection (curb to curb) (ft)
L = length of vehicle (usually 20 ft) (ft)

2.3 HUMAN FACTORS AT HIGH-SPEED SIGNALIZED INTERSECTIONS

At high-speed signalized intersections, PRT and braking behavior are of particular relevance. These two elements are reviewed in more detail in this section.

2.3.1 Perception-Reaction Time

PRT refers to the time interval that starts when an object enters the visual field of a driver and ends when the driver initiates a response. If various drivers' PRT values were plotted, they would resemble a left skewed normal distribution. As a result, PRT values should be evaluated by using references to the median and percentiles rather than averages (*Dewar & Olson, 2002*). Dewar and Olson (*2002*) determined that the majority of research results indicate that response time generally varies between 0.75 and 1.5 seconds when the driver is able to easily detect and readily identify the hazard (or situation) and have no problems during the decision or response time intervals.

Perchonok and Pollack (*1981*) distinguished four stages of PRT: detection, identification, decision, and response. In terms of PRT for high-speed intersections, each of these stages offers insight into likely errors and challenges that may potentially be addressed by the use of targeted countermeasures. In the *detection* stage, the driver is presented with the object within the visual field but may not be aware of it. This is particularly true when the driving environment is placing high demand on the driver, when the object is small, or when the object initially appears on the far side of the visual field. Detection is also affected by driver expectation. The *identification* stage is critical because it allows the driver to collect sufficient information to make an appropriate decision. The *decision* stage is where the driver actually decides on a particular action. This action is usually a speed change, a directional change, or both. In the case of a high-speed signalized intersection through movement, during the *response* stage the driver will decide to decelerate and stop behind the stop bar or to proceed through the intersection. In the case of a turning movement the driver will decelerate and laterally displace the vehicle into the appropriate lane to perform the turning movement.

2.3.2 Perception-Brake Time

Brake-reaction time, or perception-brake time, is particularly important when reviewing the human factors related to braking behavior at signalized intersections. This interval includes perception time and the time to complete the braking action. Green (*2000*) performed a critical review and a re-evaluation of brake-reaction time. He determined that braking time estimates from various sources differed by as much as a factor of four, likely resulting from differences in signals, responses, and conditions during testing. His analysis was limited to daylight time during clear weather and good visibility conditions and did not consider urgency as a key factor.

Information processing can be automatic or attentive. Automatic processing refers to responses to a common signal that are highly practiced. Attentive processing requires a driver to think more. When presented with an unusual situation, a driver needs to acquire more sensory input, recall memory to interpret the situation, and decide what response is warranted. Attentive processing is slower and the driver is more likely to make an error (*Kay 1971*). Another factor that can affect response time is the level of driver expectation. When approaching an expected traffic signal, the driver would anticipate potential changes in the light but would not know the timing of these changes (*Kay 1971*). However, when the presence of the signal itself is unexpected, driver expectancy is low and response times will be slower. Green (*2000*) also indicated that, in these cases, the movement by the driver will also be slower. He reported that basic reaction time for older drivers is generally slower; although some studies suggest that there is not a difference because older drivers tend to be more experienced (longer PRT but shorter decision time).

Braking behavior can also differ across age groups and gender. Bao and Boyle (*2007*) evaluated braking behavior at high-speed rural expressway intersections across younger (ages 18 to 25), middle-aged (ages 35-55), and older driver (ages 65 to 80) populations. Three different movement types were evaluated: crossing the intersection, turning left, and turning right. The braking profiles of younger and older drivers were distinctly different than observed for middle-age drivers. The middle-aged group had the highest frequency of complete stops, while the younger drivers were the least likely to come to a complete stop. The younger drivers delayed their initial response and then braked more suddenly and harder. Bao and Boyle concluded that the younger and older drivers tend to take higher risks at these intersections.

2.3.3 Elements in the Driving Task

Tijerina et al. (*1994*) and Chovan et al.(*1994*) identified the elements in the driving tasks of straight-path movements and left-turn crossing-path movements at intersections. The elements in these tasks and likely associated errors provide valuable insight into the approaches to and likely successes of particular countermeasures to address concerns at high-speed intersections. Table 2.1 summarizes these tasks.

Table 2.1: Driving Tasks in the Safe Negotiation of High-Speed Signalized Intersections

Straight-Path Maneuvers	Left-Turn Crossing Path Maneuvers
• Identify the intersection and appropriately reduce approach speed • Identify the status of the signal correctly • Determine whether sufficient time exists to cross if the signal changes from green to yellow • Foresee that the leading vehicle may suddenly decelerate on the approach to the intersection • Determine the presence or absence of cross traffic at the intersection • Determine whether the cross traffic, when present, presents a safety concern (this may include speed estimation, and vehicle behavior such as acceleration or deceleration. • Identify objects that may reduce sight distance and adjust approach speed in an effort to overcome it if it exists • Detect and expect other road users (such as pedestrians) that may affect the decision to proceed through the intersection or influence the manner in which the driver proceeds through the intersection	• Identify presence of intersection and intersection geometry • Activate turning signal in vehicle • Reduce speed sufficiently to allow for the accurate processing of critical information • Identify presence of traffic control device, along with characteristics such as phase timing • Correctly identify signal indication – includes correct perception of status (such as signal color, flashing/steady) • Take appropriate action based on signal indication • Identify any cross-traffic or oncoming traffic on the approaches to the intersection • Identify an appropriate gap for the left-turning maneuver if not prohibited by traffic signal • Correctly position the vehicle prior to execution of the left-turn movement as to maximize sight distance to oncoming approaching traffic • Identify the anticipated vehicle path of the oncoming approaching vehicle and anticipated vehicle behavior • Correctly adjust vehicle speed to execute the turning maneuver in a timely and safe manner. • Complete left turn maneuver successfully

Source: Tijerina et al. (*1994*) and Chovan et al. (*1994*) as summarized in (*Lee et al. 2004*)

2.4 CRASH EXPERIENCE AT HIGH-SPEED INTERSECTIONS

Two age groups exhibit higher crash risks at intersections: younger drivers (*Retting, Weinstein, & Solomon 2003*) and older drivers (*Keskinen, Ota, & Katila 1998; Guerriera, Manivannanb, & Nair 1999; Stamatiadis, Taylor, & McKelvey 1991; Zhang et al.2000*). As previously indicated these extreme driver age groups exhibit differences in perception-reaction time and braking behavior.

Three predominant crash types are of particular concern at high-speed signalized intersections: straight-path crashes, left-turn crossing-path crashes, and straight crossing-path crashes.

A rear-end crash is one of the most common straight-path crashes at high-speed intersections. Although a study of 476 signalized intersections in Florida by Wang and Abdel-Aty (*2006*) was not limited to high-speed intersections, their findings may be relevant in evaluating appropriate countermeasures at these intersection types. Their results indicate that the following factors are associated with an increase in rear-end crash potential: high traffic volumes on the minor and major approaches, left-turn protected phase on the minor approach, high posted speeds on major approach, and high population density areas. They found that the presence of turning lanes on the minor approaches, medians on minor approaches, and increased signal spacing were associated with a reduction in rear-end crash potential at an intersection.

In terms of left-turn crossing-path crashes, analysis of the 1991 General Estimating System (GES) data by Chovan et al. (*1994*) indicates that:

- The most common contributory factors were erroneous perceptions and sight distance restrictions (from vehicular presence).
- Older drivers tended to be overrepresented proportionally in this crash type.
- 15 percent of the crashes involved a signal violation.
- In 49 percent of crashes, the left-turning vehicle was unaware of the presence of oncoming vehicles.
- 30 percent of the left-turning drivers in these crashes underestimated the gap.

Intersection treatments that can target these critical crash types may help enhance safety at these high-speed intersections. The following section introduces some of these candidate treatments as identified in the published literature.

2.5 INTRODUCTION TO TREATMENTS AT HIGH-SPEED SIGNALIZED INTERSECTIONS

The objective for placement of candidate safety-based treatments at high-speed signalized intersections is primarily to increase driver expectancy in order to reduce the need for abrupt stops. The treatments that have been previously used and evaluated for this purpose can be categorized as active, passive, or other.

Active treatments include those involving adjustments to signal timing or the use of flashing lights. *Passive treatments* relate to physical modifications to the driving environment such as signs, geometric features, or surface treatments. These passive engineering treatments are generally static and do not adapt to traffic conditions. Other non-engineering measures for high-speed signalized intersections include enforcement traffic control devices and other related efforts. Any of these treatments can also be targeted towards specific user groups, such as heavy vehicles.

2.5.1 Active Treatments

There are two primary groupings of active treatments at high-speed intersections. The first refers to any treatment involving only dynamic advance warning, and the second refers to any treatment involving modification of signal timing in response to real-time site conditions. Detection features are often part of these active treatment approaches. The activation of these treatments is often impacted by the length of the brake zone, the dilemma zone, and the clearance zone (*Lee et al. 2004*).

2.5.1.1 Dynamic Advance Warning Treatments

There is extensive literature that focuses on the placement and performance of advance warning systems at high-speed intersections. The goal of advance warning treatments is to improve driver expectancy and thus alert the driver that he or she is approaching a high-speed intersection. The use of advance warning treatments can potentially increase driver awareness and, as a result, increase the length of the decision zone resulting in a gradual speed reduction and lower likelihood of red-light running events. Since these treatments can be active (by then adjusting signal timing) or passive (by simply providing the driver information), this summary only reviews the known active treatments. This review does not cover Advance Warning Flasher systems (AWF). These treatments are included as part of *Passive Treatments* (see Section 2.5.2).

The criteria used for activation of active advance warning treatments depend on several factors. These factors include the time required for the driver to brake (*Lee et al. 2004*), the time-to-collision (TTC) (*Green 2000*), and the decision-making distance (as previously reviewed).

2.5.1.1.1 Speed funnel

The concept of a speed funnel originated in Germany over 50 years ago and was tested as early as the 1960s in the United States. The speed funnel configuration establishes a system of dynamic signs that provide advisory speed guidance to drivers as they approach a high-speed intersection. If the signalized intersection operates under semi-actuated control, the system also includes sensors on both the major street and the cross street approaches so as to determine when the light may change unexpectedly. If the downstream traffic signal is expected to be green, the advisory speed signs provide higher speed information. If the downstream traffic signal is expected to change to a red indication, the advisory speed messages provide slower speeds. This treatment can then help optimize traffic flow by minimizing unnecessary speed reductions and can help enhance safety by alerting drivers to essential speed reductions when appropriate (*Dare 1969a; Dare*

1969b). Though this treatment promises to provide safety benefits, a simulation study performed for the Minnesota Department of Transportation determined that the cost of deploying a speed funnel is substantially greater than other effective candidate treatments (*SRF 2001*). Information regarding the effectiveness of this measure as it directly relates to safety is not available since this treatment has seen little use since its conception.

2.5.1.2 Signal Timing Adjustment Treatments

Signal timing adjustment treatments are primarily aimed at increasing the decision zone distance to accommodate alternative reaction or stopping times such as those for less alert drivers or for heavy vehicles.

2.5.1.2.1 Extension of Green Time

Extension of green time systems use multiple advance detectors along the high-speed approach and a controller to determine the appropriate extension time for a green indication. When the maximum green interval is reached or no vehicles are approaching the intersection, the controller ends the green phase (*Bonneson et al., 2002*). This treatment helps to reduce the number of vehicles caught in a decision zone and helps to reduce overall delays.

Zegeer and Deen (*1978*) performed two naïve before-after studies on a green time extension system. In the first, they observed a reduction in the frequency of total crashes of 54 percent as a result of the extension of green time system at three sites. In the second study, the crash rate was reduced by 35 percent at ten isolated intersections.

The Detection-Control System (D-CS) developed by the Texas Transportation Institute (TTI) is an example of a recently developed system that extends the green time. This system uses the number of vehicles in the dilemma zone and the number of vehicles waiting on the minor approaches to determine the optimum time to terminate the green indication. It uses two detectors located 800ft and 1000ft upstream of the major approaches to the intersection. When comparing the D-CS system with the traditional multiple-detector system, the D-CS system had a lower risk of red-light running, lower rear-end crash occurrence, reduction of delays and stops for the major approach, and overall reduction of intersection delay (*Zimmerman & Bonneson 2005*).

2.5.1.2.2 Enhanced Extension of Green Time

The principles of the standard green-extension system also apply to the enhanced green-extension system, but additional features are included for the enhanced system. These features may provide higher priority to heavy vehicles or allow for the through phases of the major roadway to terminate at different times. Two basic enhanced green-extension systems include the TTI Truck Priority System and the LHOVRA system that is used in Sweden. Each letter of the LHOVRA acronym stands for specific system functions, but a translation is not known. The

L-function provides truck priority. The H-function provides priority to all major-road vehicles. The O-function targets dilemma zone protection. The V-function varies the yellow timing. The R-function enhances permitted left-turns, and the A-function influences the all-red phase. The LHOVRA system allows the engineer to customize for specific site characteristics and he or she can use some or all of the functions. In general, this Swedish system is used primarily in urban areas (*Bonneson et al. 2002*).

The TTI Truck Priority System extends the green time and holds the green interval when the approaching heavy vehicle is within 500 ft of the stop line. The primary goal of this system is to reduce the amount of stopping by heavy vehicles. In a limited evaluation at one intersection, Sunkari and Middleton (*2000*) found that the system reduced the number of heavy vehicle stops by four-percent; this translated into reduced pavement damage and a reduction in delay.

Zimmerman (*2007*) evaluated a modification of the D-CS to provide additional dilemma zone protection for heavy vehicles. By increasing the dilemma zone for heavy vehicles by 1.5 to 7 seconds, the number of heavy vehicles in the dilemma zone was reduced by 47 percent.

2.5.1.2.3 Green Time Termination System

A *green time termination system* assesses the safety of through movements on the major roadway and delay on the minor approaches to determine the appropriate time to terminate the green phase.

The Self Optimizing Signal (SOS) system is an example of a green time termination system. The purpose of the SOS system is to prioritize the safety of traffic on the major approaches balanced with delay at the minor approaches to optimize the end of the green phase of the particular signal. This system is one of several that offer dynamic dilemma zone protection that permits the traffic controller to make modifications to the green time in an effort to enhance decision and dilemma zone operations. Kronborg and Davidsson (*1993*) found that SOS reduces the number of vehicles in the dilemma zone by as much as 38 percent, reduces red-light running by 16 percent, and reduces multiple vehicles in the dilemma zone by 58 percent.

TTI developed an Intelligent Detection-Control System (*Bonneson et al. 2002*). It predicts the presence of a vehicle in the dilemma zone on a per-vehicle basis and minimizes the number of vehicles in the dilemma zone. It offers the ability to process heavy vehicles (longer than passenger cars) as part of the optimization process.

2.5.1.2.4 Extension of Yellow Interval

A common signal modification is to extend the duration of the yellow interval so that when the driver of a vehicle becomes aware that the light is about to change, he or she can safely stop or continue through the intersection. By extending the yellow interval, drivers with slower reaction times or vehicles with diminished deceleration or acceleration capabilities can be accommodated safely. Results from extension of the yellow interval applications vary greatly.

Lee et al. (*2004*) argued that extension of the yellow interval only addresses crashes related to the Type II dilemma zone (the driver making improper decisions in the dilemma zone) and does not address crashes related to distraction. In a follow-up study Liu et al. (*2007*) determined that yellow indication extension may not eliminate the dilemma zones at high-speed intersections. They identified three groups of drivers: conservative, normal, and aggressive. Aggressive drivers tend to have a larger range of dilemma zones. In an analysis of six intersections, they increased the yellow time from 4.5 to 6.0 seconds and some drivers in the normal and aggressive driver population still experienced the Type II dilemma zone. The researchers evaluated two different safety improvements. In the first, three modules are used to extend the yellow or all-red indication to allow the driver to safely clear the intersection: a vehicle detection module, a driver behavior analysis module, and the signal control module. If a vehicle runs the red light, a ticket could be issued. In the second approach, classification, prediction, and dilemma zone distribution modules can be added. These additional modules allow the system to identify different potential for experiencing a dilemma zone based on specific site characteristics.

2.5.1.2.5 Provision of Flashing Amber Prior to Onset of Solid Amber

Mussa et al. (*1996*) evaluated the provision of flashing amber prior to the onset of solid amber in an urban setting with 45-mph approach speeds. In all cases the response times during the four-phase configuration were longer than for the three-phase configuration. They found that the four-phase option increased the Type II dilemma zone and that response times had much larger variability (indicating higher probability of rear-end crashes). They recommend that this measure be evaluated at high-speed intersections with low traffic density – i.e. locations where the consequence of red-light running would be more severe than a rear-end crash.

2.5.1.2.6 Blank-Out Overhead Dynamic Advance Warning Signal

Schultz et al. (*2007*) described an experimental implementation of the blank-out overhead dynamic advance warning signal (BODAWS) system on a four lane divided highway with a 60mph posted speed limit (64mph 85th percentile speed). The intersection was a skew intersection (30 degrees counterclockwise from perpendicular) with limited sight distance on one approach because of horizontal curvature. On the other major approach sight distance to the signal heads was limited by a pedestrian overpass. The system consisted of an overhead-mounted dynamic-variable sign that displays the words “PREPARE TO STOP” combined with an AWF system that allows for green extension. The initial assessment indicated that the system resulted in a statistically significant reduction in red-light running.

2.5.1.2.7 Left-Turn Phasing

Mueller et al. (*2007*) evaluated 101 urban high-speed intersections and found that protected left-turn phases had the lowest likelihood of crashes. When comparing the different left-turn phasing alternatives within the younger, middle-aged, and older driver groups, the highest likelihood of crashes was associated with protected/permitted and permitted phasing. It is unknown if these urban conditions would translate directly to the high-speed rural intersections of interest in this study.

2.5.1.2.8 Different Detector Configurations

Si, Urbanik and Han (*2007*) investigated four different detector configurations at high-speed signalized intersections and evaluated their effects on safety and efficiency. While they were unable to conclude that any one detector is better than another, they state that use of the Bonneson configuration published in the *Manual of Traffic Detector Design, 2nd Edition* results in less vehicles in the decision zone and a lower average total delay time (*Bonneson & McCoy 2005*).

2.5.2 Passive Treatments

Passive treatments represent countermeasures that do not involve modification of signal settings or devices that account for the state of the signal indication on the particular approach. Passive treatments generally provide consistent information to the driver without consideration for the real-time traffic conditions. A number of these treatments are summarized in this section and, where available, the effectiveness of the particular measure is also provided.

2.5.2.1 Advance Warning Flasher Systems

The AWF treatment can take many different forms, but often consists of a system of flashers and a Signal Ahead Sign (SAS). These measures are placed to allow adequate distance for the driver to detect and respond to the flasher and execute a safe stop. When the particular measure involves activation of the flashers based on the signal timing of the downstream intersection, the onset of the yellow interval is used as a reference point to provide adequate warning to drivers.

2.5.2.1.1 Types of AWF Systems

There are several different types of AWF systems: Prepare to Stop when Flashing (PTSWF), Flashing Symbolic Signal Ahead (FSSA), Continuous Flashing Symbolic Signal Ahead (CFSSA), and the Advance Warning for End-of-Green System (AWEGS) developed by TTI. Each of these systems is briefly discussed in the following sections.

Prepare to Stop when Flashing

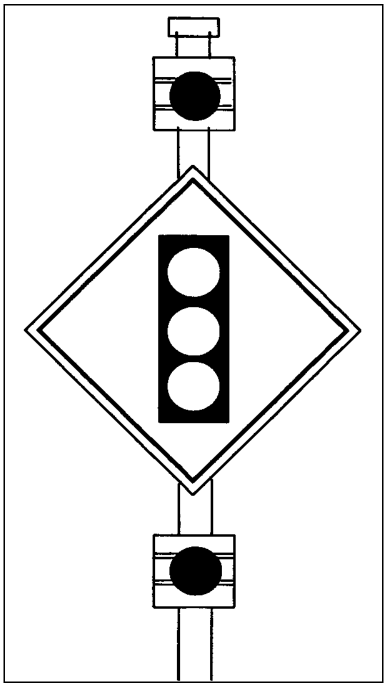
The PTSWF system consists of a warning sign with text “Prepare to Stop When Flashing” and two amber flashers. The amber flashers are activated a few seconds before the start of the yellow interval of the downstream intersection and deactivated at the end of the red interval (*FHWA & ITE 2003*).

Source: FHWA & ITE, 2003

Figure 2.1: Prepare to Stop when Flashing System

Flashing Symbolic Signal Ahead

The FSSA system consists of a warning sign with a schematic traffic signal (with solid red, yellow, and green circles) and two amber flashers. The amber flashers are activated a few seconds before the start of the yellow interval of the downstream intersection and deactivated at the end of the red interval (*Sayed, Vahidi, & Rodriguez 1999*). Figure 2.2 depicts a schematic of the FSSA configuration.



Source: Pant & Cheng, 2001

Figure 2.2: Flashing Symbolic Signal Ahead System

Continuous Flashing Symbolic Signal Ahead
The CFSSA system consists of a warning sign with a schematic traffic signal (with solid red, yellow, and green circles) and two amber flashers that continuously flash (regardless of the state of the downstream traffic signal) (*Sayed, Vahidi, & Rodriguez 1999*). This appearance of this system is identical to the FSSA system. The only difference is that the CFSSA system flashes constantly.

Advance Warning for End-of-Green System
AWEGS systems are often used alongside other AWF systems and utilize inductive loop detectors placed along an intersection approach to provide dilemma zone protection. TTI developed an AWEGS system for TxDOT with the primary goals of reducing red-light running and improved dilemma zone protection for heavy vehicles and high-speed vehicles. It is currently only installed at a few selected locations (*Messer et al. 2004*).

2.5.2.1.2 Evaluation of AWF Systems

Sayed, Vahidi, and Rodriguez (*1999*) list two key considerations for AWF installations: location of the AWF measure to allow for driver response and timing of the onset of the yellow indication. Klugman, Boje, & Belrose (*1992*) reported that some agencies use primarily engineering judgment when deciding on installations. The effectiveness of AWF systems, according to Sayed, Vahidi, and Rodriguez (*1999*), should be measured by one or more of the following: a reduction in crash frequency, a reduction in the approach speed of vehicles, and a reduction in particular traffic conflict types. A Minnesota report indicates that their typical installation of AWF systems is in response to locations with observed high speeds, isolated or unexpected signalized intersection location, limited sight distance, marginal dilemma zone, crash history, or based on engineering judgment (*Farraher, Weinholzer, & Kowski 1999*).

The following list represents research results for the general effects of AWF systems:

- A reduction in right-angle, rear-end, and total crash rates (multivariate study of 40 intersections with 10 years of crash data by Gibby, Washington, and Ferrara (*1992*));
- A re intersections with 10 years of crash data by Gibby, Washington, and Ferrara (1992));
- Reductions or increases in right-angle, rear-end, and total crash rate depending on location (simple before-after study of 14 intersections with 6 years of crash data by Klugman, Boje, and Belrose (*1992*)); and
- Sayed, Vahidi, and Rodreguez (*1999*) (multivariate study of 25 intersections) determined that AMF systems are associated with an average reduction in rear-end, severe, and total crash frequency by 8-percent, 14-percent, and 18-percent respectively, but found that the reductions are not statistically significant. duction in the proportion of nighttime crashes (multivariate study of 40

When studying particular AWF systems, the impacts of these systems are less clear. A simulator study indicated that the FSSA sign is more easily understood and the PTSWF sign is more likely to be identified incorrectly (*Sabra 1985*). However, in an Ohio study, Pant and Huang (*1992*) determined that FSSA and PTSWF have the same effect on driving behavior. They recommended the use of the CFSSA sign rather than the FSSA and PTSWF signs. They found that approach speeds tend to increase on tangent sections with PTSWF and FSSA systems when the signal indication was green (the flashers were not active) compared to when the flashers were active. This was similar to the findings by Klugman, Boje, and Belrose (*1992*). McCoy and Pesti (*2003*) compared two PTSWF systems, the first system was the conventional PTSWF system with multiple detectors at several locations on the approach and the second system had a single advance detector. With a fixed maximum allowable headway of 3 seconds, the single advance detector reduced the likelihood of loss of dilemma-zone protection. Unfortunately, this detector strategy also narrows the range of speeds for which it provides dilemma-zone protection. The researchers suggested a modification of the single detector installation to resolve this limitation.

In terms of crash reduction, Baker, Clouse, and Karr (*1980*) found that the PTSWF sign significantly reduced total, rear-end, property-damage only, and crashes contributed to trucks. Styles (*1982*) found that the flashing Red Signal

Ahead (RSA) sign successfully reduced right-angle crashes at sign-obstructed signalized intersections. The RSA sign appeared to be more effective in reducing total and rear-end crashes on curved approaches.

When reviewing the impact on traffic conflicts, Klugman, Boje, and Belrose (*1992*) determined that red-light running violations were consistently higher at locations without AWF systems. Pant and Xie (*1995*) compared the different systems and found that the likelihood of red-light running was twice as high with CFSSA signs compared to the other systems. In addition, they determined that PTSWF signs are associated with a higher incidence of abrupt stops when compared to other AWF systems. At two intersections with AWEGS, the incidence of red-light running reduced by 40 to 45-percent (*Messer et al. 2004*).

Sayed, Vahidi, and Rodreguez (*1999*) compared crash frequencies at locations with AWF in British Columbia. AWFs are considered for facilities with a posted speed of 43.5 mph (70 km/h), limited sight distance, a grade on the approach to the intersection, or locations where drivers transition from high-speed facilities into more developed land-use areas. Using 25 sites, their research suggests that AWF benefits increase as minor approach traffic increases. In other words, the benefits of AWF are negligible where minor approach volumes are low (average annual daily traffic (AADT) of 3,000). Consistent crash reduction was associated with high minor approach volumes (AADT of 18,000).

2.5.2.2 "Signal Ahead" Pavement Markings

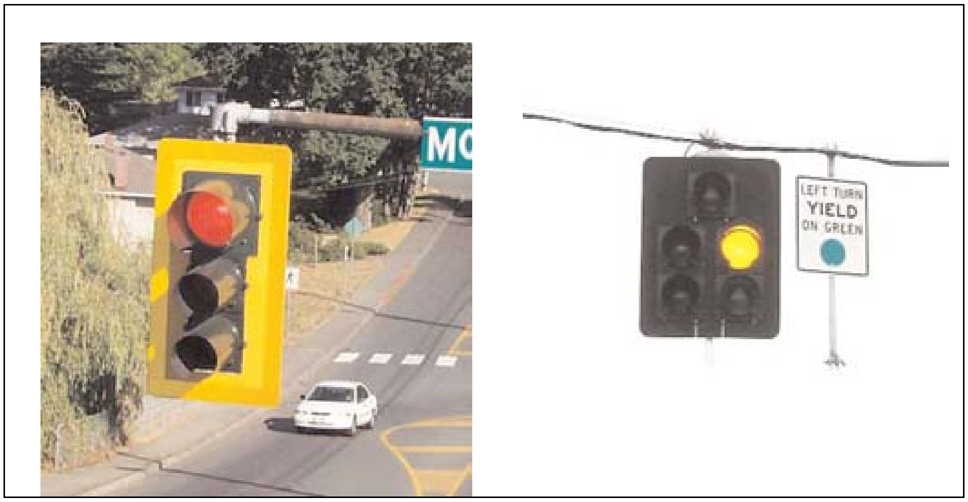
An alternative to conventional traffic signs is the use of "Signal Ahead" pavement markings. Radwan et al. (*2006*) evaluated "Signal Ahead" pavement markings with a driving simulator and observed a reduction in red-light running from 3.27 percent to 1.27 percent. In addition, Yan et al. (*2009*) used a simulator to determine that the "Signal Ahead" markings result in lower deceleration rates for higher speed intersections; however, they do not appear to significantly influence the driver's brake response time.

2.5.2.3 Improve Traffic Signal Visibility

According to Antonucci et al. (*2004*), drivers may not be able to see traffic signals because the signals are blocked by physical objects, obscured by weather conditions, or surrounded by extraneous signs. Inadequate visibility of traffic signals may contribute to a driver's inability to stop at an intersection. Techniques for improving traffic signal visibility include installation of additional signal heads, installation of visors to shade the signal lenses from sunlight, installation of backplates, installation of 12-inch signal lenses instead of 8-inch signal lenses, and relocation of extraneous signs. Additional details about the installation of backplates are provided below. Two more examples of improving traffic signal visibility, high-intensity strobe lights and light-emitting diode (LED) signals, are also discussed.

2.5.2.3.1 BackPlates on Traffic Signals

Backplates are installed with traffic signals to increase the visual contrast of the signal with the surrounding environment, particularly on east-west approaches. There are two common backplate configurations: backplates with a dull black finish, and backplates with a yellow retro-reflective tape strip around the edge (*Rodegerdts et al.2004*). Miska, de Leur, and Sayed (*2002*) determined in an empirical Bayes before-after study that backplates with reflective yellow borders reduced insurance claims at 19 of 25 intersections by between 2.8 percent and 60.7-percent and increased claims at six intersections by 2.3 percent up to 20.6 percent. The average reduction in claims was 14 percent (a combined confidence interval for the measured reductions was not available).



Source: FHWA & ITE, 2003

Figure 2.3: Traffic Signals with Back Plates

2.5.2.3.2 High-Intensity Strobe Lights

High-intensity strobe lights are intended to increase the visibility of a traffic signal. Ordinarily these lights are installed inside the signal head lens and flash at one-second intervals during the red indication. Studies by Cottrell (*1994*) and Ryan (*1984*) show that this treatment does not have a statistically significantly effect on crash occurrence.

2.5.2.3.3 Light-Emitting Diode Traffic Signals

The recent trend in traffic signals is to replace traditional incandescent signals with LED signals because the LED units are more energy efficient, appear brighter, and last longer. Though this shift in technology appears to be determined, a report by the Traffic Engineering Division of the City of Little Rock, Arkansas (*2003*) lists a few additional considerations that may influence LED signal visibility:

- Incandescent bulbs stop emitting light and require immediate replacement when their single filament burns out. LED signals, however, contain several dozen LED diodes and will continue to function even after several individual diodes have failed.
- Reflectors behind incandescent bulbs can cause all three indications to appear illuminated during morning and evening hours when sunlight directly hits the traffic signal. LED signals do not require reflectors and do not experience this problem.
- LED signals tend to be visible from only one direction. Signals suspended from span wires should be tethered from both the top and the bottom to ensure correct orientation during high wind.
- LED signals do not generate as much heat as incandescent signals and may not be able to melt any snow or ice that can accumulate on the lenses during winter storms. Accumulation of snow or ice can greatly decrease visibility of the traffic signal.

2.5.2.3.4 Near-Side Signal Heads

According to the Federal Highway Administration's (FHWA) *Signalized Intersections: Informational Guide* (*Rodegerdts et al. 2004*), supplemental traffic signals may be installed on the near side of an intersection to increase visibility and are particularly useful on excessively wide intersections. The guide states that, "Supplemental pole-mounted traffic signals appear to reduce the number of fatal and injury collisions at an intersection, according to the limited research that has been done on their effectiveness at preventing collisions." Increased signal visibility and decreased angle collisions are the two specific safety benefits listed.

Additional information about the effects of near-side signal heads at high-speed intersections is not readily available.

2.5.2.4 Lighted Warning Signs

A technique common to urban regions is the use of warning signs that are backlit. These lighted warning signs require regular maintenance and so are rarely used at isolated, rural locations. Lyles (*1980*) did evaluate signs at hazardous rural intersections and found that lighted warning signs are more effective than unlighted warning signs in terms of speed reduction and increased awareness.

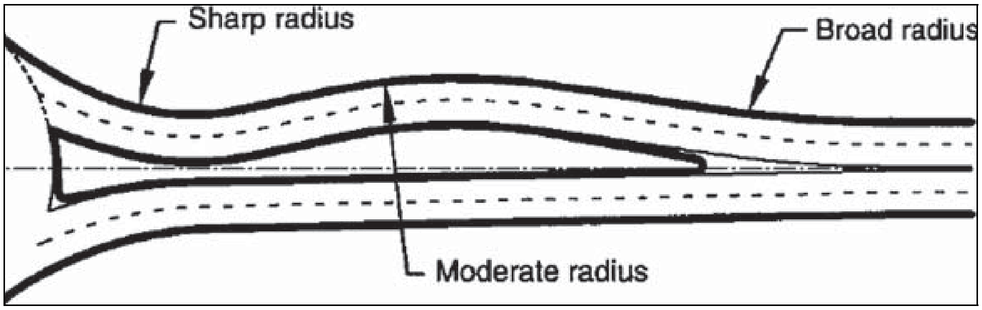
2.5.2.5 Surface Treatment (Skid Resistance)

Vehicles approaching high-speed intersections may be unable to stop before entering the intersection if there is not sufficient friction between the vehicle's tires and the road. This scenario is particularly likely if the driver is not anticipating a stop and does not immediately recognize the need to apply the brakes. The friction allowing vehicles to stop before an intersection is influenced by factors such as pavement age, condition, texture, mix characteristics, etc. (*FHWA & ITE, 2003*). Additionally, a film of water only

0.05 mm thick can reduce friction by 20 to 30 percent (*Ali, Al-Mahrooqi, & Taha 1999*). Rodegerdts et al. (*2004*) indicates that potential benefits of improved pavement treatments will help reduce wet-weather crashes, reduce angle crashes that are due to skidding, and reduce rear-end or sideswipe crashes that could be due to either skidding or braking.

2.5.2.6 Approach Curvature

According to Ray et al. (*2008*), approach curvature is a method used to slow traffic approaching an intersection. Drivers are forced to negotiate a series of curves with progressively decreasing radii that are designed to encourage a desired approach speed. This method is generally applied to roundabouts, but has potential for slowing vehicles at other intersections as well. It is recommended that approach curvature be used in addition to advisory speed signs. Other factors that should be considered before implementation include right of way issues, grading, driver workload, and heavy vehicle movements. Additional information about how approach curvature affects vehicle speed and safety is primarily available for roundabouts (*Ray et al. 2008*). It is worth noting, however, that adequate intersection sight distance should be maintained when deploying this approach curvature treatment.



Source: Ray et al. 2008

Figure 2.4: Approach Curvature

2.5.2.7 Transverse Rumble Strips

Rumble strips can be raised or depressed and provide both audible and tactile warnings to drivers (*Ray et al. 2008*). They are inexpensive to install and can span an entire lane or a region as narrow as the width of a vehicle's wheel path (allowing drivers familiar with the area to avoid the strip) (*Corkle, Marti, & Montebello 2001*). Ray et al. (*2008*) indicate that the installation of rumble strips led to statistically significant speed reductions at their perception-response time collection point (250 feet from the intersection, upstream of the rumble strip location), but that speed reductions were not observed at the rumble strip location or at the crash avoidance location (100 feet upstream of the intersection).

While there are plenty of studies examining speed reduction capabilities of rumble strips, simply looking at speed reduction may not be an effective way to determine the effectiveness of rumble strips for unfamiliar or inattentive drivers. This point is noted by Martens, Comte, and Kaptein (*1997*) who expand on studies by Cheng, Gonzalez, and Christensen (*1994*) and Ribeiro and Seco (*1997*). Researchers for both studies evaluated the effects of transverse rumble strips before pedestrian crossings. They found no reductions in driving speed, but found that the rumble strips improve safety by alerting drivers about the presence of the pedestrian crossing.

A study on sleep deprived drivers in a driving simulator found that the presence of rumble strips at an intersection approach prompts drivers to brake harder and earlier. This study also found that intersection approaches with rumble strips had statistically significantly slower mean speeds than intersection approaches without rumble strips (*Harder & Bloomfield, 2005*).

Other factors to consider for the installation of rumble strips include noise, damage caused by snow plows (for raised rumble strips), and adverse influences on motorcycles and bicycles (*Ray et al. 2008; Corkle, Marti, & Montebello 2001*).

Source: Corkle, Marti, & Montebello

Figure 2.5: Full Width Transverse Rumble Strips

Source: Corkle, Marti, & Montebello 2001

Figure 2.6: Wheel Path Transverse Rumble Strips

2.5.2.8 Transverse Pavement Markings

Transverse pavement markings, such as transverse bars or transverse chevrons, can be used to reduce speeds by modifying drivers' perceptions of the driving environment (*Rothenberg, Benavente, & Swift 2004*). Installation of markings at gradually decreasing intervals (called *optical speed bars*) produces an illusion of acceleration that may cause drivers to decelerate in response (*Martens et al. 1997*).

Transverse pavement markings have been used in many situations where drivers have maintained high speeds and may be somewhat desensitized to the driving environment. These transverse markings are often placed at approaches to roundabouts, intersections, horizontal curves, construction areas, and freeway off-ramps (*Griffin & Reinhardt 1995*).

Transverse pavement markings applied only along the edges of a lane are called *peripheral transverse markings*. Peripheral transverse markings are easy to install and maintain, are located outside of the wheel path of a vehicle (and thus do not contribute to slick surfaces on wet roads), and are very cost effective (*Katz, Duke, & Rakha 2006*). In a driving simulator test, Godley, Triggs, and Fildes (*2000*) found that transverse markings are more effective than peripheral transverse markings for the beginning of a treatment area, but both methods produce similar speed reductions overall. They also found that optical speed bars provide no significant benefit over constantly spaced bars.

Many studies have shown the effects of transverse pavement markings on speed. At high-speed intersections, however, it is important to examine the affect of these transverse markings on unfamiliar or inattentive drivers. Arnold and Lantz (*2007*) determined that even though installation of transverse pavement markings may result in initial speed reductions, the effect decreases as drivers become familiar with the markings. This result suggests that these markings are more effective on unfamiliar drivers than those who traverse the corridor on a regular basis.

Meyer (*2001*) examined the use of transverse pavement markings with both constant and decreasing spacing in work zones. He determined that the markings can create both a warning effect and a perceptual effect. Overall, he observed that following the placement of optical speed bars there was a reduction in mean speed, 85th percentile speed, and variation in operating speed.

Ray et al. (*2008*) note that "transverse pavement markings improve visibility and driver attention." Their study also documented the effects of transverse pavement markings at high-speed intersections after a 90-day acclimation period. Transverse pavement markings were found to be effective for minor reductions of speeds at high-speed intersections (mean speed reduction of 0.6 mph, standard error of 0.3 mph) and found to be slightly more effective for reducing speeds at the point where the driver would first see or react to an intersection (mean speed reduction of 0.9 mph, standard error of 0.4 mph).

Source: Arnold & Lantz 2007

Figure 2.7: Full Width Transverse Bars

Source: Arnold & Lantz, 2007

Figure 2.8: Peripheral Transverse Bars

2.5.2.9 Interchange or Grade Separation

Construction of interchanges or grade separation is an expensive proposition to improve intersection safety, so other options are generally considered first and the construction of the interchange is often reserved for when other measures have failed. This approach can be used at locations with excessive crash records, but is often applied simply to accommodate very high volumes. By physically separating the intersecting roads, crossing and turning traffic is minimized and congestion can be reduced. These reductions can decrease the frequency and severity of rear-end and angle crashes (*Antonucci et al. 2004*).

2.5.3 Other Treatments

Because many other treatments fall outside of conventional safety treatments, other countermeasures may be considered for dangerous intersections. Two common treatments include the use traffic control enforcement via red-light running cameras. This strategy should be used so as to help reduce intentional red-light violations, but it is more common to high volume intersections and so may not be appropriate for isolated high-speed rural intersections.

A second alternative treatment that is not a standard department of transportation option is the use of in-vehicle systems. The Intersection Crash Avoidance, Violation (ICAV) warning system targets red-light running crashes (crossing-path crashes) by providing a warning to the driver when there is a strong likelihood that the driver will run the red-light. The ICAV is an in-vehicle system that consists of four components: a driver-vehicle interface, a positioning component, in-vehicle sensors, and a dynamic algorithm for computations (*Lee et al. 2004*).

The Cooperative Collision Warning (CCW) project is an ongoing project by the University of California Partners for Advanced Transit and Highways (PATH) program and General Motors Research and Development. This system provides the driver with collision warnings through an in-vehicle system (*Misener, Sengupta, & Krishnan 2005*).

For the purposes of this literature review, the focus is on roadway related measures rather than in-vehicle devices or systems. As a result, the ICAV and the CCW are not explored in detail.

3.0 RESEARCH METHODOLOGY

The ODOT *Traffic Signal Policy and Guidelines* (*2006*) provides guidance for the design, timing, and placement of rural traffic signals. Specifically, this guideline indicates that traffic signals should generally not be installed at high-speed locations on rural highways. It further indicates that rural traffic signals are not anticipated by unfamiliar drivers on these higher speed facilities and this unexpected signal placement is likely to result in longer reaction times and consequently longer stopping sight distance.

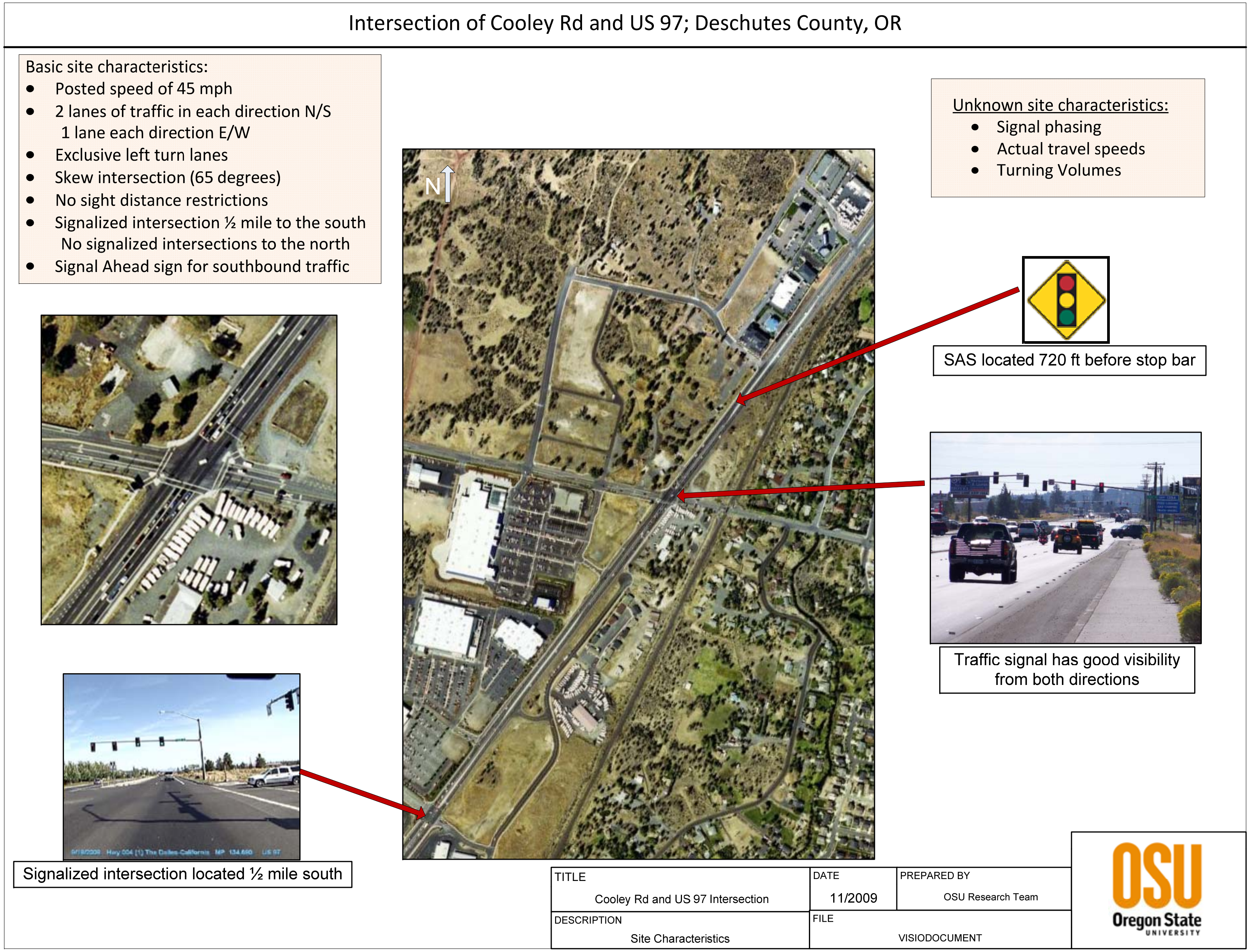
At select locations the use of traffic signals at these isolated intersections is deemed necessary. These high-speed signalized locations are the focus of this research. In an effort to assess the extent of safety issues at these intersection types, the research team performed a preliminary crash analysis at sample locations. The purpose of this effort was to focus the research on locations where safety risks appear to be greater and to demonstrate the types of readily available data that can be applied while investigating these intersections. To aid in the study of these intersections, the research team compiled a comprehensive list of Oregon's isolated, high-speed, signalized intersections (IHSSI) locations. This intersection list led to the creation of average crash rates and crash type percentages based on crash data from years 2003 to 2007. After collecting data and further analyzing eight case study intersections, the research team developed a general template to aid in future safety evaluations of IHSSIs.

3.1 HISTORIC SAFETY EVALUATION

ODOT currently does not maintain a data resource that can be used to directly identify specific traffic control devices at high-speed rural intersection locations. As a result, as an initial method for locating candidate case study locations, members of the research team reviewed several intersections using the online digital video log of the state highways.

The study data included information depicting current conditions at select case study locations via ODOT data, aerial photographs readily available via the internet, and crash history information. In order to evaluate historic safety conditions, the research team developed a graphic summary for multiple candidate locations. The figures indicate basic site characteristics, unknown site characteristics (to be collected in the field), traffic control devices, aerial photographs, and crash summaries. These graphics provide an initial demonstration of typical site and crash information. After identification of intersections for additional investigation (as will be discussed in Section 3.4), the research team created historic safety evaluations for each of the selected intersections.

Appendix C presents these historic safety evaluations. Figure 3.1 and Figure 3.2 demonstrate a sample historic safety evaluation of the intersection of Cooley Road and US 97 in Deschutes County, Oregon. The intersection will be used as an example case study throughout the body of this report.



Intersection of Cooley Rd and US 97; Deschutes County, OR

Basic site characteristics:

- Posted speed of 45 mph
- 2 lanes of traffic in each direction N/S
  1 lane each direction E/W
- Exclusive left turn lanes
- Skew intersection (65 degrees)
- No sight distance restrictions
- Signalized intersection ½ mile to the south
  No signalized intersections to the north
- Signal Ahead sign for southbound traffic

Unknown site characteristics:

- Signal phasing
- Actual travel speeds
- Turning Volumes

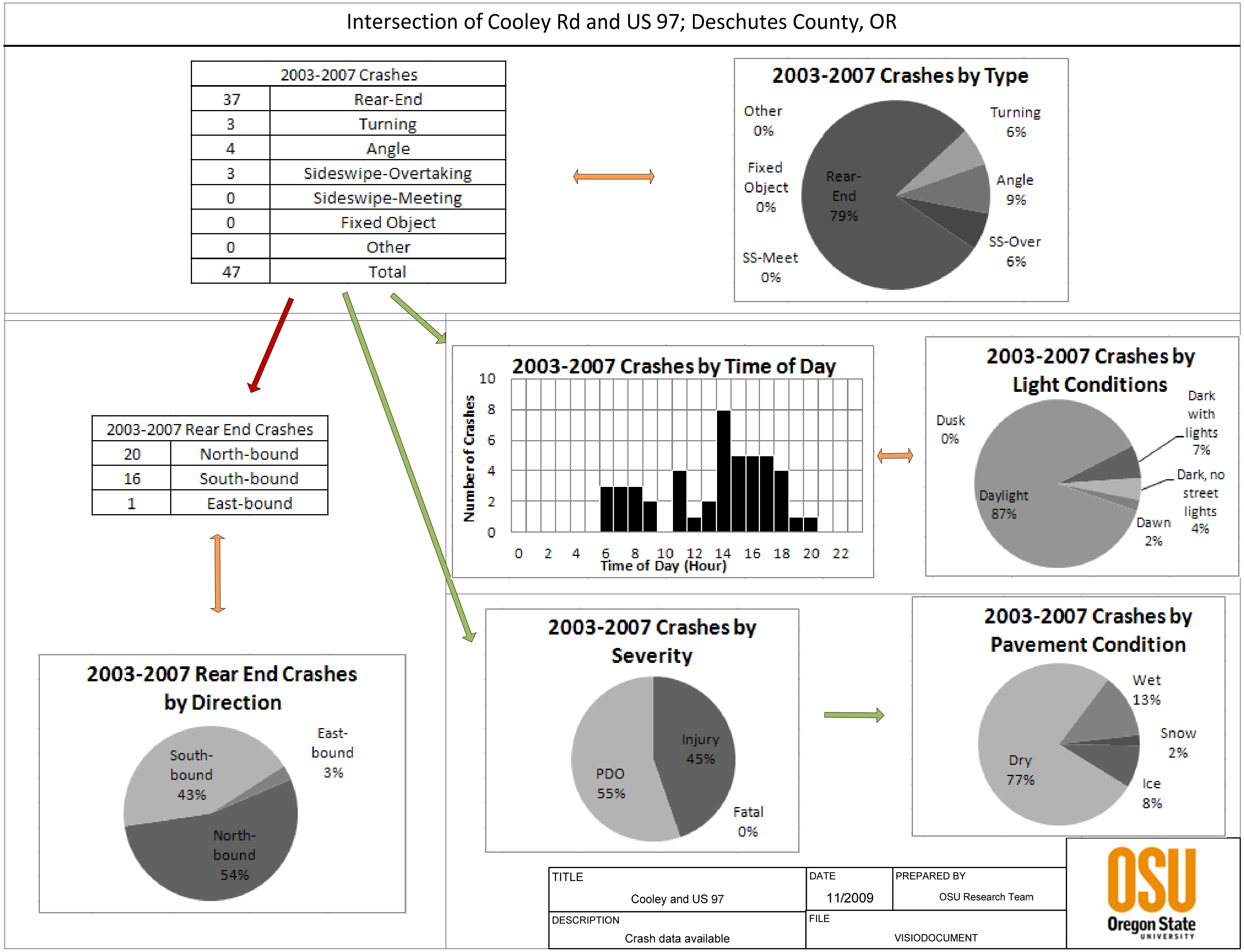
SAS located 720 ft before stop bar

Traffic signal has good visibility from both directions

Signalized intersection located ½ mile south

TITLE Cooley Rd and US 97 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE	VISIODOCUMENT

Figure 3.1: Example Case Study in Deschutes County, Oregon (Site Information)



Intersection of Cooley Rd and US 97; Deschutes County, OR

2003-2007 Crashes	
37	Rear-End
3	Turning
4	Angle
3	Sideswipe-Overtaking
0	Sideswipe-Meeting
0	Fixed Object
0	Other
47	Total

2003-2007 Rear End Crashes	
20	North-bound
16	South-bound
1	East-bound

TITLE Cooley and US 97	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

Figure 3.2: Example Case Study in Deschutes County, Oregon (Crash Data)

3.2 INTERSECTION IDENTIFICATION AND ANALYSIS

The ODOT external digital video logs permitted members of the research team to identify signalized intersections along state highways. After evaluating every signalized approach in the video log based on speed limits and distances from previous signalized intersections, the research team compiled a comprehensive list of IHSSI locations and sorted this list into categories of four-leg approach intersections (4-leg); T-intersections with the high-speed, isolated approach on the through road (T-thru); T-intersections where the high-speed, isolated approach ends (T-end); and any other configuration (Other). Table 3.1 displays the number of approaches identified within each category. This table also contains the number of intersections associated with these approaches because some of these intersections have multiple isolated, high-speed approaches (note that one intersection falls under both the T-thru and T-end categories, resulting in a total number of intersections different than the sum of the individual categories).

Table 3.1: Oregon Isolated, High-Speed, Signalized Intersections by Type

Intersection Type	Number of High-Speed Approaches	Number of Intersections
4-leg	75	60
T-thru	18	16
T-end	5	5
Other	9	8
Total	107	88

The four-leg intersections account for more than 80-percent of Oregon’s IHSSI locations. Due to this majority, the research team focused its efforts on these four-leg intersections.

Table 3.2 presents an example of data identified for the four-leg intersections. This table lists the “safety technology” associated with the sites as None (no advanced warning at all), SAS, or CFSSA. The research team further sorted the identified IHSSIs based on the speed limit at the intersection. Speed limit categories include 55 mph, 50 mph, 45 mph, and 45 mph sites with approaching speed limits of 55 mph upstream of the intersection. The entire set of locations is included in the appendix in Table B.1 and Table B.2. The included AADT values correspond to 2007 data and represent an averaged AADT value of the major approach from either side of the intersection. In situations where two major highways intersect, the highway with higher volumes determines the AADT. Table 3.2 also lists the number of standard lanes per direction for the major approach (one lane, two lanes, or a change from one to two lanes).

Table 3.2: Site Characteristics Summary for 45 mph IHSSIs

County	State Highway Number	Route Number	Cross Road	AADT (Major Road Approach)	Safety Technology[1]	Speed Limit	Change in Speed Limit	Standard Number of Lanes per Direction
				Speed Limit 45mph				
Umatilla	54	US 395	Punkin Center	13600	SAS	45	--	1
Benton	33	US 20	53rd	15200	SAS	45	--	1
Benton	33	US 20	SW 15th	19750	SAS	45	--	1
Lincoln	9	US 101	Devils Lake	16600	CFSSA	45	--	1
Tillamook	9	US 101	Wilson River Loop	13800	None	45	--	2
Lane	15	OR 126	69th	13500	None	45	--	2
Deschutes	7	US 20	27th	16750	None	45	--	2
Jackson	63	OR 99	South Stage Rd	15950	None	45	--	2
Multnomah	123	US 30BY	NE 60th	21550	None	45	--	2
Josephine	25	US 199	Dowell	19750	None	45	--	2
Linn	58	OR 99E	Off-ramp (milepoint 7.9)	8250	SAS	45	--	2
Jackson	272	OR 238	Sage	13500	SAS	45	--	2
Curry	9	US 101	Zimmerman	15650	SAS	45	--	2
Clatsop	9	US 101	Pacific Way	16400	SAS	45	--	2
Deschutes[2]	4	US 97	Cooley	31800	SAS	45	--	2
Yamhill	39	OR 18	Norton	14450	CFSSA	45	--	2

[1] SAS = Signal Ahead Sign; CFSSA = Continuous Flashing Symbolic Signal Ahead

[2] Shaded row represents example case study location highlighted in this report

3.3 EVALUATION OF CRASH TRENDS

The research team obtained crash data for the years from 2003 to 2007 for all of the four-leg IHSSI locations. Appendix B includes a summary of the data collected as well as the methods used to calculate the distances to determine which crashes were considered related to a specific intersection. Table 3.3 provides a summary of these boundary distances based on the speed limit at the intersection. As an example, the intersection of Cooley Road and US 97 is a 45 mph intersection located at milepoint 134.11. When collecting crash data for this intersection, the research team collected data coded as US 97 crashes between milepoints 134.03 and 134.19 (or 134.11 ± 0.08).

Table 3.3: Crash Distances Considered Intersection-Related

Speed Limit	Distance Considered
45 mph	.08 miles
50 mph	.09 miles
55 mph	.10 miles

Members of the research team also briefly evaluated each intersection to determine whether or not it was suitable for inclusion in later average crash frequency calculations. The final list of intersections does not include recently installed intersections, as determined by comparing satellite imagery to the digital video logs. The final list also excludes intersections with crash data that is incomprehensible or inconsistently coded. These problems and other issues resulted in the removal of 16 of the original 60 4-leg intersections. Appendix B contains a comprehensive list of the included intersections.

The research team used five years of crash data to determine trends in crashes and their associated traffic control configurations. These trends include average crash percentages and average crash rates and are sorted into categories based on associated speed limits. As shown in **Error! Reference source not found.** and Equation 3-1, *crash percentages* relate the number of crashes of one type of collision to the total number of crashes while *crash rates* relate the number of crashes of one type of collision to the AADT. *Equation 3-1* includes multiplication by a constant in order to make the numbers more functional (eliminates the use of extremely small values).

Crash Percentage Calculation **(3-1)**

Crash Percentage = (Number of one type of crash) / (Number of total crashes)

Equation 3-1: Crash Rate Calculation

Crash Rate = (Number of one type of crash in a 5 year period) x (10,000) / (AADT)

The research team members calculated the crash percentages and crash rates for each intersection and then averaged them to obtain expected crash trends. These trends, which will be presented in Section 4.1, allow for a comparison between a given individual intersection and average expected values for similar intersections.

Table 3.4 demonstrates a sample of raw crash statistics by collision type for 45 mph IHSSIs. Table 3.5 shows calculated values for the intersection of Cooley Road and US 97 (AADT = 31,800). This intersection will be used throughout the body of this report as an example case study. All other case studies are included in Appendix C.

Table 3.4: Number of Collisions by Type for 45mph IHSSIs

Route Number	Cross Road	Number of Collisions												
		Rear-End	Turning	Angle	Sideswipe-Overtaking	Non-Collision	Other	Sideswipe-Meeting	Fixed Object	Backing	Pedestrian	Head-On	Parking	Total
US 395	Punkin Center	4	4	4	2	0	0	0	0	0	0	0	0	14
US 20	53rd	25	8	1	0	0	0	1	1	1	0	0	0	37
US 20	SW 15th	14	5	2	2	0	1	0	0	0	0	0	0	24
US 101	Devils Lake	13	3	0	0	0	0	0	1	0	0	0	0	17
US 101	Wilson River Loop	6	15	3	3	0	0	1	0	0	2	0	0	30
OR 126	69th	8	8	1	1	0	0	0	0	0	1	0	0	19
US 20	27th	10	8	0	0	0	0	0	1	1	0	0	0	20
OR 99	South Stage Rd	12	4	2	1	0	0	0	0	0	0	0	0	19
US 30BY	NE 60th	9	7	4	3	0	0	0	1	0	1	0	0	25
US 199	Dowell	9	5	8	0	0	0	0	1	0	0	1	0	24
OR 99E	Off-ramp	2	3	1	0	1	0	0	0	0	0	0	0	7
OR 238	Sage	10	2	4	0	0	0	0	0	1	0	0	0	17
US 101	Zimmerman	2	4	1	0	0	0	0	0	0	0	0	0	7
US 101	Pacific Way	5	6	1	0	0	0	0	0	0	0	0	0	12
US 97 [1]	Cooley	37	3	4	3	0	0	0	0	0	0	0	0	47
OR 18	Norton	13	3	1	0	0	0	1	2	0	0	0	0	20

[1] Shaded row represents example case study location highlighted in this report

Table 3.5: Sample Crash Data Calculations for Cooley and US 97

Cooley Road and US 97	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total
Number of Crashes	37	3	4	3	0	0	0	47
Crash Percentages (%)	78.7	6.4	8.5	6.4	0.0	0.0	0.0	100.0
Crash Rates	11.6	0.9	1.3	0.9	0.0	0.0	0.0	14.8

The research team also investigated the types of vehicles involved in these collisions. The pie chart depicted in Figure 3.3 indicates the division of vehicle types involved in collisions (for all IHSSIs used in the determination of crash percentages and rates). As shown by the chart, passenger cars are involved in the vast majority of crashes. Despite being cited as a specific safety concern in much of the literature, heavy vehicles (including trucks, buses, farm equipment and any other large vehicles) only represent three percent of the total vehicles involved in the reported crashes.

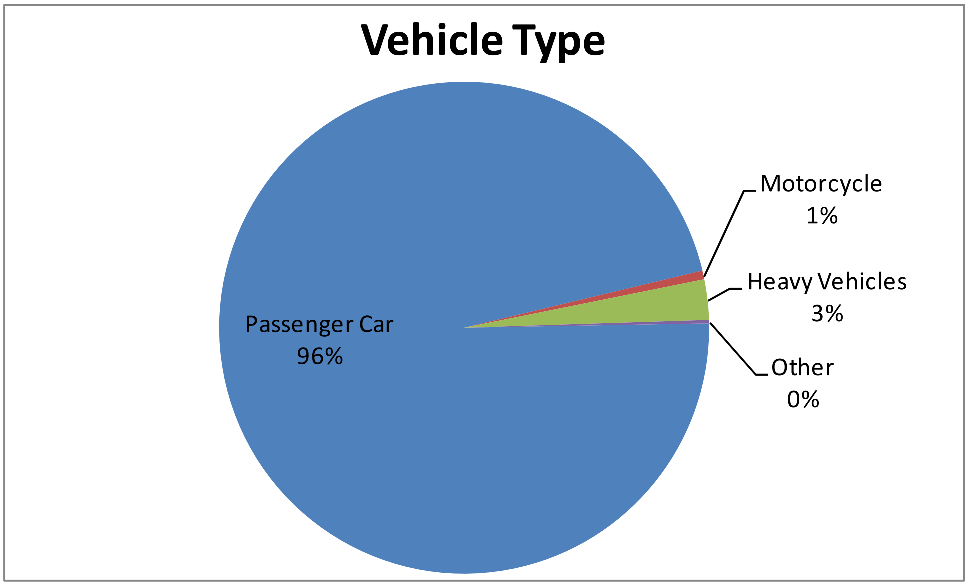


Figure 3.3: Percentage of Vehicle Types Involved in Collisions

3.4 DATA COLLECTION

In order to establish general IHSSI evaluation techniques, the research team first collected data for eight IHSSIs. The TAC recommended these eight intersections based on input from signal timers across Oregon's five regions. Table 3.6 displays these eight intersections and their general characteristics.

Table 3.6: General Characteristics of Intersections Selected for Further Investigation

Region	County	State Highway Number	Route Number	Cross Road	AADT	Safety Technology	Speed Limit	Change in Speed Limit	Standard # of Lanes / Direction	# of Isolated, High-Speed Approaches
4	Deschutes [1]	4	US 97	Cooley	35900	SAS	45	--	2	1
1	Clackamas	26	US 26	J Jarl/Orient	28800	SAS	55	--	2	1
5	Malheur	455	OR 201	SW 18th/Butler	6800	CFSSA	55	--	2	2
2	Lane	69	OR 569	Roosevelt	23100	SAS	55	45-55	2	2
1	Columbia	92	US 30	Deer Island/ Liberty Hill	15300	SAS	50	--	2	1
2	Benton	91	OR 99W	Circle	18200	SAS	50	--	2	1
2	Benton	91	OR 99W	Conifer	16000	CFSSA	50	--	2	1
1	Clackamas	81	OR 99E	Barlow	11000	CFSSA	55	--	2	2

[1] Shaded row represents example case study location highlighted in this report

The research team conducted site visits for each of the intersections shown in Table 3.6 and collected data that was not available via satellite imagery or the digital video logs. Appendix B includes the list of data variables identified prior to data collection. Information collected during the site visits included volumes (turning volumes and minor road volumes), operating speeds, road surface conditions, vertical grades (if necessary), available sight distance, and basic signal phasing data. Appendix D contains sample data collection sheets. The research team performed all data collection during the early afternoon hours of clear weather weekdays.

The research team collected volumes on all approaches for 30 minutes and collected speed data on each isolated, high-speed approach. Because this project is primarily concerned with free-flow conditions, speed data includes values for every isolated vehicle, the first vehicle in every platoon, and every fifth vehicle in a platoon. The speed data also includes a description of the total platoon length. The researchers determined the presence of platoons as vehicle headways of approximately five seconds or less. The final speed datasets do not include vehicles that turned onto or off of the major road prior to the intersection of interest. Signal timing data for at least three full cycles of a traffic signal, collected using a stopwatch, provides basic signal phasing information. Photographs of each site demonstrate signal placement and other relevant intersection characteristics. Researchers obtained basic intersection distances and locations of signs using a distance wheel.

The research team used this data and the crash data obtained previously to evaluate these intersections and determine potential safety treatments. These evaluations and treatments are presented in Section 4.4.

3.5 CREATING A GENERAL TEMPLATE FOR FUTURE INTERSECTION DIAGNOSIS

Based on the systematic analysis of these study intersections, the research team developed a general template for analyzing Oregon’s IHSSIs. This template provides a logical reporting format to facilitate fast and effective evaluation of intersections. As shown in Section 4.3, the template includes space for basic site characteristics, speed data, volume data, and crash statistics. The template also includes the previously determined expected crash trends and treatment options determined through the literature review.

This template does not contain information about signal timing and clearance intervals because that information should be more accurately available through signal timing plans. For the purposes of evaluating the eight studied intersections without the benefit of signal timing plans, Appendix C contains information on basic signal phasing and clearance intervals.

4.0 SUMMARY OF FINDINGS

This chapter summarizes results obtained through the previously described research methodology.

4.1 AVERAGE CRASH RATES AND CRASH PERCENTAGES

Table 4.1 and Table 4.2 display the average crash percentages and average crash rates for Oregon's four-leg IHSSIs as discussed in Section 3.3. In Table 4.1, the columns on the left depict expected average crashes separated by both speed limit and number of lanes. The columns on the right in Table 4.1 depict average crash values sorted only by speed limit, with the bottom row representing an average for all intersections. The column labeled "Number of Intersections" displays the number of intersections available to create the averages. For example, the average values for two-lane, 45 mph intersections are based on data from 12 candidate intersections. The average crash rates are similarly depicted in Table 4.2.

Table 4.1: Average Crash Percentages for Oregon's Four-Leg IHSSIs

Average Crash Percentages																	
Speed Limit (mph)	**Number of Lanes**	**Rear-End**	**Turning**	**Angle**	**Sideswipe-Overtaking**	**Sideswipe-Meeting**	**Fixed Object**	**Other**	**Number of Intersections**	**Rear-End**	**Turning**	**Angle**	**Sideswipe-Overtaking**	**Sideswipe-Meeting**	**Fixed Object**	**Other**	**Number of Intersections**
45	1	58	22	9.9	5.7	0.7	2.1	1.7	4	49	30	12	3.8	0.7	2.0	3.3	16
	2	46	32	12	3.2	0.7	1.9	3.8	12								
55 to 45	1	53	11	16	16	0.0	5.3	0.0	1	50	21	14	5.6	1.3	3.3	4.2	9
	2	47	25	17	2.9	1.2	3.3	4.0	6								
	1→ 2	58	15	7	8.9	2.2	2.2	6.7	2								
50	2	55	19	16	2.6	3.3	0.0	4.3	5	55	19	16	2.6	3.3	0.0	4.3	5
55	1	50	26	10	1.3	3.3	4.4	4.1	5	41	24	12	8.5	1.9	6.4	5.7	15
	2	37	23	13	12	1.1	7.4	6.4	10								
Overall										47	25	13	5.7	1.4	3.4	4.5	44

Table 4.2: Average Crash Rates for Oregon's Four-Leg IHSSIs

Average Crash Rates (# Crashes in 5 year period x 10,000/AADT)																				
Speed Limit (mph)	**Number of Lanes**	**Rear-End**	**Turning**	**Angle**	**Sideswipe-Overtaking**	**Sideswipe-Meeting**	**Fixed Object**	**Other**	**Total**	**Number of Intersections**	**Rear-End**	**Turning**	**Angle**	**Sideswipe-Overtaking**	**Sideswipe-Meeting**	**Fixed Object**	**Other**	**Total**	**Number of Intersections**
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→ 2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

The average crash percentages and average crash rates highlight a number of trends and many of the values are very similar across different categories of intersections. The tables allow users to pinpoint expected values for a specific intersection configuration. However, when using these tables it is important to look at multiple rows because the average values for some configurations only represent a small number of intersections. Values for the same number of lanes and different speed limits, values averaged across multiple lane configurations for a given speed limit, and values for overall averages can also provide beneficial comparisons.

The general template shown in Section 4.3 also provides these average crash percentages and average crash rates.

4.2 HIERARCHY OF DIAGNOSIS STRATEGIES

Table 4.3 shows a list of treatment options for IHSSIs (*Caltrans 2002; Ohio Governor's Task Force on Safety 2009; New York State Department of Transportation 2000; FHWA 1981*). Separate crash type categories allow users to quickly target a specific problem. The general template shown in Section 4.3 incorporates this list as a component of the data collection and analysis templates.

Table 4.3: Potential Countermeasures for IHSSIs

Rear End
- Create turn lanes
- Install advanced warning devices
- Remove sight obstructions
- Install 12 inch signal lenses
- Install visors
- Install/enhance backplates
- Improve location/number of signal heads (e.g. near-side)
- Adjust/extend amber/all-red
- Provide progression (if not isolated approach)
- Adjust signal timing
- Improve skid resistance
- Reduce speeds - traffic calming or lower speed limit (after study)
- Lengthen mast arms
- Install additional loops
- Check equipment for malfunction
- Install transverse pavement markings
- Install extension of green time systems (Advance Detection Control Systems)
- Remove signal (see MUTCD)

Turning

General treatments
- Remove sight obstructions
- Adjust signal timing
- Adjust/extend amber/all-red
- Reduce speeds - traffic calming or lower speed limit (after study)

If turning vehicle at fault
- Add protected phase (remove permitted phase)
- Increase/add turn lane
- Provide channelization
- Increase curb radii

If through vehicle at fault refer to Angle treatments

Angle
- Remove sight obstructions
- Install advanced warning devices
- Install 12 inch signal lenses
- Install visors
- Install/enhance backplates
- Improve location/number of signal heads (e.g. near-side)
- Reduce speeds - traffic calming or lower speed limit (after study)
- Adjust/extend amber/all-red
- Adjust signal timing
- Provide progression (if not isolated approach)
- Improve skid resistance
- Channelize intersection
- Check equipment for malfunction
- Install transverse pavement markings
- Install extension of green time systems (Advance Detection Control Systems)

Sideswipe

General treatments
- Install/improve pavement markings
- Channelize intersection

Overtaking Sideswipe
- Provide turning bays
- Install acceleration/ deceleration lanes
- Install/improve directional signing
- Restrict driveway access near intersection
- Reduce speeds - traffic calming or lower speed limit (after study)

Meeting Sideswipe
- Install median divider/barrier
- Widen lanes
- Install no passing zone signage

Fixed Object
- Remove/relocate obstacles
- Install barrier curbing
- Install breakaway features
- Reduce number of utility poles
- Relocate islands
- Widen lanes
- Install/improve pavement markings (include edgeline delineation)
- Install edgeline rumble strips
- Protect objects with guardrail or attenuation device
- Re-align intersection
- Check vertical alignment
- Upgrade roadway shoulders
- Improve channelization
- Close curb lanes
- Install advanced warning devices
- Reduce speeds - traffic calming or lower speed limit (after study)

Wet Pavement Treatments
- Overlay/groove existing pavement
- Reduce speeds - traffic calming or lower speed limit (after study)
- Provide "slippery when wet" signs
- Improve skid resistance
- Provide adequate drainage
- Upgrade pavement markings
- Install chip seal
- Install open graded asphalt concrete

Night Accident Treatments
- Install/improve street lighting
- Install/improve pavement markings
- Install/improve warning signs
- Upgrade signing
- Provide illuminated signs
- Install pavement markings
- Provide raised markers
- Upgrade advance warning signs

Source: Caltrans (*2002*); Ohio Governor's Task Force on Safety (*2009*); New York State Department of Transportation (*2000*); FHWA (*1981*)

4.3 DATA COLLECTION AND ANALYSIS WORKSHEETS FOR DIAGNOSIS

The following pages show Figure 4.1, the general evaluation template discussed in Section 3.5. The template provides basic instructions for use. For further guidance, Appendix C contains completed templates for each of the eight studied intersections. Section 4.4 summarizes the safety recommendations that the research team identified using these templates for the case study intersections.

Intersection of ________ and ________ , _______ County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit				
Isolated Major Approach (>1mile Isolation)				
Advanced Intersection Warning*				
Other				

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

Aerial photograph or diagram indicating intersection geometry and lane configurations

Figure 4.1: General Evaluation Template

Intersection of ________ and ________ , _______ County (Page 2)

Picture showing typical arrangement and number of signal heads

Graphs of speed data for high-speed approaches

		Volumes between ______ and ______ on __/__/__ Su M T W R F Sa		
Direction	AADT	% left turns	% right turns	% total turns

Other notes:

Figure 4.1: Continued

Intersection of ________ and ________ , _______ County (Page 3)

Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Figure 4.1: Continued

Intersection of ________ and ________, ________ County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
									Overall		47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
									Overall		5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments:

Figure 4.1: Continued

Potential Countermeasures for Isolated, High-Speed, Signalized Intersections

Rear End

- Create turn lanes
- Install advanced warning devices
- Remove sight obstructions
- Install 12 inch signal lenses
- Install visors
- Install/enhance backplates
- Improve location/number of signal heads (e.g. near-side)
- Adjust/extend amber/all-red
- Provide progression (if not isolated approach)
- Adjust signal timing
- Improve skid resistance
- Reduce speeds - traffic calming or lower speed limit (after study)
- Lengthen mast arms
- Install additional loops
- Check equipment for malfunction
- Install transverse pavement markings
- Install extension of green time systems (Advance Detection Control Systems)
- Remove signal (see MUTCD)

Turning

General treatments

- Remove sight obstructions
- Adjust signal timing
- Adjust/extend amber/all-red
- Reduce speeds - traffic calming or lower speed limit (after study)

If turning vehicle at fault

- Add protected phase (remove permitted phase)
- Increase/add turn lane
- Provide channelization
- Increase curb radii

If through vehicle at fault refer to Angle treatments

Angle

- Remove sight obstructions
- Install advanced warning devices
- Install 12 inch signal lenses
- Install visors
- Install/enhance backplates
- Improve location/number of signal heads (e.g. near-side)
- Reduce speeds - traffic calming or lower speed limit (after study)
- Adjust/extend amber/all-red
- Adjust signal timing
- Provide progression (if not isolated approach)
- Improve skid resistance
- Channelize intersection
- Check equipment for malfunction
- Install transverse pavement markings
- Install extension of green time systems (Advance Detection Control Systems)

Sideswipe

General treatments

- Install/improve pavement markings
- Channelize intersection

Overtaking Sideswipe

- Provide turning bays
- Install acceleration/ deceleration lanes
- Install/improve directional signing
- Restrict driveway access near intersection
- Reduce speeds - traffic calming or lower speed limit (after study)

Meeting Sideswipe

- Install median divider/barrier
- Widen lanes
- Install no passing zone signage

Fixed Object

- Remove/relocate obstacles
- Install barrier curbing
- Install breakaway features
- Reduce number of utility poles
- Relocate islands
- Widen lanes
- Install/improve pavement markings (include edgeline delineation)
- Install edgeline rumble strips
- Protect objects with guardrail or attenuation device
- Re-align intersection
- Check vertical alignment
- Upgrade roadway shoulders
- Improve channelization
- Close curb lanes
- Install advanced warning devices
- Reduce speeds - traffic calming or lower speed limit (after study)

Wet Pavement Treatments

- Overlay/groove existing pavement
- Reduce speeds - traffic calming or lower speed limit (after study)
- Provide "slippery when wet" signs
- Improve skid resistance
- Provide adequate drainage
- Upgrade pavement markings
- Install chip seal
- Install open graded asphalt concrete

Night Accident Treatments

- Install/improve street lighting
- Install/improve pavement markings
- Install/improve warning signs
- Upgrade signing
- Provide illuminated signs
- Install pavement markings
- Provide raised markers
- Upgrade advance warning signs

Figure 4.1: Continued

4.4 SAFETY TREATMENT RECOMMENDATIONS

The following sections discuss recommended safety treatments as determined through the processes discussed in this report. Table 4.4 lists key observations and treatment recommendations for each intersection. Section 4.4.1 demonstrates a case study example to further describe the recommendation process.

4.4.1 Case Study: Cooley and US 97

This section contains more details about using the general templates for data collection and analysis. Figure 3.1 and Figure 3.2 (previously reviewed) depict the site investigation data and the historic crash information, respectively, for the Cooley Road at US 97 cast study intersection. Figures 4.2, 4.3, 4.4, and 4.5 demonstrate completed traffic control, conditions, and crash summary worksheets as presented in Section 4.3. Appendix C incorporates a complete set of documents for all eight case studies (including the Cooley Road at US 97 location).

4.4.1.1 Observations

As shown in Figure 4.5, a comparison of the crash rates and crash percentages for the Cooley Road at US 97 intersection to typical values shows that rear-end collisions are highly overrepresented. As shown in the collision diagram (see Figure 4.4), these collisions are primarily occurring on the northbound and southbound approaches. Values for overtaking-sideswipe collisions are also slightly above average. Based on the speed data, a large percentage of the southbound traffic at this location is traveling above the posted speed limit of 45 mph (average speed = 49.9 mph). While collecting this speed data, the researchers also observed long queues extending to distances past the existing SAS.

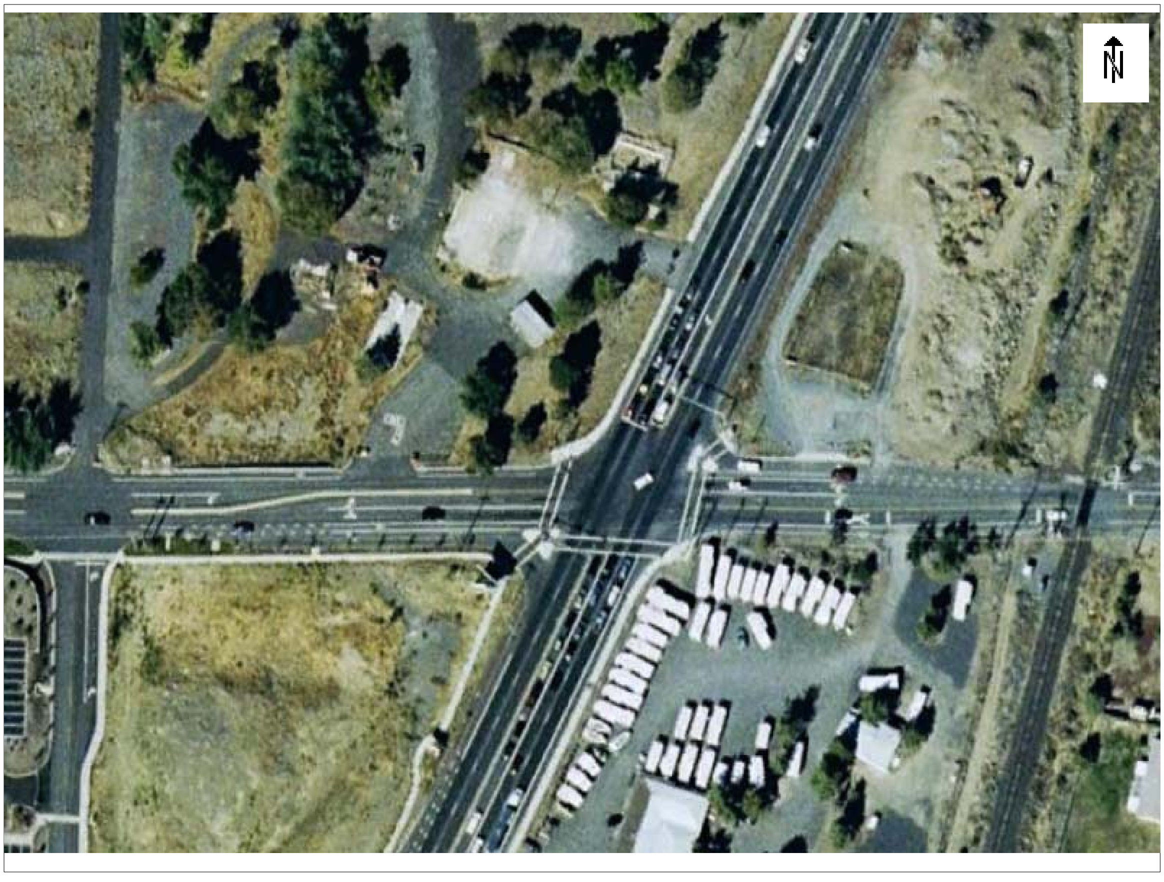
4.4.1.2 Recommendations

Treatments to reduce rear-end collisions have the greatest potential for increasing safety at this location. Near-side signal heads at the intersection may be beneficial for giving advance warning to drivers. Signs or transverse pavement markings installed prior to the existing SAS may also prove beneficial when long queues are present. Converting the SAS to a CFSSA by installing a beacon may draw more attention to the sign. Additionally, techniques to reduce speeds on the southbound approach may be advantageous for reducing the likelihood and severity of rear-end collisions. One of the primary causes for collisions at this intersection is likely the high volumes.

Intersection of Cooley and US 97 , Deschutes County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	45 mph	45 mph	35 mph	35 mph
Isolated Major Approach (>1mile Isolation)	No	Yes	No	No
Advanced Intersection Warning*	--	SAS	--	--
Other	--	--	--	--

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing



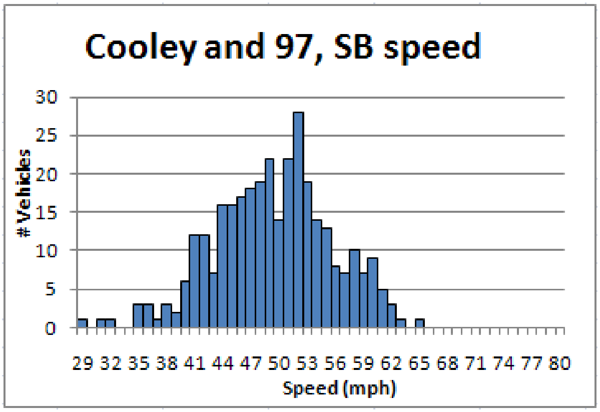
Aerial photograph or diagram indicating intersection geometry and lane configurations

Figure 4.2: Traffic Control Worksheet for Cooley Road and US 97

Intersection of Cooley and US 97 , Deschutes County (Page 2)

Image shows southbound approach.

Picture showing typical arrangement and number of signal heads



Average southbound speed = 49.9 mph

Graphs of speed data for high-speed approaches

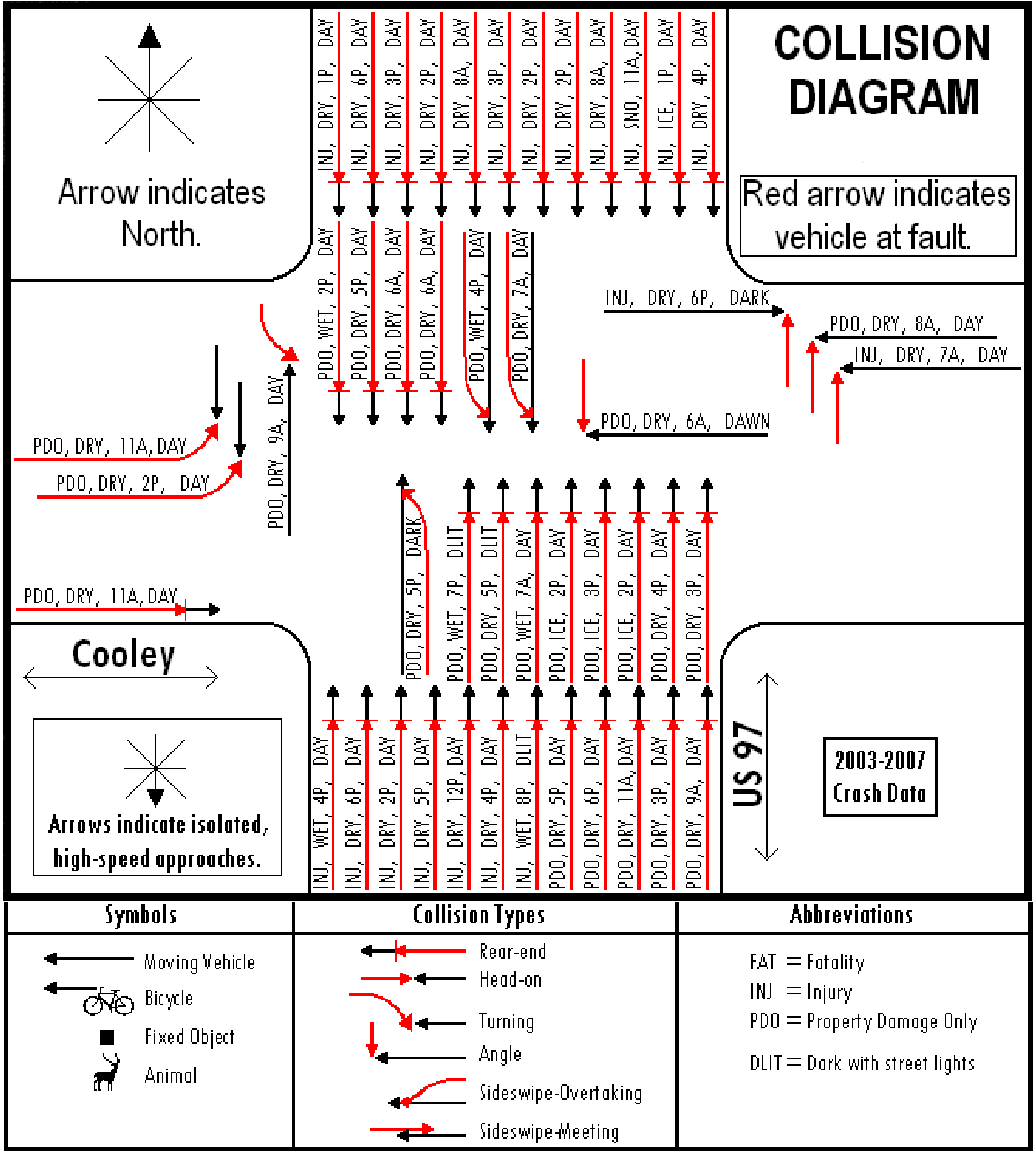
		Volumes between 2:05pm and 2:35pm on 9/16/09 Su M T [✓ W] R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	35,900	6.2	6.7	12.9	593
Southbound	27,700	5.0	4.5	9.5	462
Eastbound	unknown	53.3	15.0	68.3	107
Westbound	unknown	50.5	27.1	77.6	107

Other notes: Westbound traffic crosses railroad tracks ~270 ft before stop bar.

Eastbound and westbound traffic have two left turn lanes (one of which is a shared thru/left lane).

Figure 4.3: Traffic Condition Worksheet for Cooley Road and US 97

Intersection of Cooley and US 97 , Deschutes County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Figure 4.4: Collision Diagram Worksheet for Cooley Road and US 97

Intersection of Cooley and US 97, Deschutes County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
										Overall	47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

45	**2**	**79**	**6.4**	**8.5**	**6.4**	**0**	**0**	**0**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

45	**2**	**12**	**0.9**	**1.3**	**0.9**	**0**	**0**	**0**	**15**

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Rear-end collisions are highly overrepresented.**

Overtaking sideswipe crashes are also slightly high.

Figure 4.5: Crash Percentage and Rate Worksheet for Cooley Road and US 97

4.4.2 Key Observations and Treatment Recommendations

Table 4.4 summarizes the findings and recommendations for the eight case study intersections. The column labeled ‘Unusual Crash Trends’ provides a list of overrepresented collision types as compared to expected values. The next column describes possible contributing factors for these overrepresentations. The final column lists specific safety treatment recommendations to improve safety based on the crash trends and contributing factors. Though recommendations such as those shown in Table 4.4 are based on field observations and engineering judgment, the procedure outlined in this report demonstrates a consistent analysis method that provides documented recommendations when considering safety enhancements at high-speed isolated intersections.

Table 4.4: Case Study Observations and Recommendations

Intersection	Unusual Crash Trends	Notes/Possible Contributing Factors	Recommendations
Barlow and OR 99E	All crash rates appear high (except sideswipes), but percentages appear near average	High volumes on minor roads are not accounted for in crash rates and can make the rates appear high	Lighten backplate color to increase contrast for westbound approach
			Near-side signal heads
		Eastbound speeds are high	Speed reduction techniques
	Most collisions due to minor approaches	Likely errors in coding due to skew (It appears that crashes on minor approaches may have occurred on major approaches.)	
	Turning crashes are slightly overrepresented	Minor approach has no protected phase	Protected left-turn phase for minor approaches
	Fixed object collisions are overrepresented	Many objects near road	Relocate objects further from road
Butler and OR 201	Angle collisions are overrepresented	At fault vehicles primarily on major approaches	Improve yellow/all-red times
		High speeds on major approaches	Speed reduction techniques
			Transverse pavement markings (SIGNAL AHEAD or similar)
			Install D-CS
	Overrepresented turning collisions from minor approach	No protected turning phase for minor approaches (volumes are low, protected phase may not be practical)	Monitor intersection for future improvement needs
Circle and 99W	Crash rates all appear high	Possibly due to high volumes on minor road	
	At-fault westbound vehicles in angle collisions are overrepresented	All seven collisions are coded DLIT/DARK/DAWN (dark with lights, dark without lights, or dawn)	Improve lighting
	At-fault northbound vehicles in angle collisions are overrepresented	Intersection is very wide for both the major and minor approaches	Near-side signal heads (for major and minor approaches)
		No all-red phase	Add all-red phase
	At-fault northbound and southbound vehicles in turning collisions are overrepresented		Evaluate signal timing plan, consider extending green or amber phases

Table 4.4 (Continued)

Intersection	Unusual Crash Trends	Notes/Possible Contributing Factors	Recommendations
Conifer and 99W	Two bicycle collisions	Intersections located within a city, this likely leads to higher bicycle volumes	
	Northbound and southbound rear-end collisions are high		Near-side signal heads
		No all-red phase	Add all-red phase
Cooley and US 97	Northbound and southbound rear-end collisions high	Long queues on southbound approach	Install signing or transverse pavement markings prior to SAS
			Add flashing beacon above SAS
			Near-side signal heads
		High speeds	Speed reduction techniques for southbound traffic
	Overtaking-sideswipes slightly overrepresented		
Deer Island and US 30	Meeting sideswipes overrepresented (also one head-on collision)	US 30 is a concrete road, pavement markings may be difficult to see	Improve pavement markings
		No all-red phase for minor to major transition	Add all-red phase
Orient and US 26	Fixed object collisions highly overrepresented (southbound)	No obvious objects in path	
		Eastbound speeds are high	Speed reduction techniques for eastbound traffic
		No all-red phase for minor to major transition	Add all-red phase
Roosevelt and OR 569	Northbound and Southbound rear-end collisions are high	Long queues and sight distance restrictions	Install signs or transverse pavement markings further from intersection
			Add flashing beacon above SAS
		Southbound speeds are high (vehicles are leaving freeway conditions)	Speed reduction techniques for southbound vehicles (consider reducing and enforcing speed limit)
	Angle collisions slightly overrepresented	At-fault vehicles are primarily on the minor approaches (high-volume intersection)	

5.0 CONCLUSIONS

This report describes the high-speed signalized intersection research project and summarizes the published literature relevant to this topic. In particular, the literature review in Chapter 2.0 summarizes driver response and reaction information, the concept of the dilemma or decision zone (also known as an option zone), likely crash types associated with these high-speed intersections, and possible safety treatments that can be used to help enhance safety and operations at these locations. Chapter 3.0 then describes the research methodology used to accomplish the research objectives. Chapter 4.0, along with the Appendices, provides the final recommended procedure and results of this research.

This report documents the four primary tasks set forth by the Technical Advisory Committee (TAC). The research team created a general template to efficiently evaluate isolated, high-speed, signalized intersections (IHSSIs). This template contains expected crash percentages and crash rates for IHSSIs. The template also contains a hierarchy of diagnosis strategies to be used when analyzing these intersections. This template is demonstrated through the evaluation of eight sample intersections. Chapter 4.0 and the Appendices provide historic safety evaluations, general templates, and specific safety recommendations for these intersections.

The research team recommends that ODOT utilize this general template as a tool for evaluating and improving the safety of Oregon's IHSSIs by implementing a system requiring periodic analysis of all IHSSIs. This arrangement would ensure that irregular crash trends do not go unnoticed. When safety concerns are noted, the treatment hierarchy provided in the general template can be used as guidance for establishing incremental measures to improve safety. The case studies in this report provide the potential to increase safety at eight intersections, but implementation of this system has the ability to increase safety at IHSSI locations across the State of Oregon.

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APPENDIX A:
ACRONYM DEFINITIONS

Table A.1: Acronym Definitions

Acronym	Definition
AADT	Average Annual Daily Traffic
AWEGS	Advanced Warning for End-of-Green System
AWF	Advance Warning Flasher
BODAWS	Blank-out Overhead Dynamic Advance Warning Signal
CCW	Cooperative Collision Warning
CFSSA	Continuous Flashing Symbolic Signal Ahead
D-CS	Detection-Control System
FHWA	Federal Highway Administration
FSSA	Flashing Symbolic Signal Ahead
GES	General Estimates System
ICAV	Intersection Crash Avoidance, Violation
IHSSI	Isolated, High-Speed, Signalized Intersection
ITE	Institute of Transportation Engineers
LED	Light-emitting Diode
Mph	Miles per Hour
ODOT	Oregon Department of Transportation
PATH	Partners for Advanced Transit and Highways
PRT	Perception Reaction Time
PTSWF	Prepare to Stop when Flashing
RSA	Red Signal Ahead
SAS	Signal Ahead Sign
SOS	Self Optimizing Signal
TAC	Technical Advisory Committee
TTC	Time-to-collision
TTI	Texas Transportation Institute

APPENDIX B:
DATA COLLECTION INFORMATION

This appendix contains supplemental data collection information. This information includes data variables of interest, equipment used in this study to collect information about these variables, a sample calculation of crash-related distances, and a complete list of the intersections used to calculate average crash frequencies.

Data Variables

The following list illustrates data variables that may help explain safety at high-speed signalized intersections. Items shown in bold require field collection. Other information can be obtained or approximated through ODOT crash databases, ODOT digital video logs, and satellite imagery.

- Current Advisory Signs or Safety Techniques
- **Volume (turning versus straight)**
- Number of Lanes
- Presence of Exclusive Turn Lanes
- Width of Lanes
- Posted Speed Limit
- **Operating Speeds (Average, 85th Percentile, Top 5th Percentile, Etc.)**
- **Road Surface/Pavement Type**
- **Vertical Grade**
- Intersection Type (Number of Approaches, Measure of Skew, Etc.)
- **Available Sight Distance**
- Distance from Previous Signal
- Nearby Horizontal Curves
- Type of Signal (LED vs Incandescent, Presence of Backplates, Arrangement, Etc.)
- **Signal Phasing**
- Crash History
- Crash Hour/Day of Week
- Crash Light/Weather Conditions
- Collision Type

Data Collection Equipment

The research team used a SpeedLaser R from Laser Atlanta to collect operating speed data and a Jamar board to collect volume data. An ordinary stopwatch and distance wheel allowed researchers to obtain approximate signal phasing information and intersection distances. No other data variables required special equipment.

Intersection-Related Crash Distance Calculations

This section provides a sample calculation demonstrating the method used to determine which crashes should be considered related to an intersection. The following calculation assumes a combined perception-reaction and brake-reaction time of 2.5 sec (.000694 hr), a deceleration rate of 11.2 ft/sec2 (27,500 mi/hr2), and level grade. Also, because the milepoint for each intersection is coded to the center of the intersection, an approximate distance of 50 ft (.01 mi) is added to represent the distance from the center of the intersection to the stop bar. All final distances are rounded to the nearest .01 because the crash data is coded at .01 mile intervals.

$d = (PRT)x(v)+(v^2)/(2a)+offset$

d = intersection related crash distance (mi)

v = velocity (posted speed limit) (mi/hr)

a = deceleration rate (mi/hr^2)

offset = distance from center of intersection to stop bar (mi)

Sample calculation:

$d = (.000694)x(45)+(45^2)/(2x27,500)+.01$

d = .08 mi

Thus, for 45 mph intersections, crashes coded as less than or equal to .08 miles from the intersection should be included in crash frequency calculations. Table 3.1 in the body of this report summarizes the distances calculated for all relevant speed limits.

Complete Intersection List

The following tables contain a complete list of the intersections used to calculate expected crash trends.

Table B.1: 45 mph Intersections Included in Crash Trend Calculations

County	State Highway Number	Route Number	Cross Road	AADT	Safety Technology	Speed Limit	Change in Speed Limit	Standard Number of Lanes per Direction
Speed Limit 45mph								
Umatilla	54	US 395	Punkin Center	13,600	SAS	45	--	1
Benton	33	US 20	53rd	15,200	SAS	45	--	1
Benton	33	US 20	SW 15th	19,750	SAS	45	--	1
Lincoln	9	US 101	Devils Lake	16,600	CFSSA	45	--	1
Tillamook	9	US 101	Wilson River Loop	13,800	None	45	--	2
Lane	15	OR 126	69th	13,500	None	45	--	2
Deschutes	7	US 20	27th	16,750	None	45	--	2
Jackson	63	OR 99	South Stage Rd	15,950	None	45	--	2
Multnomah	123	US 30BY	NE 60th	21,550	None	45	--	2
Josephine	25	US 199	Dowell	19,750	None	45	--	2
Linn	58	OR 99E	Off-ramp (mp 7.9)	8,250	SAS	45	--	2
Jackson	272	OR 238	Sage	13,500	SAS	45	--	2
Curry	9	US 101	Zimmerman	15,650	SAS	45	--	2
Clatsop	9	US 101	Pacific Way	16,400	SAS	45	--	2
Deschutes	4	US 97	Cooley	31,800	SAS	45	--	2
Yamhill	39	OR 18	Norton	14,450	CFSSA	45	--	2
Speed Limit 45mph (reduced from upstream of intersection)								
Lane	62	OR 126	Territorial/200	9,200	SAS	45	55-45	1
Curry	9	US 101	Benham	13,250	None	45	55-45	2
Deschutes	4	US 97	Odem Medo Way	33,050	None	45	55-45	2
Linn	16	US 20	Goldfish Farm Rd	9,850	SAS	45	55-45	2
Linn	58	OR 99E	Old Hwy 34	14,650	SAS	45	55-45	2
Multnomah	26	US 26	Palmquist/14th	30,100	SAS	45	55-45	2
Yamhill	39	OR 18	Norton	14,450	CFSSA	45	55-45	2
Marion	81	OR 99E	Chemewa/Hazel Green	13,750	SAS	45	55-45	1 to 2
Lane	69	OR 126	Terry/Lane Mem Gardens	21,050	SAS	45	55-45	1 to 2

Table B.2: 50 mph and 55 mph Intersections Included in Crash Trend Calculations

County	State Highway Number	Route Number	Cross Road	AADT	Safety Technology	Speed Limit	Change in Speed Limit	Standard Number of Lanes per Direction
Speed Limit 50mph								
Douglas	Hwy 35	OR 42	Carnes/Roberts Cr	24,400	None	50	--	2
Columbia	Hwy 92	US 30	Deer Island/Liberty Hill	15,300	SAS	50	--	2
Benton	Hwy 91	OR 99W	Circle	16,350	SAS	50	--	2
Columbia	Hwy 92	US 30	E St	13,100	CFSSA	50	--	2
Benton	Hwy 91	OR 99W	Conifer	14,950	CFSSA	50	--	2
Speed Limit 55mph								
Polk	Hwy 91	OR 99W	Hoffman Rd	12,700	SAS	55	--	1
Marion	Hwy 81	OR 99E	Douglas/Mt. Angel-Gervois	11,500	SAS	55	--	1
Lincoln	Hwy 09	US 101	Salashan Lodge and Center(?)	12,200	CFSSA	55	--	1
Lane	Hwy 69	OR 126	Greenhill	16,950	CFSSA	55	--	1
Jackson	Hwy 270	OR 140	Hwy 22	29,000	Overhead CFSSA	55	--	1
Linn	Hwy 58	OR 99E	Beta Dr	14,650	None	55	--	2
Columbia	Hwy 92	US 30	Rockcrest	14,600	SAS	55	--	2
Lane	Hwy 69	OR 569	Roosevelt	21,400	SAS	55	--	2
Clackamas	Hwy 26	US 26	J Jarl/Orient	29,850	SAS	55	--	2
Malheur	Hwy 455	OR 201	SW 18th/Butler	6,800	CFSSA	55	--	2
Lane	Hwy 91	OR 99	Airport Rd	18,700	CFSSA	55	--	2
Lane	Hwy 91	OR 99	Hwy 229	16,350	CFSSA	55	--	2
Clackamas	Hwy 81	OR 99E	Barlow	16,200	CFSSA	55	--	2
Umatilla	Hwy 8	OR 11	State Line Rd	14,100	CFSSA 2 flashers	55	--	2
Lane	Hwy 227	OR 126	High/52nd	26,300	Overhead CFSSA	55	--	2

APPENDIX C:
CASE STUDY INFORMATION

This appendix contains information about the eight case studies. Historic safety evaluations and general templates provide the information used to reach the results provided in Table 4.4. In addition, the following section contains information about each intersection's signal phasing and clearance intervals. The general templates do not contain this phasing information because more detailed information should be available to practitioners through signal timing plans.

Observed Signal Phasing Information

Figure C.1 presents the observed signal phasing diagrams and clearance interval timing for the eight studied intersections. In the phasing diagrams, black arrows indicate protected movements and gray arrows indicate permitted movements. Right turns are assumed to be permitted during the through phase. Major movements appear on the left half of the phasing, and minor movements appear on the right. All arrows follow the same convention for north.

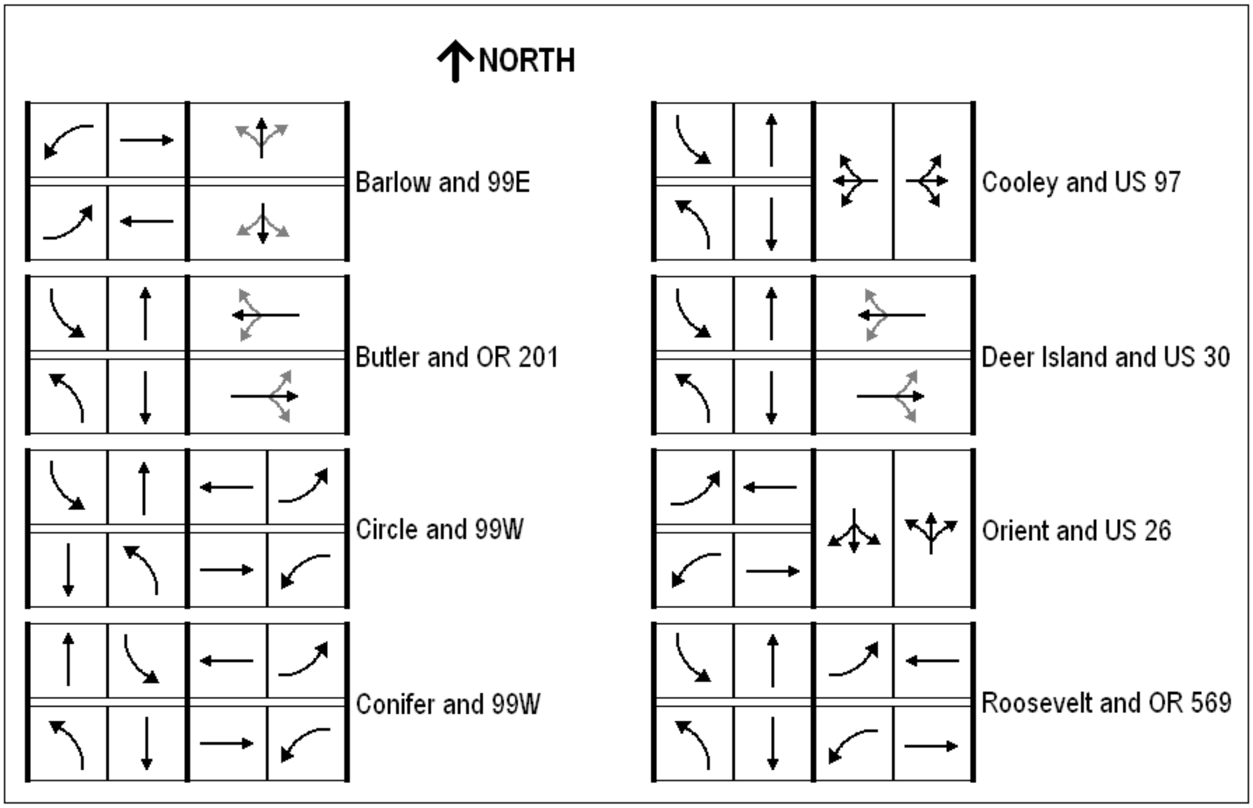


Figure C.1: Observed Signal Phasing

Table C.1: Intersection Transition Times

Intersection		Yellow Time (seconds)		All-Red Time (seconds)	
Minor Road	Major Road	Major to Minor	Minor to Major	Major to Minor	Minor to Major
Barlow	OR 99E	4.5	4.5	1	1
Butler	OR 201	4	4	1	0
Circle	OR 99W	5	4	0	0
Conifer	OR 99W	4	4	0	0
Cooley	US 97	4	3	1	1
Deer Island	US 30	4	4	1	0
Orient	US 26	4.5	4	1.5	0
Roosevelt	OR 569	5	4	3	2

Historic safety evaluations and general templates

This section contains a complete set of historic safety evaluations and general templates for each of the eight studied intersections. The general template directly follows the historic safety evaluation for each intersection and the order of intersections is determined alphabetically by the name of the minor approach. Though the general template contains the previously described treatment hierarchy, this hierarchy is not repeated for each sample intersection.

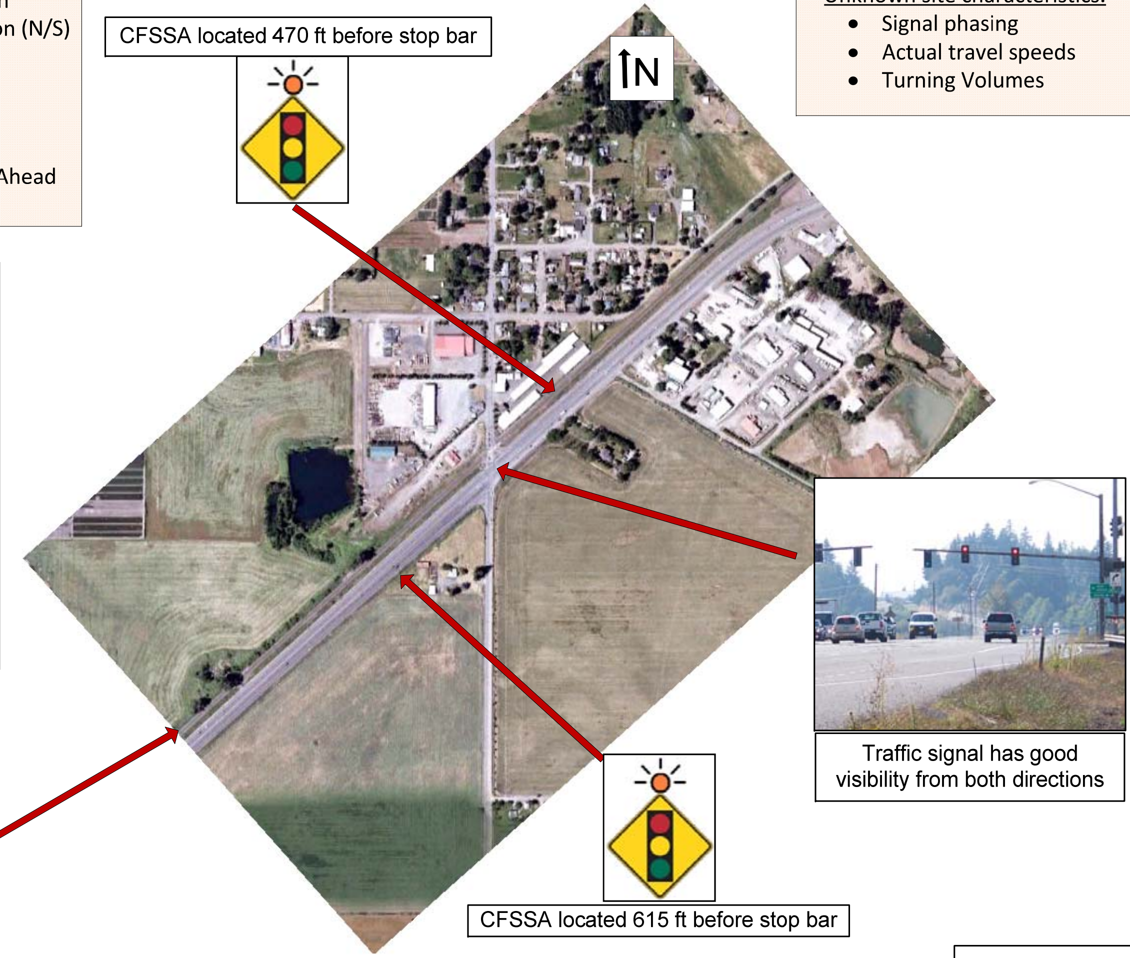
Intersection of Barlow Rd and OR 99E; Clackamas County, OR

Basic site characteristics:

- Posted speed of 55 mph on major approaches
- 2 lanes of traffic in each major direction (NE/SW). 1 lane in each minor direction (N/S)
- Exclusive left and right turn lanes
- Skew intersection (45 degrees)
- No sight distance restrictions
- Both major approaches are isolated
- Continuously Flashing Symbolic Signal Ahead sign on both major approaches

Unknown site characteristics:

- Signal phasing
- Actual travel speeds
- Turning Volumes



CFSSA located 470 ft before stop bar

Traffic signal has good visibility from both directions

CFSSA located 615 ft before stop bar

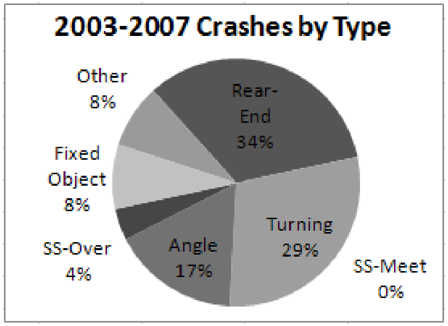
Railroad tracks parallel OR 99E

TITLE Barlow and 99E Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE	VISIODOCUMENT

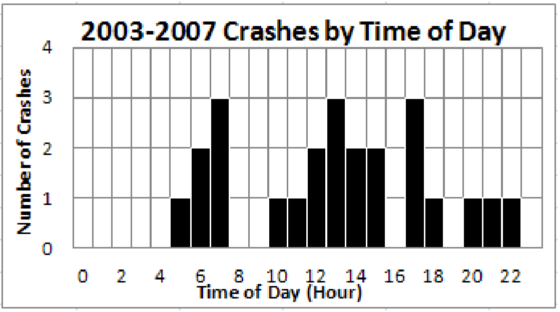
OSU Oregon State UNIVERSITY

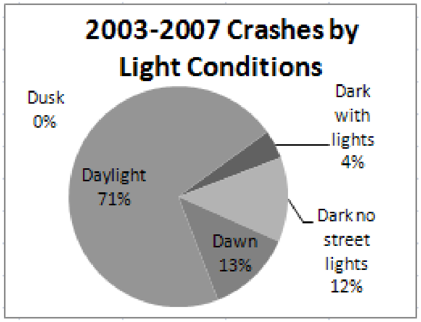
Intersection of Barlow Rd and OR 99E; Clackamas County, OR

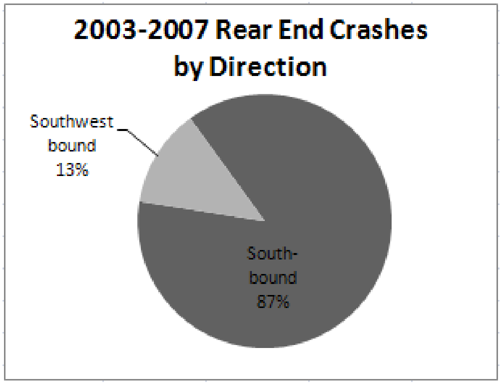
2003-2007 Crashes	
8	Rear-End
7	Turning
4	Angle
1	Sideswipe-Overtaking
0	Sideswipe-Meeting
2	Fixed Object
2	Other
24	Total

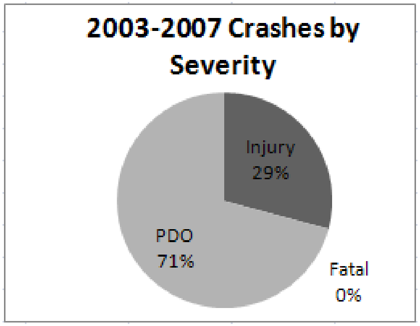


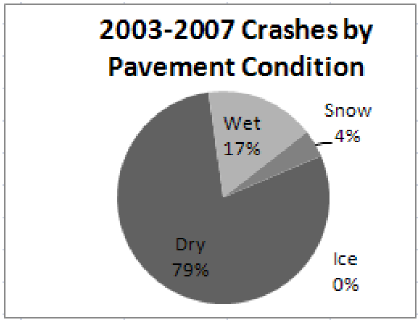
2003-2007 Rear End Crashes	
7	Southbound
1	Southwest-bound











TITLE Barlow and 99E Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

Intersection of Barlow and OR 99E , Clackamas County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	55 mph	35 mph	55 mph	55 mph
Isolated Major Approach (>1mile Isolation)	No	No	Yes	Yes
Advanced Intersection Warning*	CFSSA	CFSSA	CFSSA	CFSSA
Other	--	--	--	--

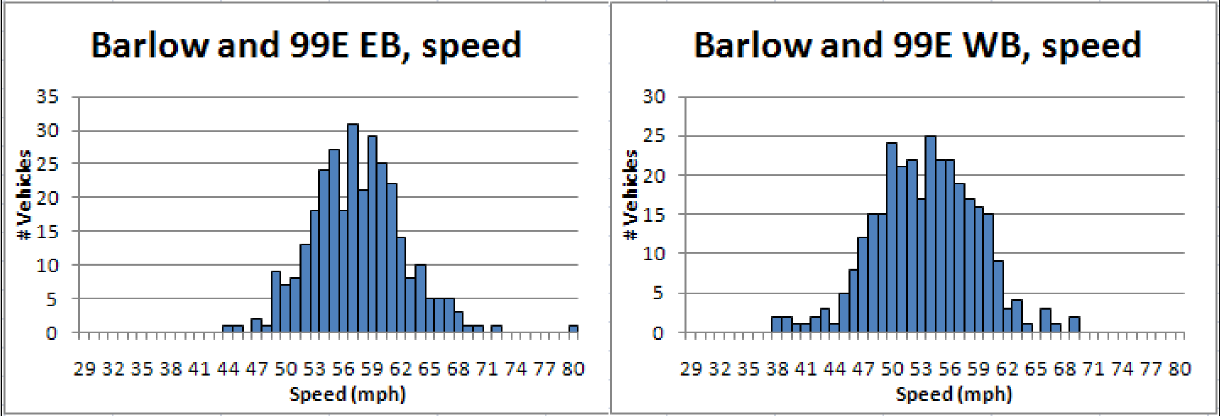
*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Barlow and OR 99E, Clackamas County (Page 2)

Image shows eastbound approach.

Picture showing typical arrangement and number of signal heads



Average eastbound speed = 57.9 mph

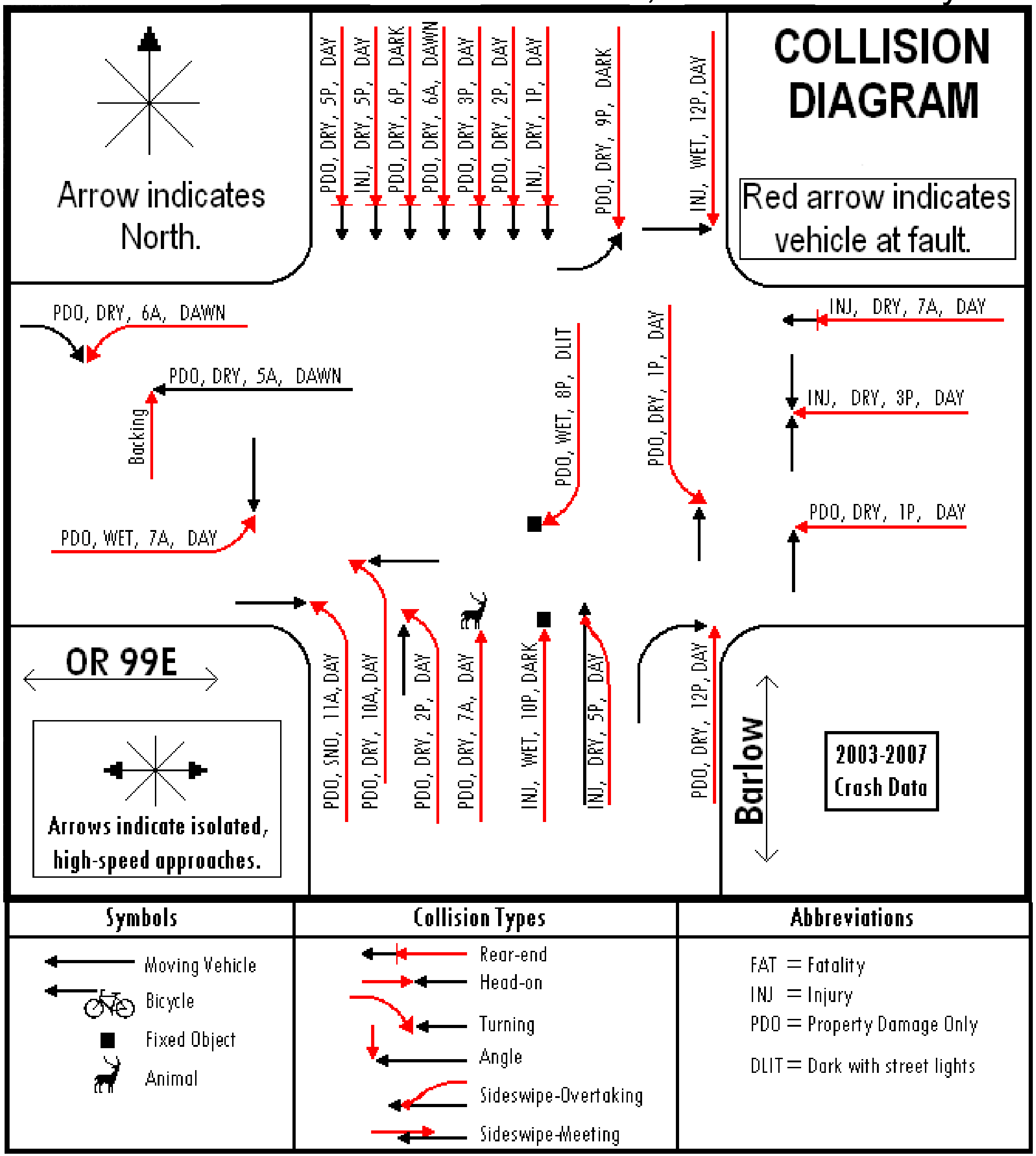
Average westbound speed = 53.9 mph

Graphs of speed data for high-speed approaches

		Volumes between 2:30pm and 3:00pm on 9/23/09 Su M T [✓ W] R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	unknown	5.3	53.3	58.6	75
Southbound	unknown	66.3	6.3	72.6	175
Eastbound	11,000	5.6	0.5	6.1	213
Westbound	21,400	13.3	30.2	43.5	398

Other notes: Northbound and southbound signal heads have extra long visors to block view from minor approaches. Railroad tracks parallel 99E on the north.

Intersection of Barlow and OR 99E , Clackamas County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Barlow and OR 99E , Clackamas County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
									Overall		47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**33**	**29**	**17**	**4.2**	**0**	**8.3**	**8.3**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
									Overall		5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**4.9**	**4.3**	**2.5**	**0.6**	**0**	**1.2**	**1.2**	**15**

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **All crash rates appear high (except Sideswipes). Percentages appear average.**

Fixed Object seems high – two crashes from minor approaches (both while wet and dark).

'Other' section based on one Backing collision and one Animal collision.

Intersection of Butler Rd/SW 18th and OR 201; Malheur County, OR

Basic site characteristics:

- Posted speed of 55 mph on major approaches
- 2 lanes of traffic in each major direction (N/S). 1 lane in each minor direction (E/W)
- Exclusive left and right turn lanes
- Intersection has no skew (90 degrees)
- No sight distance restrictions
- Both major approaches are isolated
- Continuously Flashing Symbolic Signal Ahead sign on both major approaches

Signalized intersection located ~1.0 mile north of intersection.
Next signalized intersection to the south is >>1 mile.

Unknown site characteristics:

- Signal phasing
- Actual travel speeds
- Turning Volumes

CFSSA located 710 ft before stop bar

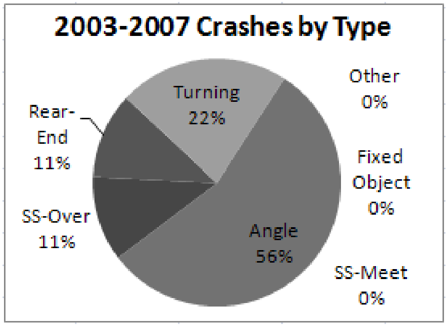
Traffic signal has good visibility from both directions

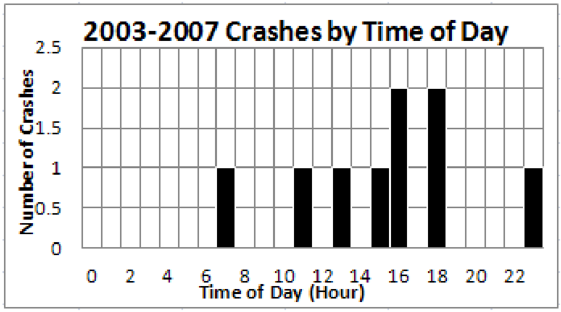
CFSSA located 690 ft before stop bar

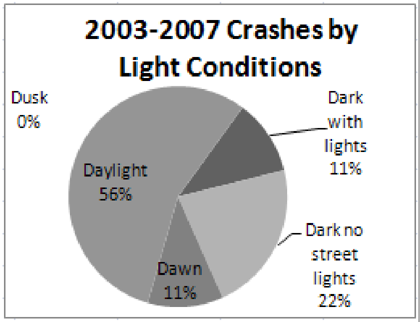
TITLE Butler and OR 201 Intersection	DATE 11/2009
	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE VISIODOCUMENT

Intersection of Butler Rd/SW 18th and OR 201; Malheur County, OR

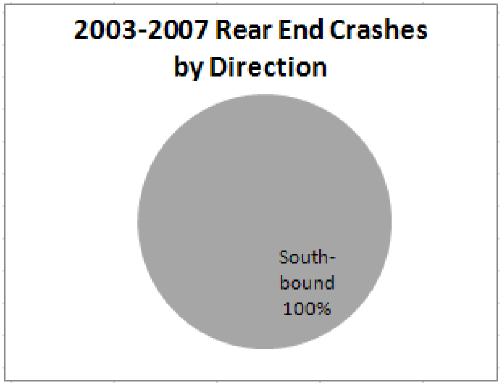
2003-2007 Crashes	
1	Rear-End
2	Turning
5	Angle
1	Sideswipe-Overtaking
0	Sideswipe-Meeting
0	Fixed Object
0	Other
9	Total

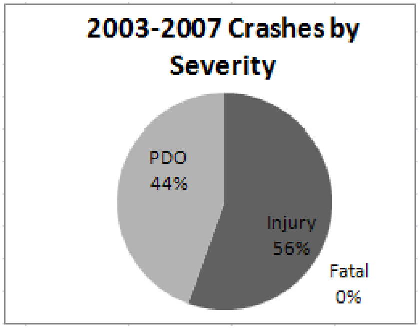

2003-2007 Crashes by Type

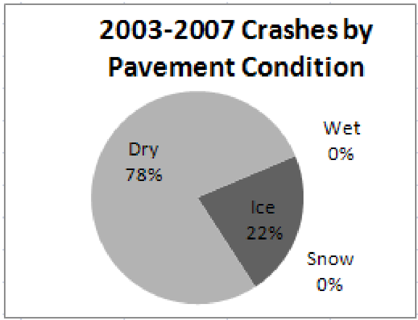

2003-2007 Crashes by Time of Day


2003-2007 Crashes by Light Conditions

2003-2007 Rear End Crashes	
1	Southbound


2003-2007 Rear End Crashes by Direction


2003-2007 Crashes by Severity


2003-2007 Crashes by Pavement Condition

TITLE Butler and OR 201 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

Intersection of Butler and OR 201 , Malheur County (Page 1)

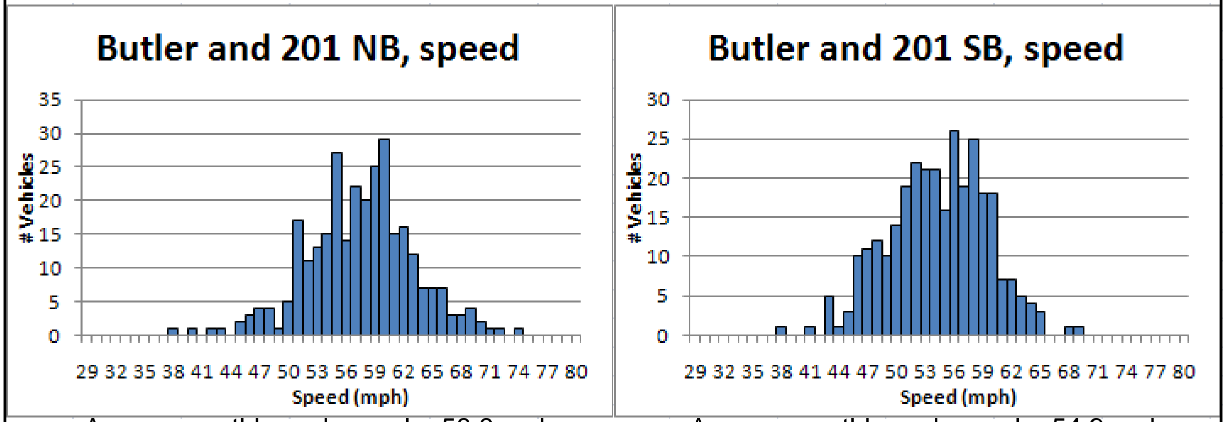
	Northbound	Southbound	Eastbound	Westbound
Speed Limit	55mph	55mph	45mph	45mph
Isolated Major Approach (>1mile Isolation)	Yes	Yes	No	No
Advanced Intersection Warning*	CFSSA	CFSSA	--	--
Other	--	--	--	--

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Butler and OR 201 , Malheur County (Page 2)

Picture showing typical arrangement and number of signal heads



Average northbound speed = 58.0 mph

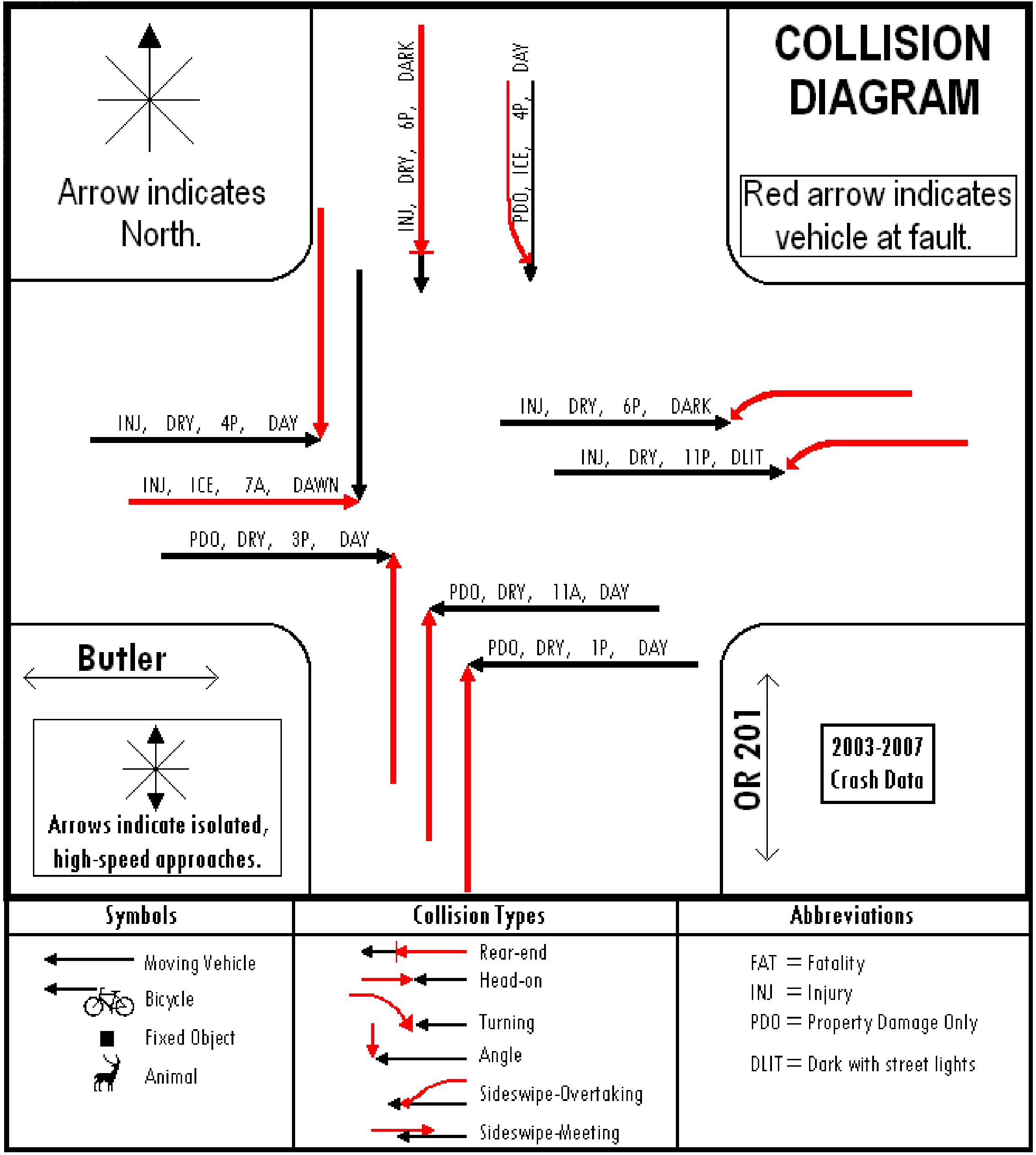
Average southbound speed = 54.9 mph

Graphs of speed data for high-speed approaches

		Volumes between 4:05pm and 4:35pm on 9/15/09 Su M [✓ T] W R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	6,800	2.5	27	29.4	204
Southbound	6,800	3.2	3.9	7.1	154
Eastbound	unknown	35.7	21.4	57.1	14
Westbound	unknown	78.6	6.8	85.4	117

Other notes:

Intersection of Butler and OR 201 , Malheur County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Butler and OR 201 , Malheur County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
										Overall	47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**11**	**22**	**56**	**11**	**0**	**0**	**0**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**1.5**	**2.9**	**7.4**	**1.5**	**0**	**0**	**0**	**13**

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Angle collisions are highly overrepresented. Turning collisions are also high.**

Overtaking Sideswipes appear high but are only based on one collision in five years.

Intersection of Circle Blvd and OR 99W; Benton County, OR

Basic site characteristics:
- Posted speed of 50 mph on major approach
- 2 lanes of traffic in each major direction (N/S). 2 lanes in each minor direction (E/W)
- Exclusive left turn lanes
- Intersection has slight skew (70 degrees)
- No sight distance restrictions
- Northbound approach is isolated
- Signal Ahead Sign on northbound approach

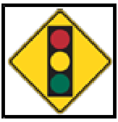
9th Street parallels OR 99W on the west.
The railroad tracks parallel OR 99W on the east.

Unknown site characteristics:
- Signal phasing
- Actual travel speeds
- Turning Volumes

Signalized intersection located ~1800 ft to the north

9th Street

Traffic signal has good visibility

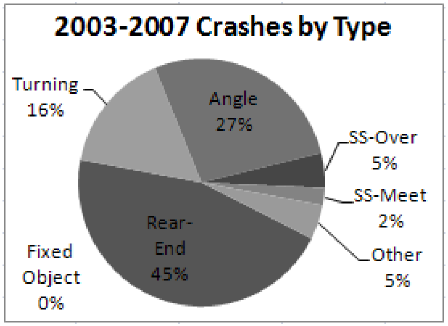


SAS located 700 ft before stop bar

TITLE Circle and 99W Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE	VISIODOCUMENT

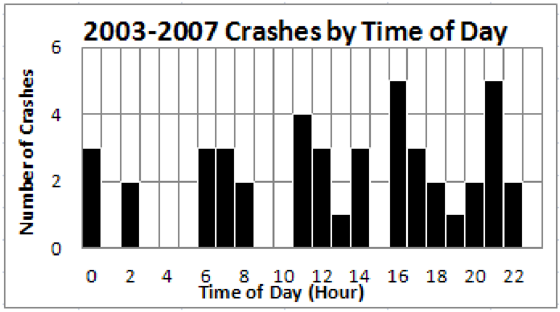
Intersection of Circle Blvd and OR 99W; Benton County, OR

2003-2007 Crashes	
20	Rear-End
7	Turning
12	Angle
2	Sideswipe-Overtaking
1	Sideswipe-Meeting
0	Fixed Object
2	Other
44	Total

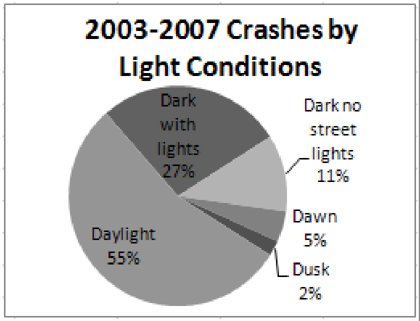


2003-2007 Crashes by Type

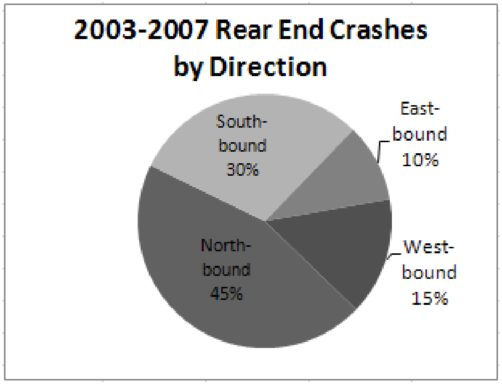
2003-2007 Rear End Crashes	
9	Northbound
6	Southbound
2	Eastbound
3	Westbound



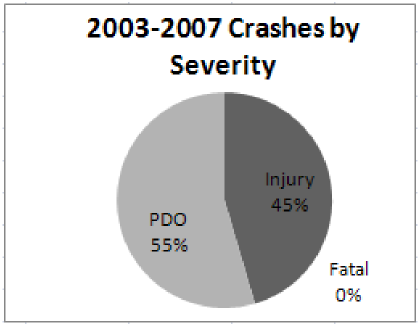
2003-2007 Crashes by Time of Day



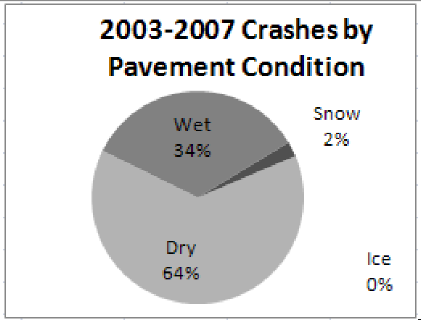
2003-2007 Crashes by Light Conditions



2003-2007 Rear End Crashes by Direction



2003-2007 Crashes by Severity



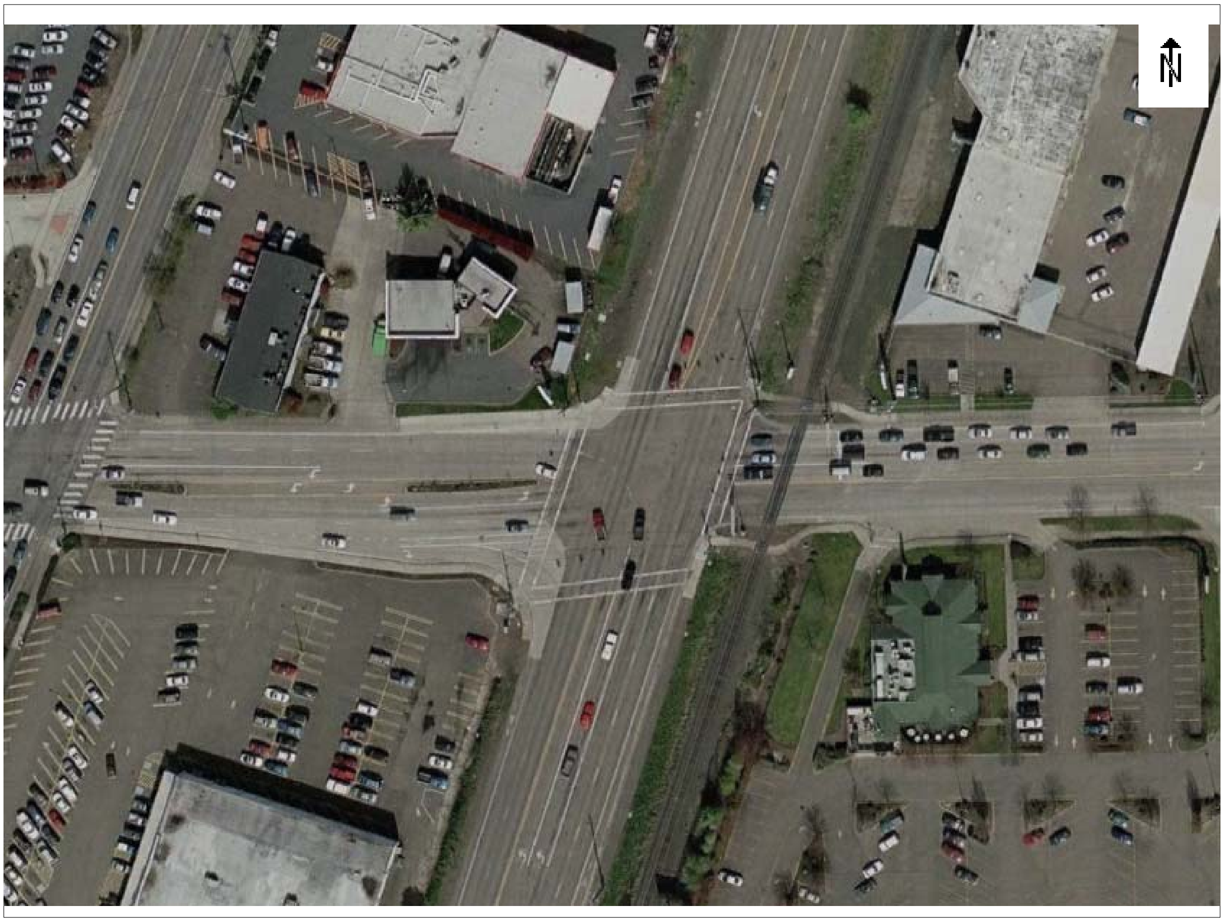
2003-2007 Crashes by Pavement Condition

TITLE Circle and 99W Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

Intersection of Circle and OR 99W , Benton County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	50 mph	50 mph	35 mph	35 mph
Isolated Major Approach (>1mile Isolation)	Yes	No	No	No
Advanced Intersection Warning*	SAS	--	--	--
Other	--	--	--	--

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

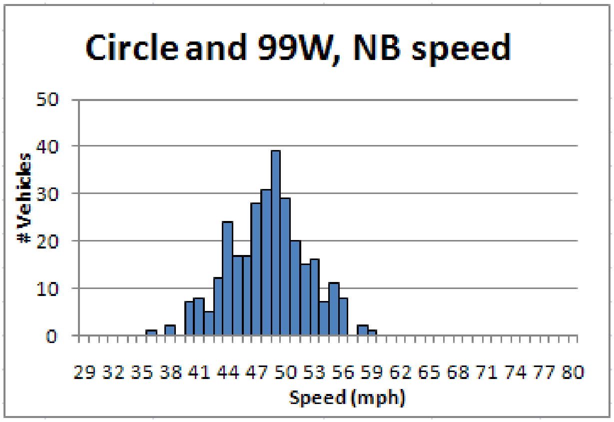


Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Circle and OR 99W , Benton County (Page 2)

Image shows northbound approach.

Picture showing typical arrangement and number of signal heads



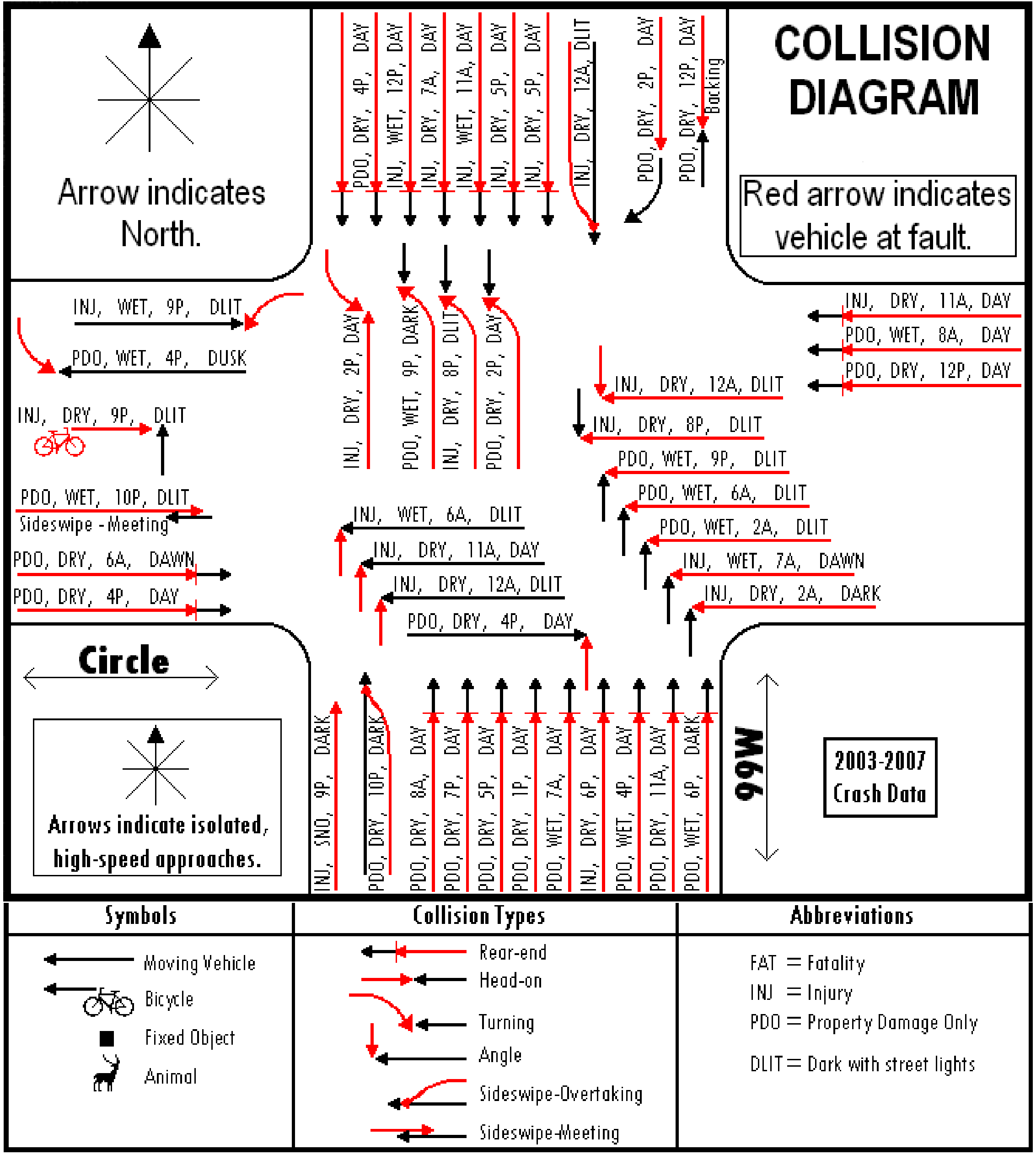
Average northbound speed = 48.7 mph

Graphs of speed data for high-speed approaches

		Volumes between 3:00pm and 3:30pm on 9 /14/ 09 Su M T W [✓ R] F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	18,200	22.5	16.1	38.6	378
Southbound	14,500	13.2	9.2	22.4	304
Eastbound	unknown	11.0	23.8	34.8	374
Westbound	unknown	15.0	12.6	27.6	293

Other notes: Stop bar for westbound traffic is ~30 ft past railroad tracks. Stop bar for eastbound traffic is ~400 ft past signalized intersection of Circle and 9th. Northbound approach changes from 1 to 2 lanes ~700 ft before stop bar.

Intersection of Circle and OR 99W , Benton County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Circle and 99W , Benton County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
									Overall		47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

50	**2**	**45**	**16**	**27**	**4.5**	**2.3**	**0**	**4.5**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

50	**2**	**12**	**4.3**	**7.3**	**1.2**	**0.6**	**0**	**1.2**	**27**

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **All crash rates are high (except Fixed Object). Percentages appear average.**

Angle collisions stand out as most overrepresented (then Overtaking Sideswipes and Rear-End).

Intersection of Conifer Blvd and OR 99W; Benton County, OR

Basic site characteristics:

- Posted speed of 50 mph on major approaches
- 2 lanes of traffic in each major direction (N/S). 1 lane in each minor direction (E/W)
- Exclusive left turn lanes
- Intersection has slight skew (70 degrees)
- Southbound approach is isolated
- Continuously Flashing Symbolic Signal Ahead sign on southbound approach

9th Street parallels OR 99W on the west.
The railroad tracks parallel OR 99W on the east.

Signalized intersection located ~1200 ft to the south

Unknown site characteristics:

- Signal phasing
- Actual travel speeds
- Turning Volumes

CFSSA located 620 ft before stop bar

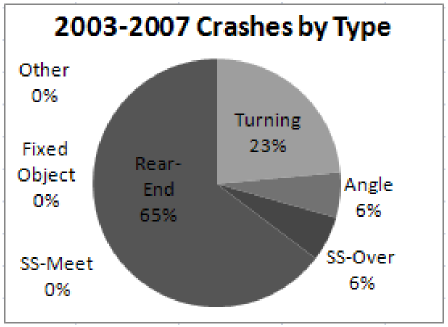
Traffic signal has good visibility for northbound approach.

TITLE Conifer and OR 99W Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE VISIODOCUMENT	

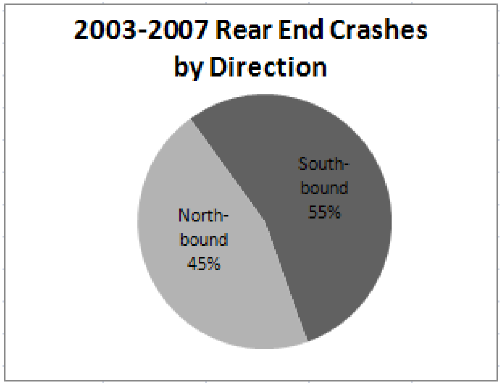
Oregon State UNIVERSITY

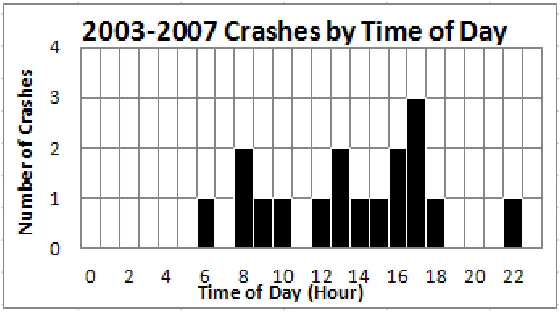
Intersection of Conifer Blvd and OR 99W; Benton County, OR

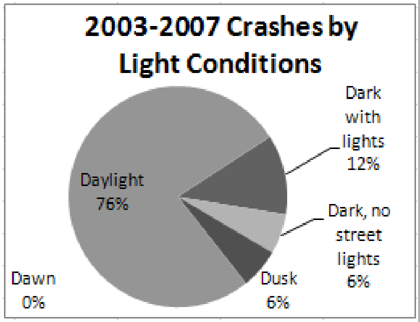
2003-2007 Crashes	
11	Rear-End
4	Turning
1	Angle
1	Sideswipe-Overtaking
0	Sideswipe-Meeting
0	Fixed Object
0	Other
17	Total

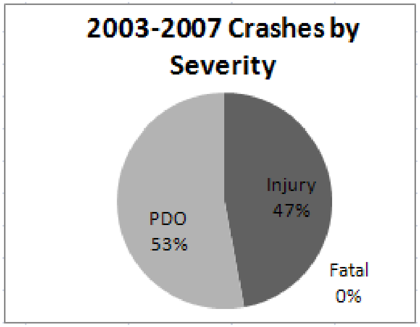


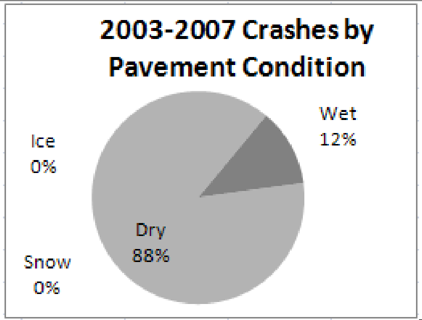
2003-2007 Rear End Crashes	
6	Southbound
5	Northbound











TITLE
Conifer and OR 99W Intersection
DATE
11/2009
PREPARED BY
OSU Research Team
DESCRIPTION
Crash data available
FILE
VISIODOCUMENT

OSU Oregon State University

Intersection of Conifer and 99W , Benton County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	50 mph	50 mph	25 mph	25 mph
Isolated Major Approach (>1mile Isolation)	No	Yes	No	No
Advanced Intersection Warning*	--	CFSSA	--	--
Other	--	--	--	--

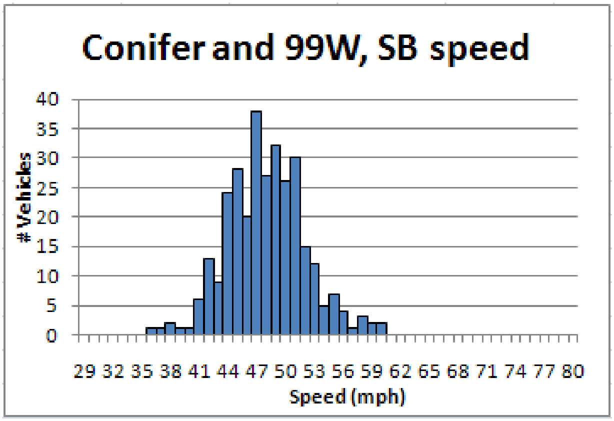
*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Conifer and 99W , Benton County (Page 2)

Image shows southbound approach.

Picture showing typical arrangement and number of signal heads



Average southbound speed = 48.4 mph

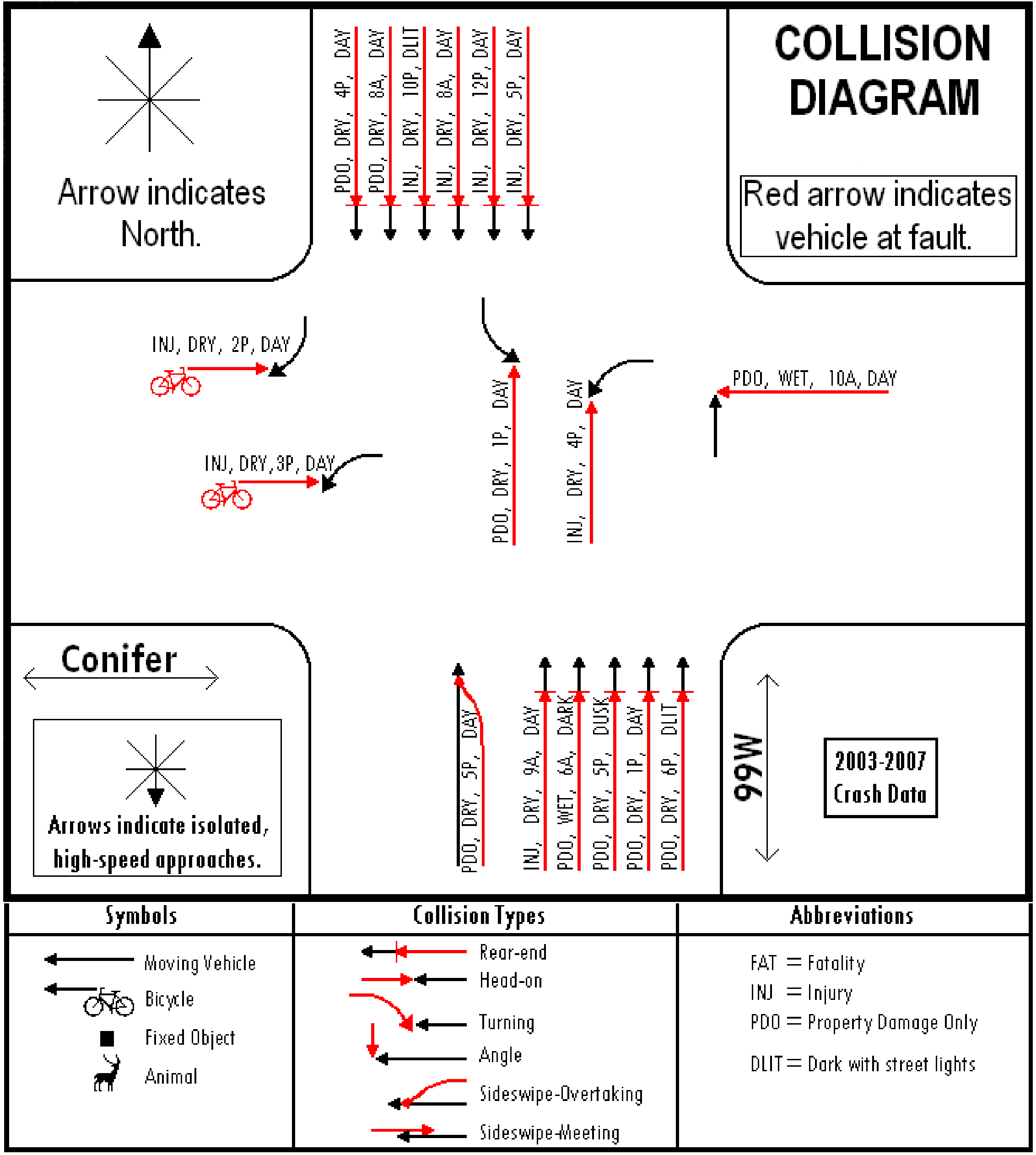
Graphs of speed data for high-speed approaches

		Volumes between 3:25pm and 3:55pm on 10/ 2 /09 Su M T W R [✓ F] Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	13,900	2.2	26.1	28.3	368
Southbound	16,000	13.8	18.9	32.7	392
Eastbound	unknown	42.7	2.0	44.7	253
Westbound	unknown	27.4	14.8	42.2	223

Other notes: Stop bar for eastbound approach is ~130 ft past intersection of Conifer and 9th.

Stop bar for westbound approach is ~25 ft past railroad tracks.

Intersection of Conifer and 99W , Benton County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Conifer and 99W , Benton County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages																			
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
									Overall		47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

50	**2**	**65**	**24**	**5.9**	**5.9**	**0**	**0**	**0**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)																			
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
									Overall		5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

50	**2**	**7.4**	**2.7**	**0.7**	**0.7**	**0**	**0**	**0**	**11**

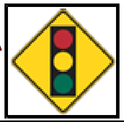
Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Rear-end collisions are slightly high. Everything else appears near average values.**

Intersection of Cooley Rd and US 97; Deschutes County, OR

Basic site characteristics:
- Posted speed of 45 mph
- 2 lanes of traffic in each direction N/S
  1 lane each direction E/W
- Exclusive left turn lanes
- Skew intersection (65 degrees)
- No sight distance restrictions
- Signalized intersection ½ mile to the south
  No signalized intersections to the north
- Signal Ahead sign for southbound traffic

<u>Unknown site characteristics:</u>
- Signal phasing
- Actual travel speeds
- Turning Volumes



SAS located 720 ft before stop bar

Traffic signal has good visibility from both directions

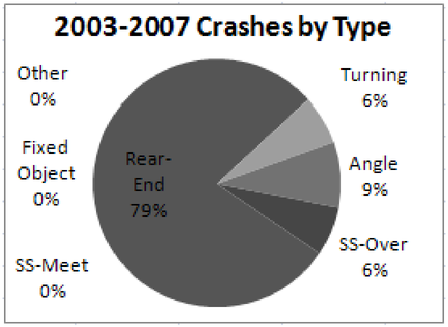
Signalized intersection located ½ mile south

TITLE Cooley Rd and US 97 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE VISIODOCUMENT	

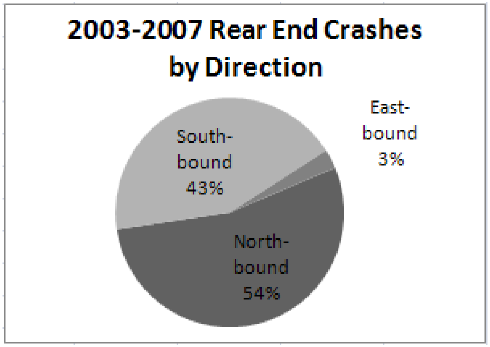
OSU
Oregon State
UNIVERSITY

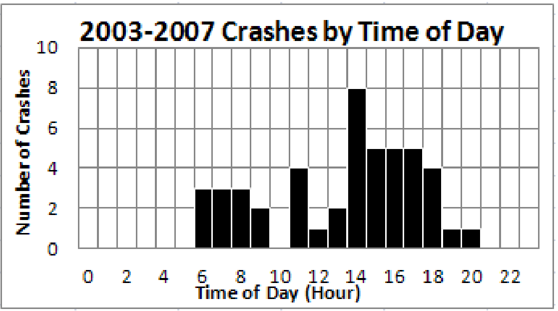
Intersection of Cooley Rd and US 97; Deschutes County, OR

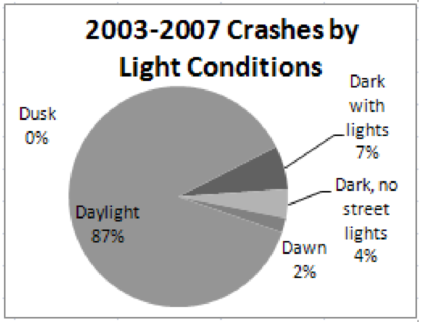
2003-2007 Crashes	
37	Rear-End
3	Turning
4	Angle
3	Sideswipe-Overtaking
0	Sideswipe-Meeting
0	Fixed Object
0	Other
47	Total

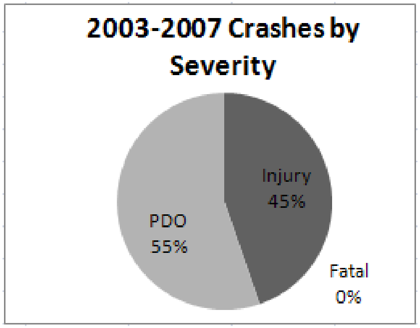

2003-2007 Crashes by Type

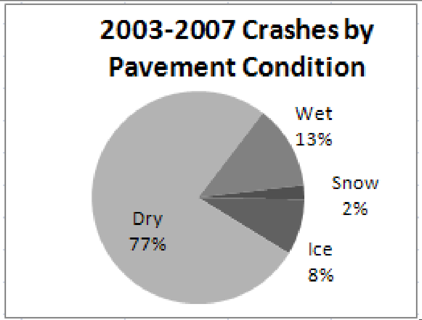
2003-2007 Rear End Crashes	
20	North-bound
16	South-bound
1	East-bound


2003-2007 Rear End Crashes by Direction


2003-2007 Crashes by Time of Day


2003-2007 Crashes by Light Conditions


2003-2007 Crashes by Severity

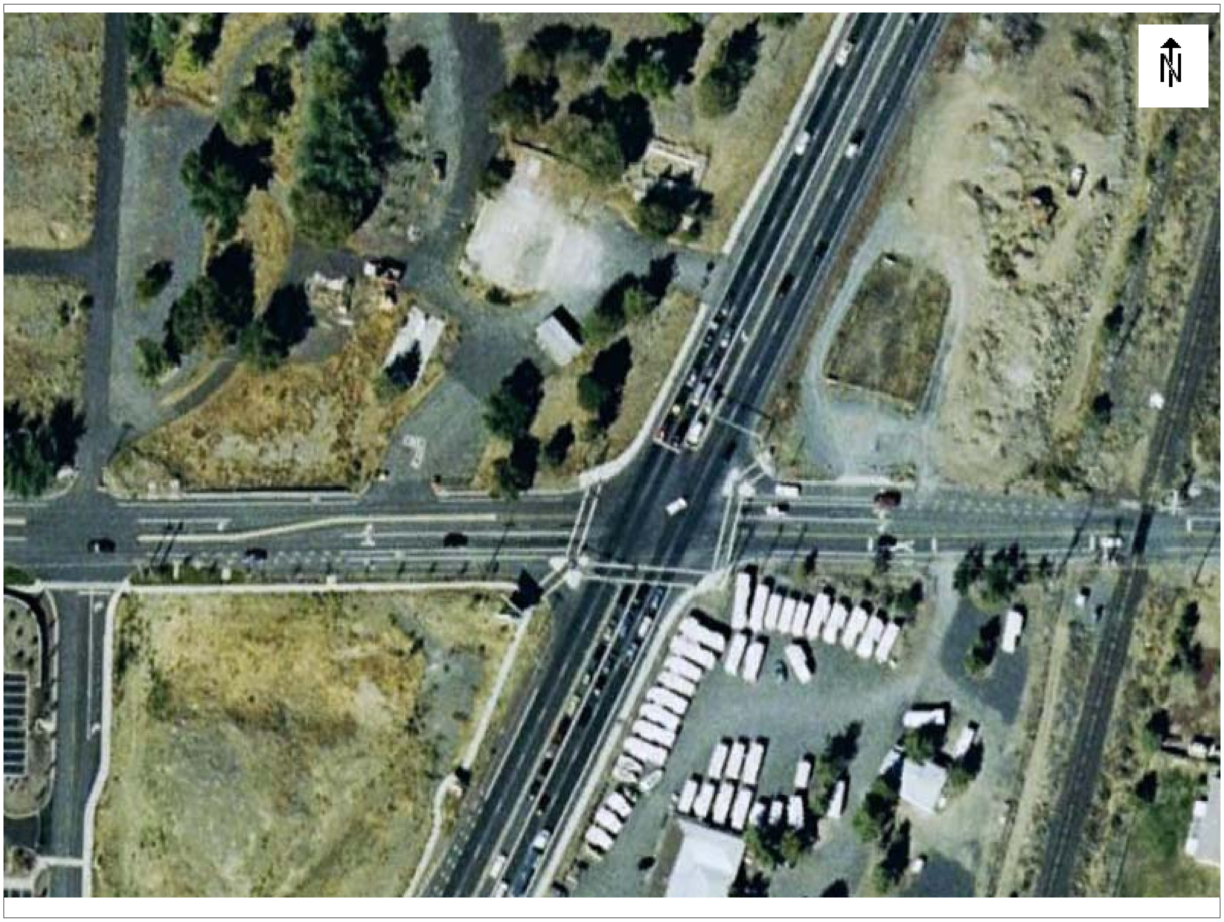

2003-2007 Crashes by Pavement Condition

TITLE Cooley and US 97	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

Intersection of Cooley and US 97 , Deschutes County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	45 mph	45 mph	35 mph	35 mph
Isolated Major Approach (>1mile Isolation)	No	Yes	No	No
Advanced Intersection Warning*	--	SAS	--	--
Other	--	--	--	--

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

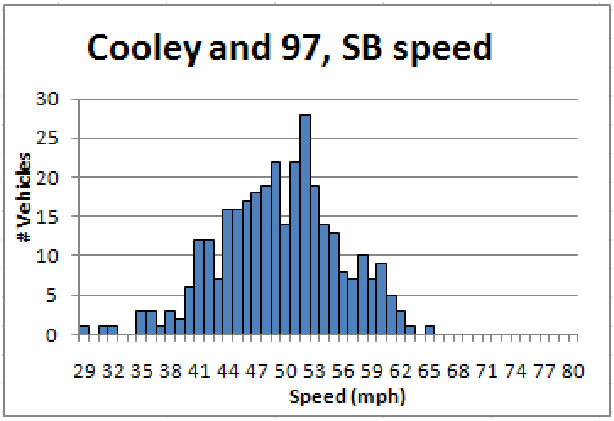


Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Cooley and US 97, Deschutes County (Page 2)


Image shows southbound approach.

Picture showing typical arrangement and number of signal heads



Average southbound speed = 49.9 mph

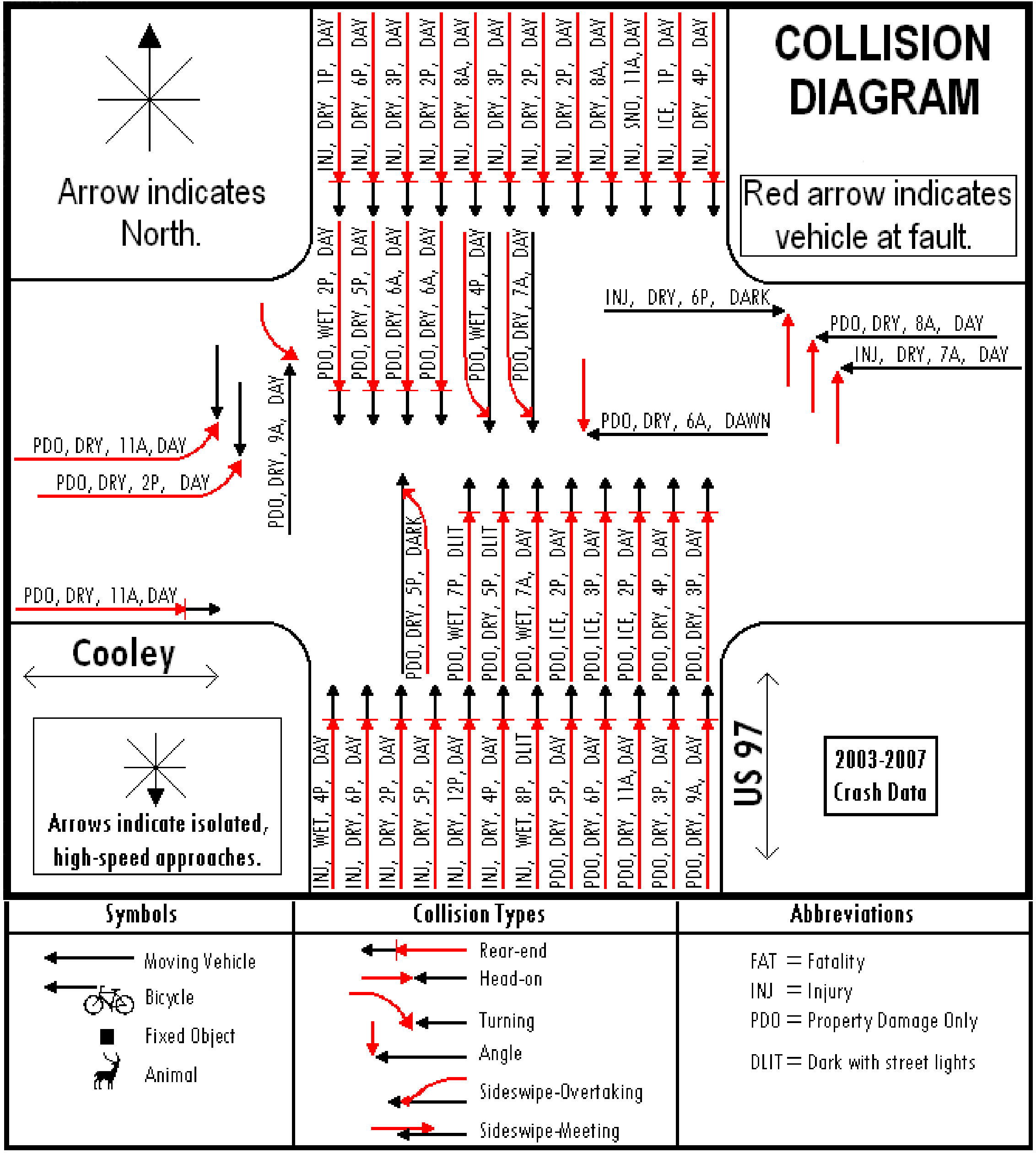
Graphs of speed data for high-speed approaches

		Volumes between 2:05pm and 2:35pm on 9/16/09 Su M T [✓ W] R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	35,900	6.2	6.7	12.9	593
Southbound	27,700	5.0	4.5	9.5	462
Eastbound	unknown	53.3	15.0	68.3	107
Westbound	unknown	50.5	27.1	77.6	107

Other notes: Westbound traffic crosses railroad tracks ~270 ft before stop bar.

Eastbound and westbound traffic have two left turn lanes (one of which is a shared thru/left lane).

Intersection of Cooley and US 97 , Deschutes County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Cooley and US 97 , Deschutes County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages																		
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
										Overall	47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

45	**2**	**79**	**6.4**	**8.5**	**6.4**	**0**	**0**	**0**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)																		
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

45	**2**	**12**	**0.9**	**1.3**	**0.9**	**0**	**0**	**0**	**15**

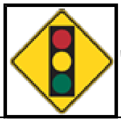
Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Rear-end collisions are highly overrepresented.**

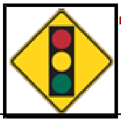
Overtaking sideswipe crashes are also slightly high.

Intersection of Deer Island Rd/Liberty Hill Rd and US 30; Columbia County, OR

Basic site characteristics:
- Posted speed of 50 mph on southbound approach and 45 mph on northbound approach
- 2 lanes of traffic in each major direction (N/S). 1 lane in each minor direction (E/W)
- Exclusive left and right turn lanes
- Intersection has no skew (90 degrees)
- Southbound approach is isolated
- Signal Ahead Signs on both major approaches



SAS located 500 ft before stop bar



SAS located 1440 ft before stop bar

Horizontal and vertical curvature limit sight distance ~1600ft before intersection.

Traffic signal has good visibility for northbound approach.

Train tracks parallel US 30

Unknown site characteristics:
- Signal phasing
- Actual travel speeds
- Turning Volumes

Signalized intersection located ~.75 miles to the south

TITLE
Deer Island and US 30 Intersection

DATE
11/2009

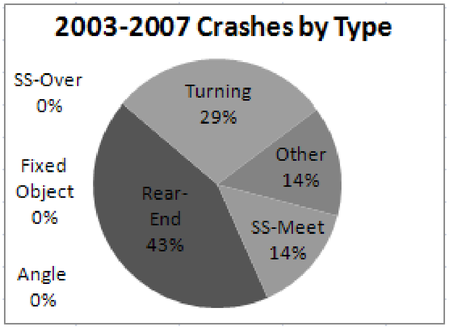
PREPARED BY
OSU Research Team

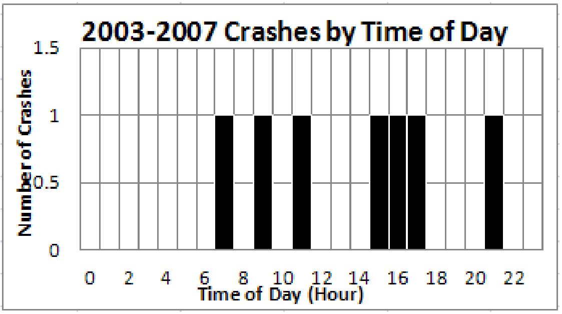
DESCRIPTION
Site Characteristics

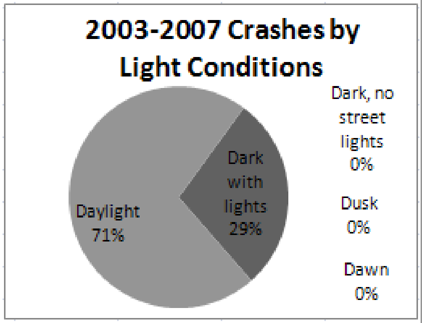
FILE
VISIODOCUMENT

Intersection of Deer Island Rd/Liberty Hill Rd and US 30; Columbia County, OR

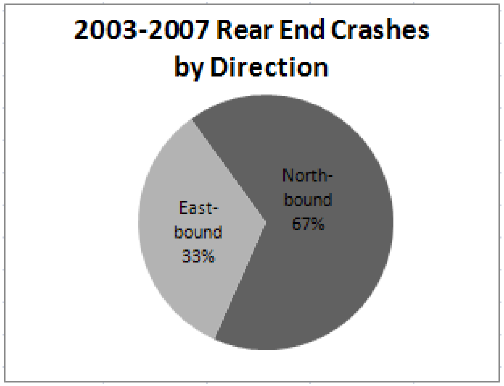
2003-2007 Crashes	
3	Rear-End
2	Turning
0	Angle
0	Sideswipe-Overtaking
1	Sideswipe-Meeting
0	Fixed Object
1	Other
7	Total

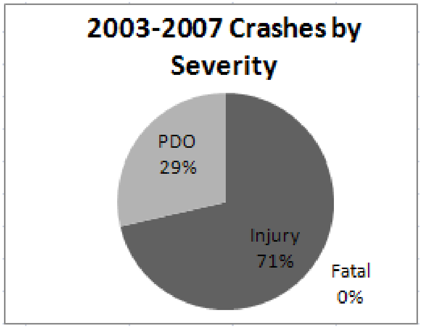

2003-2007 Crashes by Type

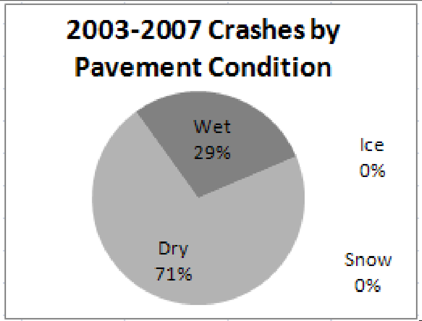

2003-2007 Crashes by Time of Day


2003-2007 Crashes by Light Conditions

2003-2007 Rear End Crashes	
2	Northbound
1	Eastbound


2003-2007 Rear End Crashes by Direction


2003-2007 Crashes by Severity

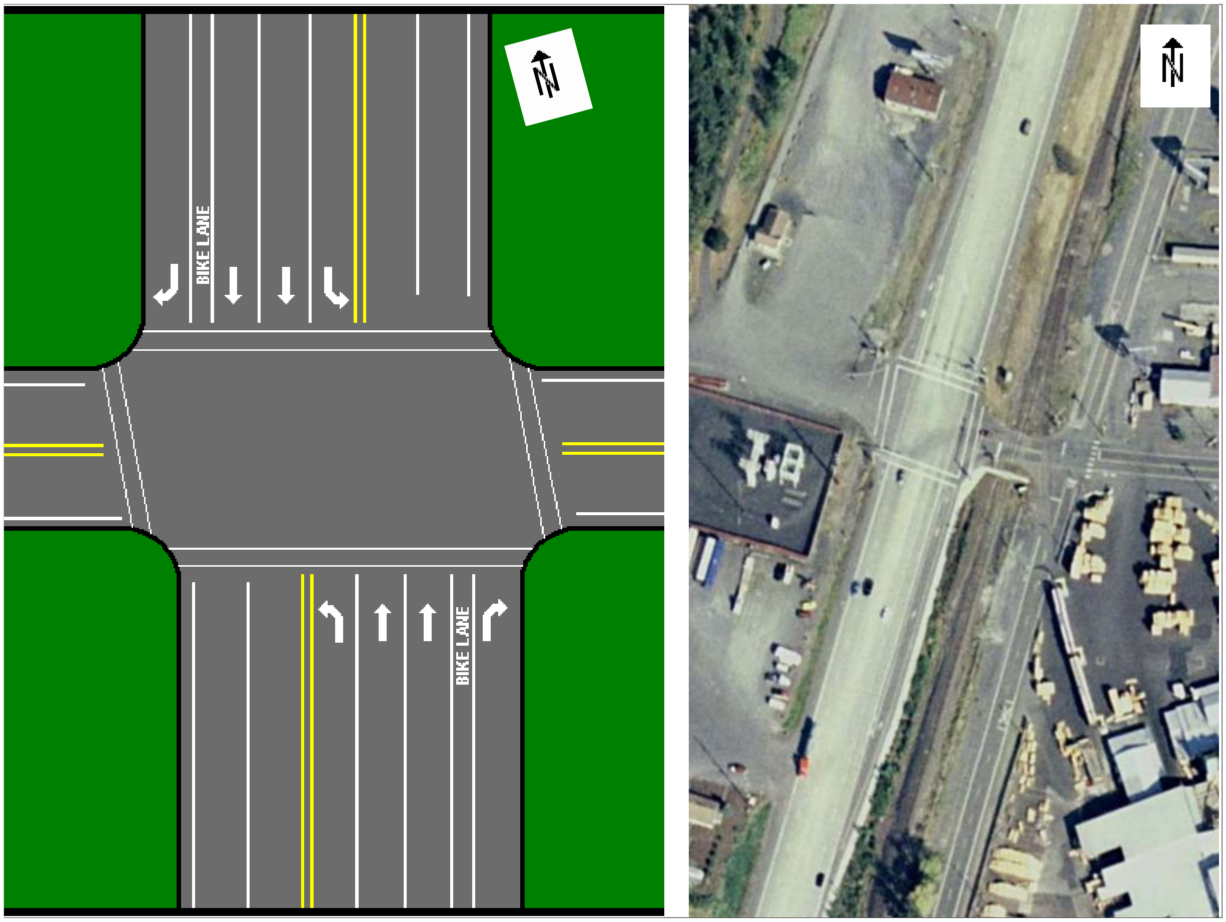

2003-2007 Crashes by Pavement Condition

TITLE Deer Island and US 30 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

Intersection of Deer Island and US 30 , Columbia County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	45 mph	50 mph	25 mph	25 mph
Isolated Major Approach (>1mile Isolation)	No	Yes	No	No
Advanced Intersection Warning*	SAS	SAS	--	--
Other	--	--	--	--

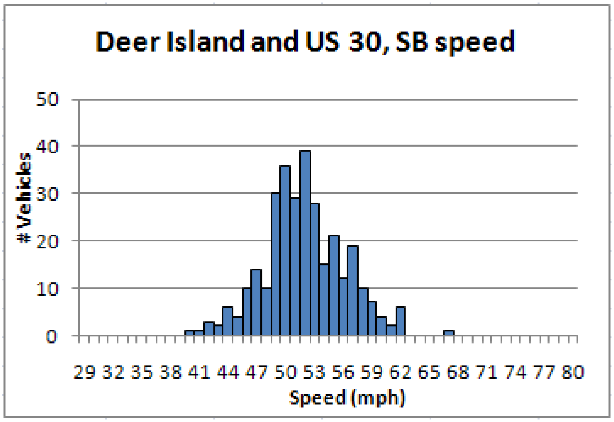
*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing



Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Deer Island and US 30, Columbia County (Page 2)

Picture showing typical arrangement and number of signal heads



Average southbound speed = 52.4 mph

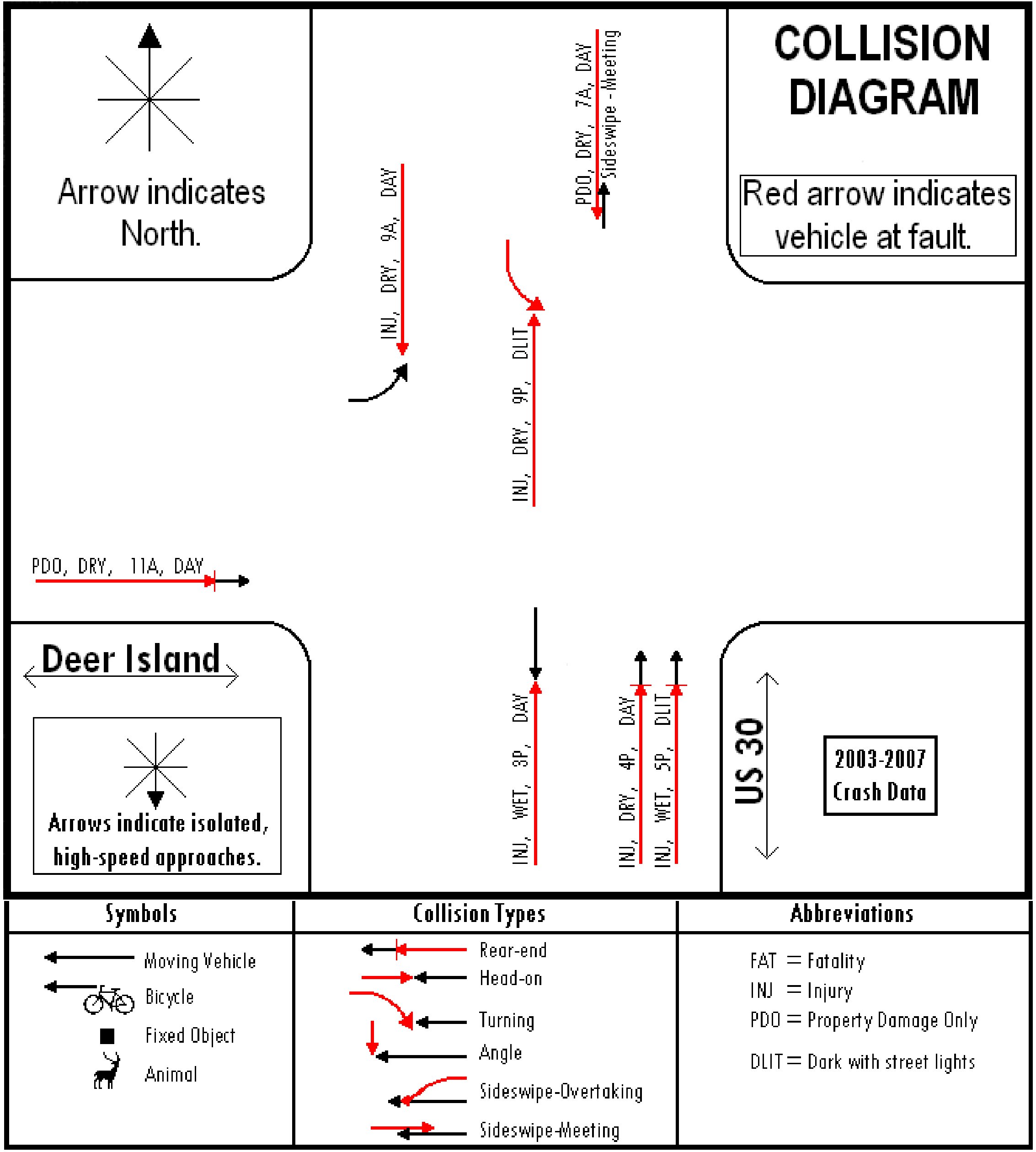
Graphs of speed data for high-speed approaches

		Volumes between 2:30pm and 3:00pm on 9/21/09 Su [✓ M] T W R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	15,300	0.3	9.9	10.2	313
Southbound	15,300	10.5	0.8	11.3	237
Eastbound	unknown	42.9	42.9	85.8	7
Westbound	unknown	45.5	52.7	98.2	55

Other notes: Horizontal and vertical curvature limit southbound sight distance ~1600ft before intersection.

Westbound approach crosses railroad tracks ~50 ft before stop bar.

Intersection of Deer Island and US 30, Columbia County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Deer Island and US 30, Columbia County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages																		
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
									Overall		47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

50	**2**	**43**	**29**	**0**	**0**	**14**	**0**	**14**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)																		
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
									Overall		5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

50	**2**	**2.0**	**1.3**	**0**	**0**	**0.7**	**0**	**0.7**	**4.6**

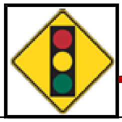
Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Meeting Sideswipes are overrepresented (based on 1 collision in 5 years).**

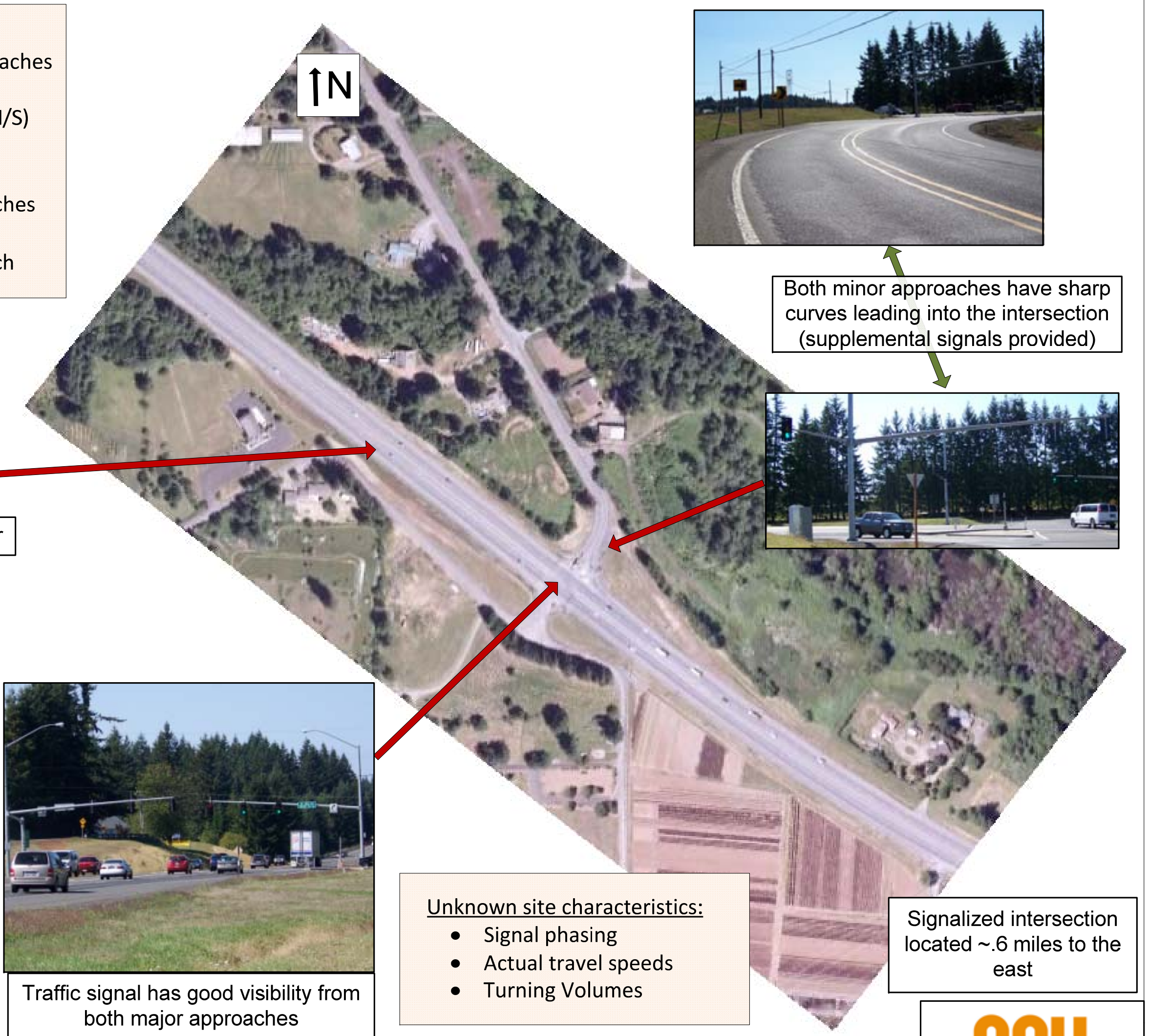
‘Other’ collision is a head-on collision (1 collision in 5 years)

Intersection of Orient Dr/Jarl Rd and US 26; Clackamas County, OR

Basic site characteristics:
- Posted speed of 55 mph on major approaches
- 2 lanes of traffic in each major direction (E/W). 1 lane in each minor direction (N/S)
- Exclusive left and right turn lanes
- Intersection has no skew (90 degrees)
- No sight restrictions from major approaches
- Eastbound approach is isolated
- Signal Ahead Sign on eastbound approach



SAS located 600 ft before stop bar



Both minor approaches have sharp curves leading into the intersection (supplemental signals provided)

Traffic signal has good visibility from both major approaches

Unknown site characteristics:
- Signal phasing
- Actual travel speeds
- Turning Volumes

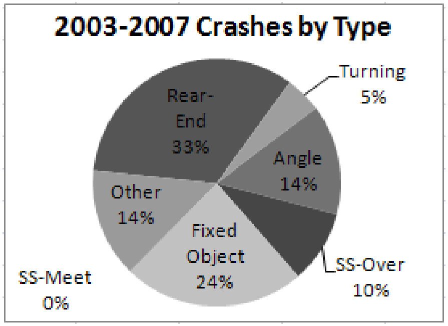
Signalized intersection located ~.6 miles to the east

TITLE Orient and US 26 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Site Characteristics	FILE	VISIODOCUMENT

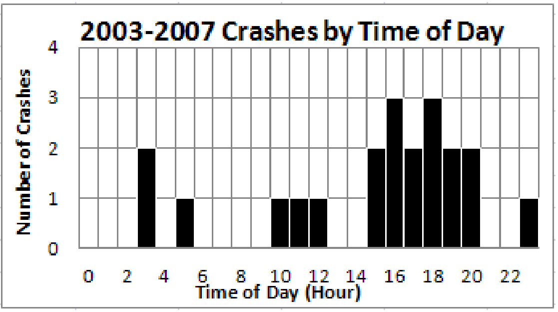
OSU Oregon State UNIVERSITY

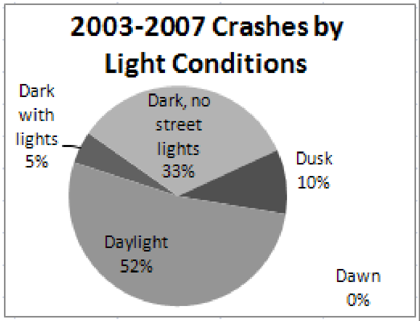
Intersection of Orient Dr/Jarl Rd and US 26; Clackamas County, OR

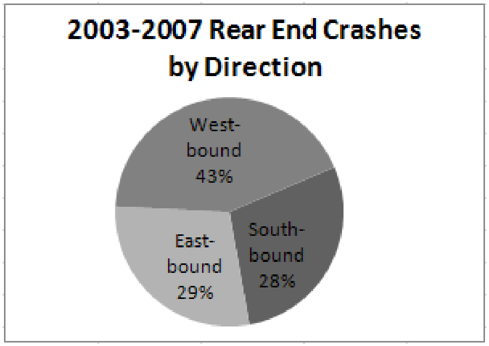
2003-2007 Crashes	
7	Rear-End
1	Turning
3	Angle
2	Sideswipe-Overtaking
0	Sideswipe-Meeting
5	Fixed Object
3	Other
21	Total

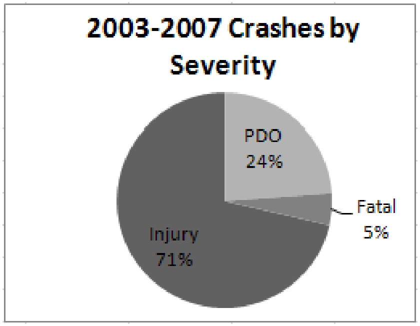

2003-2007 Crashes by Type

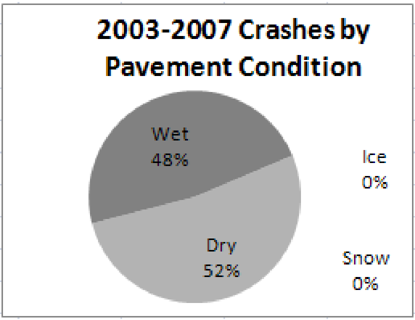
2003-2007 Rear End Crashes	
2	Southbound
2	Eastbound
3	Westbound


2003-2007 Crashes by Time of Day


2003-2007 Crashes by Light Conditions


2003-2007 Rear End Crashes by Direction


2003-2007 Crashes by Severity


2003-2007 Crashes by Pavement Condition

TITLE Orient and US 26 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

OSU
Oregon State
UNIVERSITY

Intersection of Orient and US 26 , Clackamas County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	55 mph	55 mph	30 mph (?)	30 mph (?)
Isolated Major Approach (>1mile Isolation)	No	Yes	No	No
Advanced Intersection Warning*	--	SAS	--	--
Other	--	--	--	--

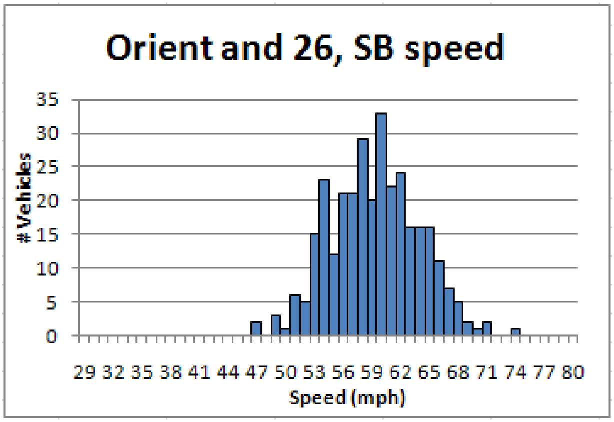
*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Orient and US 26 , Clackamas County (Page 2)

Image shows southbound approach

Picture showing typical arrangement and number of signal heads



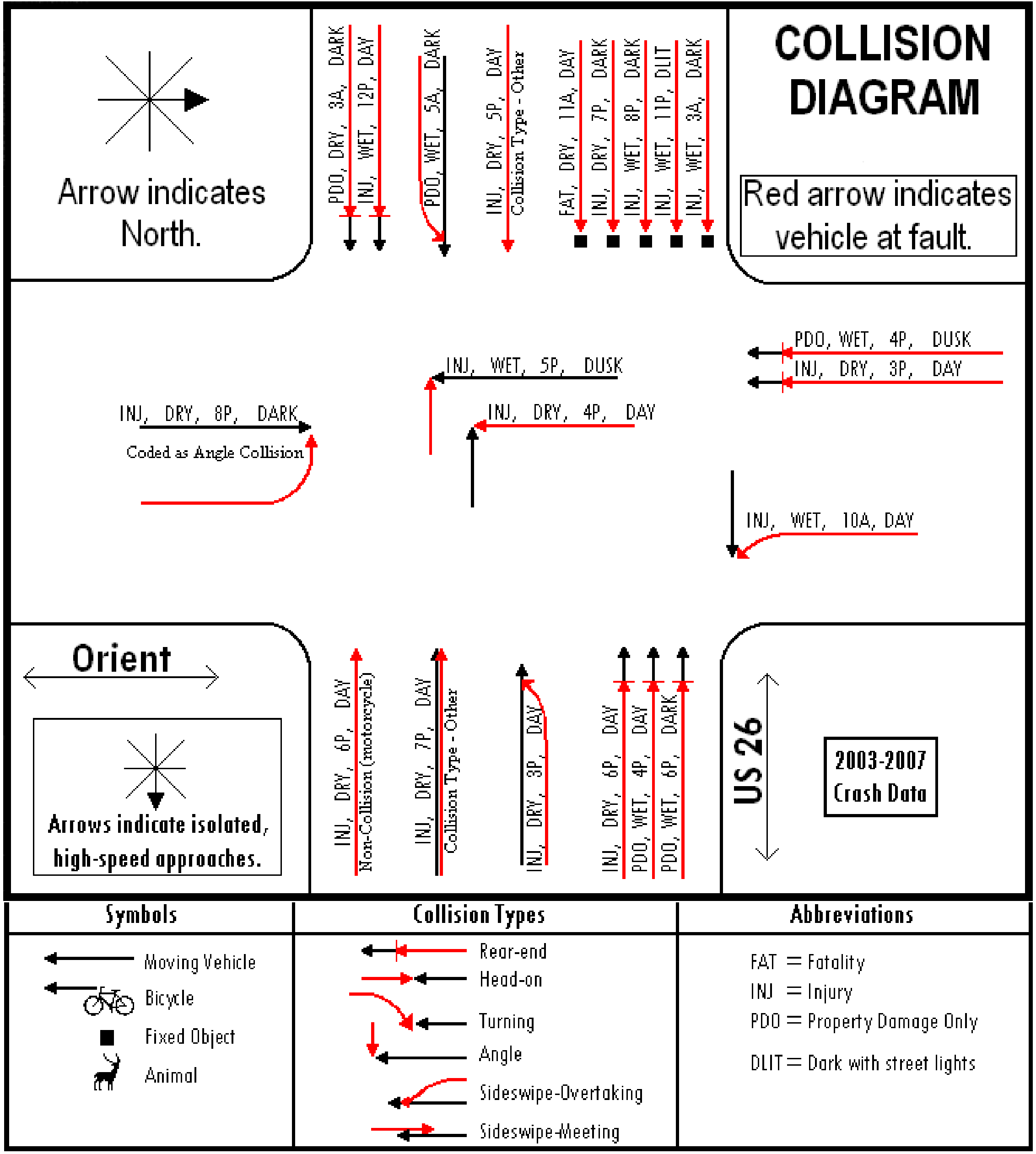
Average northbound speed = 59.8 mph

Graphs of speed data for high-speed approaches

		Volumes between 1:50pm and 2:20pm on 9 /22/09 Su M [✓ T] W R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	30,900	1.1	16.9	18.0	473
Southbound	28,800	1.1	0.9	2.0	455
Eastbound	unknown	60.0	40.0	100	5
Westbound	unknown	94.5	4.1	98.6	73

Other notes: Both minor approaches have sharp curves leading into the intersection (supplemental signals are visible before curves). Major approaches have extra long visors to block view of signals from minor approaches.

Intersection of Orient and US 26 , Clackamas County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Orient and US 26 , Clackamas County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
									Overall		47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**33**	**4.8**	**14**	**9.5**	**0**	**24**	**14**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)

Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
									Overall		5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**2.4**	**0.3**	**1.0**	**0.7**	**0**	**1.7**	**1.0**	**7.1**

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Fixed Object collisions are highly overrepresented.**

All others are near or below expected values

Intersection of Roosevelt Blvd and OR 569; Lane County, OR

Basic site characteristics:

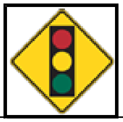
- Posted speed of 55 mph on major approaches
- 2 lanes of traffic in each major direction (N/S). 1 lane in each minor direction (E/W)
- Exclusive left and right turn lanes
- Intersection has no skew (90 degrees)
- Bridges located on both major approaches
- Northbound and Southbound approaches are isolated
- Signal Ahead Signs on both major approaches

Shared-use path crosses intersection along north crosswalk.

Unknown site characteristics:

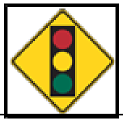
- Signal phasing
- Actual travel speeds
- Turning Volumes

Crest of bridge is located ~1900 ft before stop bar



SAS located 955 ft before stop bar

Traffic signal has good visibility. However, crest of bridges may limit sight distance to queued vehicles.



SAS located 890 ft before stop bar

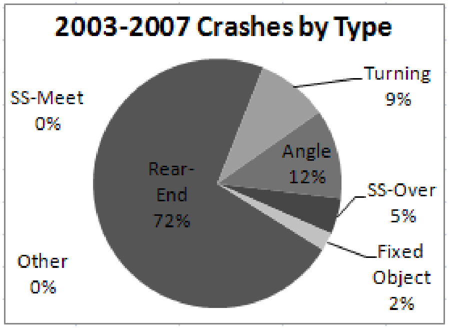
Crest of bridge is located ~1600 ft before stop bar

TITLE	DATE	PREPARED BY
Roosevelt and OR 569 Intersection	11/2009	OSU Research Team
DESCRIPTION	FILE	
Site Characteristics	VISIODOCUMENT	

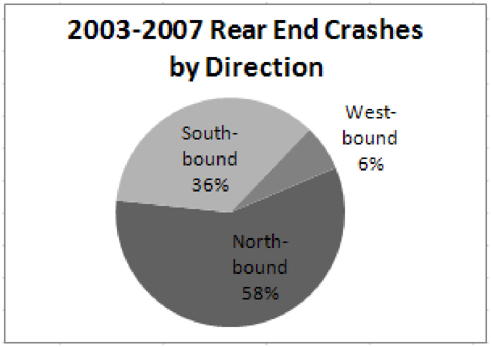
OSU Oregon State UNIVERSITY

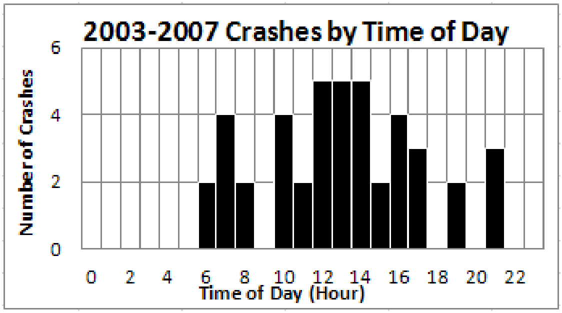
Intersection of Roosevelt Blvd and OR 569; Lane County, OR

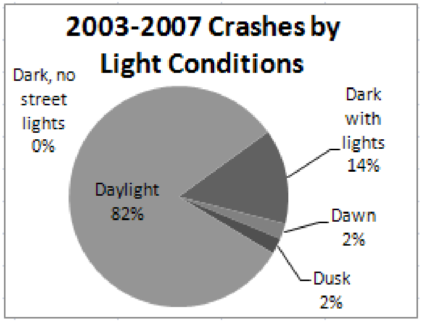
2003-2007 Crashes	
31	Rear-End
4	Turning
5	Angle
2	Sideswipe-Overtaking
0	Sideswipe-Meeting
1	Fixed Object
0	Other
43	Total

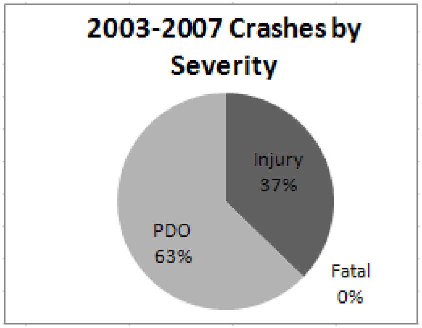

2003-2007 Crashes by Type

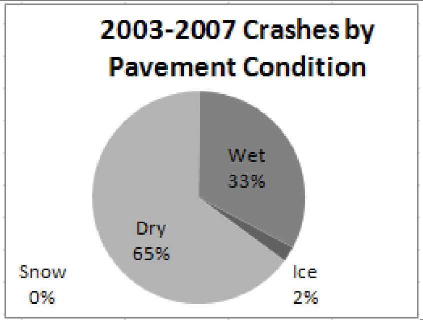
2003-2007 Rear End Crashes	
18	North-bound
11	South-bound
2	West-bound


2003-2007 Rear End Crashes by Direction


2003-2007 Crashes by Time of Day


2003-2007 Crashes by Light Conditions


2003-2007 Crashes by Severity


2003-2007 Crashes by Pavement Condition

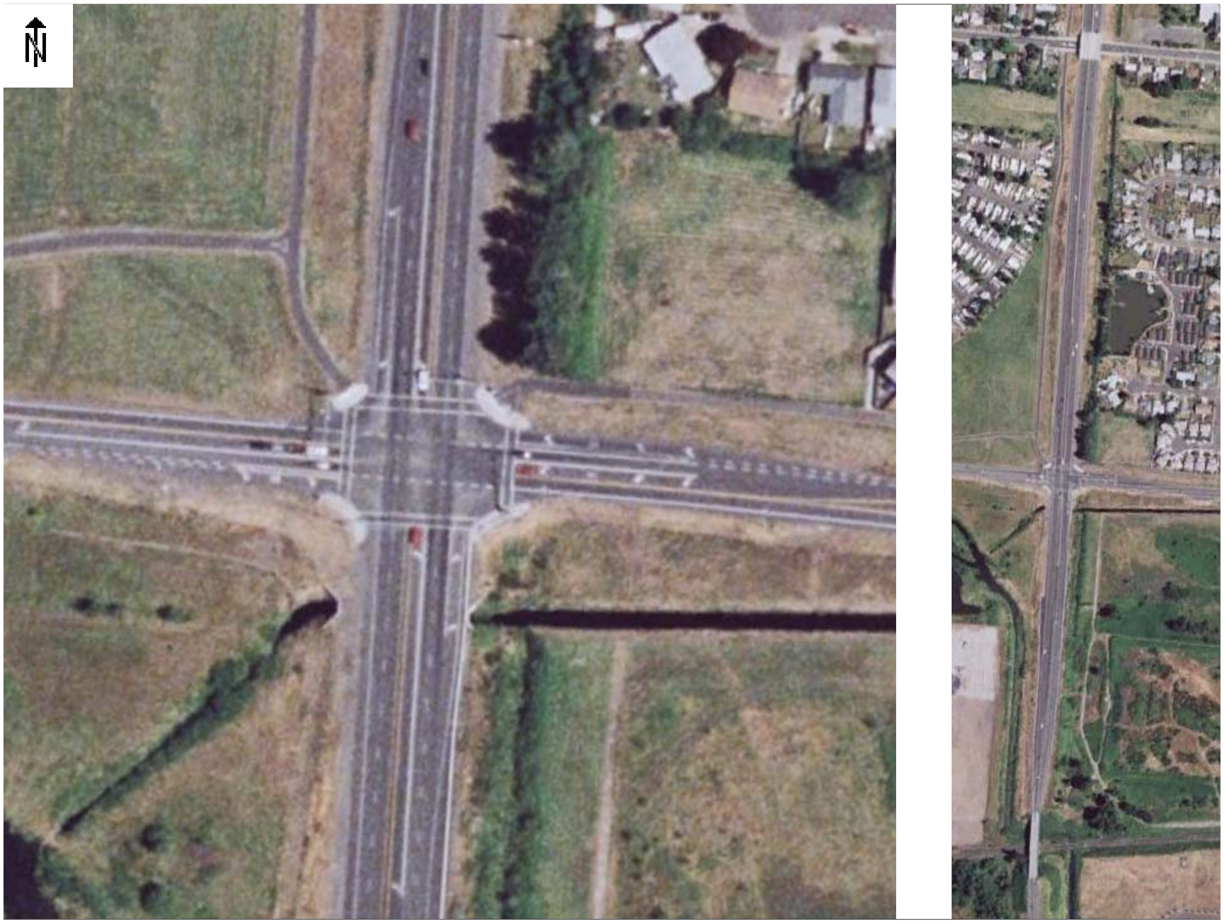
TITLE Roosevelt and OR 569 Intersection	DATE 11/2009	PREPARED BY OSU Research Team
DESCRIPTION Crash data available	FILE VISIODOCUMENT	

OSU Oregon State University

Intersection of Roosevelt and OR 569 , Lane County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit	55 mph	55 mph	45 mph	45 mph
Isolated Major Approach (>1mile Isolation)	Yes	Yes	No	No
Advanced Intersection Warning*	SAS	SAS	--	--
Other	--	--	--	--

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

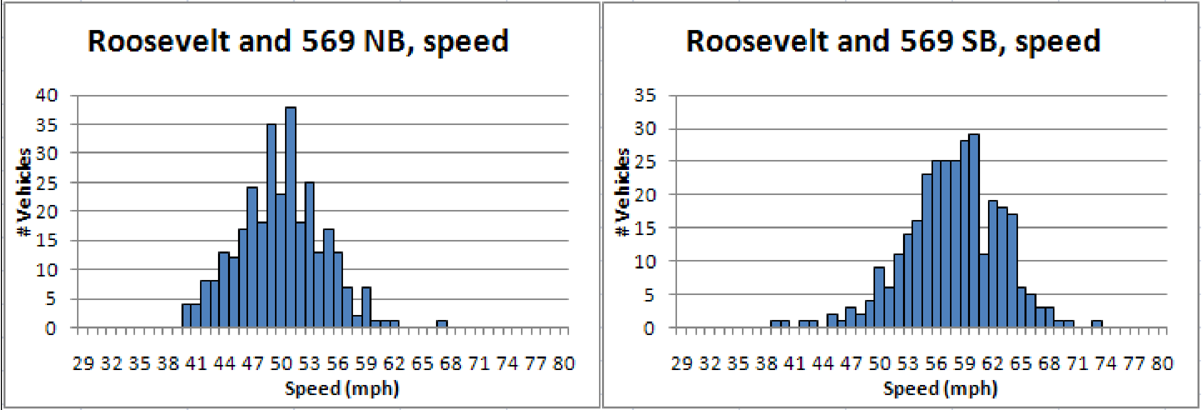


Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of Roosevelt and OR 569 , Lane County (Page 2)


Image shows southbound approach.

Picture showing typical arrangement and number of signal heads



Average northbound speed = 50.5 mph

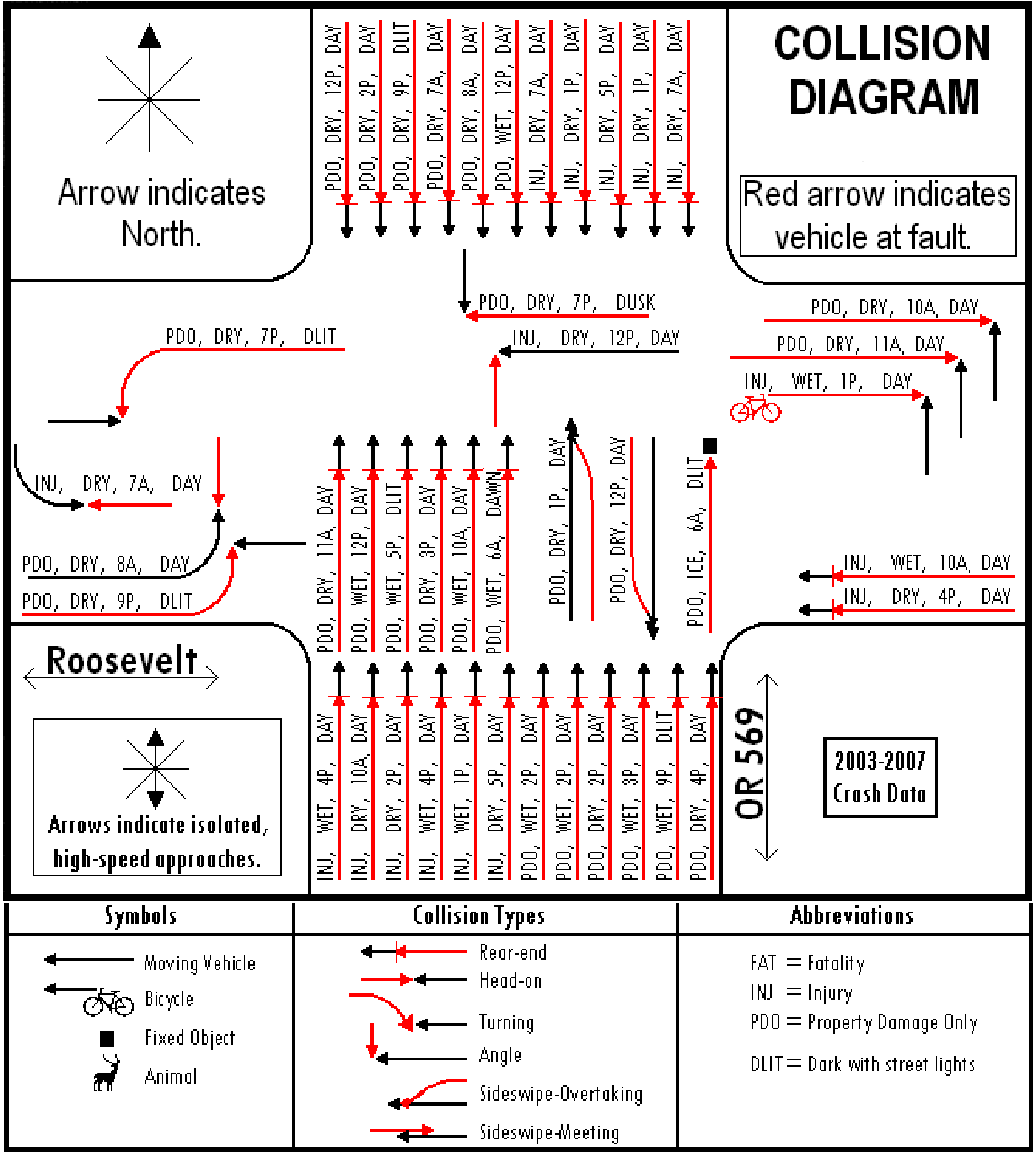
Average southbound speed = 58.2 mph

Graphs of speed data for high-speed approaches

		Volumes between 4:50pm and 5:20pm on 9/14/09 Su [✓ M] T W R F Sa			
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound	19,700	7.4	3.7	11.1	405
Southbound	23,100	15.2	28.4	43.6	592
Eastbound	unknown	62.6	7.9	70.5	190
Westbound	unknown	8.8	47.0	55.8	328

Other notes: Southbound approach goes over crest of bridge ~1900 ft before stop bar. Northbound approach goes over crest of bridge ~1600 ft before stop bar, switches from 1 to 2 lanes just past crest.

Intersection of Roosevelt and OR 569 , Lane County (Page 3)



Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of Roosevelt and OR 569 , Lane County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages																			
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
										Overall	47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**72**	**9.3**	**12**	**4.7**	**0**	**2.3**	**0**	**100**

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)																			
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

55	**2**	**14**	**1.9**	**2.3**	**0.9**	**0**	**0.5**	**0**	**20**

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments: **Rear-End collisions are highly overrepresented. Angle collisions are also slightly high.**

APPENDIX D:
EVALUATION FORMS

This appendix contains a blank sample of the data collection forms used in this project and the general template. General intersection information can be collected by using the form titled "IHSSI Data Collection Form" and basic signal phasing information can be determined using the second form titled "Traffic Signal Phasing Form."

IHSSI Data Collection Form

Date: ___/___/___
Start Time: __________
Data Collected By: __________
Weather: _________
Major Rd Name: ____________________
Major Rd #: ______
Minor Rd Name: ____________________

All Red Time: _____sec
Yellow for Major: _____sec
Yellow for Minor: _____sec
Signal Control: Pretimed ☐
Fully Actuated ☐
Semi-Actuated ☐
Max Green Northbound: _______sec
Max Green Southbound: _______sec
Max Green Eastbound: _______sec
Max Green Westbound: _______sec

Volumes Collected ☐
Jamar Code ________________
Speed Data Collected ☐
Speed Collection Location: _____________

List additional traffic devices
and other comments below.

Major Approach 1 Direction: __________
Isolated, High Speed ☐
Initial Speed Limit: ________mph
Final Speed Limit: _______mph
Change Location: _______ft behind stop bar
Advisory Sign: _______
Sign Location: ________ft behind stop bar

Major Approach 2 Direction: __________
Isolated, High Speed ☐
Initial Speed Limit: ________mph
Final Speed Limit: _______mph
Change Location: _______ft behind stop bar
Advisory Sign: _______
Sign Location: ________ft behind stop bar

Minor Approach 1 Direction: ___________
Speed Limit: ________mph

Minor Approach 2 Direction: ___________
Speed Limit: ________mph

Draw intersection on back - include lane designations, signal heads, crosswalks, stop bars, north arrow, etc. ☐
Photographs ☐

Traffic Signal Phasing Form

Draw Phasing

Site: ______________________________

Date: ______________________________

Sketch Ring if Applicable

Direction	Times

Transitions						
#	Yellow Time (sec)			All-Red Time (sec)		
1						
2						
3						
4						
5						
6						
7						
8						

Intersection of ________ and ________, ________ County (Page 1)

	Northbound	Southbound	Eastbound	Westbound
Speed Limit				
Isolated Major Approach (>1 mile Isolation)				
Advanced Intersection Warning*				
Other				

*SAS = Signal Ahead Sign
CFSSA = Continuous Flashing Symbolic Signal Ahead
PTSWF = Prepare to Stop when Flashing

N

Aerial photograph or diagram indicating intersection geometry and lane configurations

Intersection of ________ and ________, ________ County (Page 2)

Picture showing typical arrangement and number of signal heads

Graphs of speed data for high-speed approaches

	Volumes collected between ________ and ________ on __/__/__ Su M T W R F Sa				
Direction	AADT	% left turns	% right turns	% total turns	Total # of Vehicles
Northbound					
Southbound					
Eastbound					
Westbound					

Other Notes: ____

____

Intersection of ________ and ________, ________ County (Page 3)

Collision Diagram showing five years of crash data. Include severity, pavement conditions, time of day, and light conditions. Indicate vehicle at fault with red arrow. Include description of symbols/abbreviations.

Feedback from users familiar with intersection:

Intersection of ________ and ________, ________ County (Page 4)

4-leg, Signalized Oregon Intersections with at Least One High-Speed, Isolated Approach

Average Crash Percentages																			
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	58	22	9.9	5.7	0.7	2.1	1.7	100	4	49	30	12	3.8	0.7	2.0	3.3	100	16
	2	46	32	12	3.2	0.7	1.9	3.8	100	12									
55 to 45	1	53	11	16	16	0.0	5.3	0.0	100	1	50	21	14	5.6	1.3	3.3	4.2	100	9
	2	47	25	17	2.9	1.2	3.3	4.0	100	6									
	1→2	58	15	7	8.9	2.2	2.2	6.7	100	2									
50	2	55	19	16	2.6	3.3	0.0	4.3	100	5	55	19	16	2.6	3.3	0.0	4.3	100	5
55	1	50	26	10	1.3	3.3	4.4	4.1	100	5	41	24	12	8.5	1.9	6.4	5.7	100	15
	2	37	23	13	12	1.1	7.4	6.4	100	10									
										Overall	47	25	13	5.7	1.4	3.4	4.5	100	44

Fill in data for specific intersection. Circle applicable averages listed above.

Crash % = (# of one type of crash)/(# total crashes)

Average Crash Rates (#Crashes in 5 year period x 10,000/AADT)																			
Speed Limit (mph)	Number of Lanes	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections	Rear-End	Turning	Angle	Sideswipe-Overtaking	Sideswipe-Meeting	Fixed Object	Other	Total	Number of Intersections
45	1	8.6	3.1	1.2	0.6	0.2	0.3	0.3	14	4	6.3	3.5	1.4	0.5	0.1	0.3	0.4	13	16
	2	5.6	3.7	1.5	0.5	0.1	0.2	0.5	12	12									
55 to 45	1	11	2.2	3.3	3.3	0.0	1.1	0.0	21	1	5.4	2.1	1.3	0.7	0.2	0.5	0.3	11	9
	2	4.5	2.1	1.1	0.2	0.2	0.4	0.3	8.8	6									
	1→2	5.5	2.1	1.1	1.0	0.4	0.4	0.6	11	2									
50	2	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5	6.7	2.6	2.2	0.5	0.3	0.0	0.5	13	5
55	1	5.3	2.7	0.9	0.2	0.2	0.6	0.4	10	5	4.2	2.2	1.3	0.6	0.1	0.6	0.4	9.4	15
	2	3.7	1.9	1.5	0.8	0.1	0.5	0.4	8.9	10									
										Overall	5.4	2.7	1.4	0.6	0.1	0.4	0.4	11	44

Fill in data for specific intersection. Circle applicable averages listed above.

Crash rate = (#crashes in 5yr period)x(10,000)/(AADT)

Comments:

Potential Countermeasures for Isolated, High-Speed, Signalized Intersections

Rear End

- Create turn lanes
- Install advanced warning devices
- Remove sight obstructions
- Install 12 inch signal lenses
- Install visors
- Install/enhance backplates
- Improve location/number of signal heads (e.g. near-side)
- Adjust/extend amber/all-red
- Provide progression (if not isolated approach)
- Adjust signal timing
- Improve skid resistance
- Reduce speeds - traffic calming or lower speed limit (after study)
- Lengthen mast arms
- Install additional loops
- Check equipment for malfunction
- Install transverse pavement markings
- Install extension of green time systems (Advance Detection Control Systems)
- Remove signal (see MUTCD)

Turning

General treatments

- Remove sight obstructions
- Adjust signal timing
- Adjust/extend amber/all-red
- Reduce speeds - traffic calming or lower speed limit (after study)

If turning vehicle at fault

- Add protected phase (remove permitted phase)
- Increase/add turn lane
- Provide channelization
- Increase curb radii

If through vehicle at fault refer to <u>Angle</u> treatments

Angle

- Remove sight obstructions
- Install advanced warning devices
- Install 12 inch signal lenses
- Install visors
- Install/enhance backplates
- Improve location/number of signal heads (e.g. near-side)
- Reduce speeds - traffic calming or lower speed limit (after study)
- Adjust/extend amber/all-red
- Adjust signal timing
- Provide progression (if not isolated approach)
- Improve skid resistance
- Channelize intersection
- Check equipment for malfunction
- Install transverse pavement markings
- Install extension of green time systems (Advance Detection Control Systems)

Sideswipe

General treatments

- Install/improve pavement markings
- Channelize intersection

Overtaking Sideswipe

- Provide turning bays
- Install acceleration/ deceleration lanes
- Install/improve directional signing
- Restrict driveway access near intersection
- Reduce speeds - traffic calming or lower speed limit (after study)

Meeting Sideswipe

- Install median divider/barrier
- Widen lanes
- Install no passing zone signage

Fixed Object

- Remove/relocate obstacles
- Install barrier curbing
- Install breakaway features
- Reduce number of utility poles
- Relocate islands
- Widen lanes
- Install/improve pavement markings (include edgeline delineation)
- Install edgeline rumble strips
- Protect objects with guardrail or attenuation device
- Re-align intersection
- Check vertical alignment
- Upgrade roadway shoulders
- Improve channelization
- Close curb lanes
- Install advanced warning devices
- Reduce speeds - traffic calming or lower speed limit (after study)

Wet Pavement Treatments

- Overlay/groove existing pavement
- Reduce speeds - traffic calming or lower speed limit (after study)
- Provide "slippery when wet" signs
- Improve skid resistance
- Provide adequate drainage
- Upgrade pavement markings
- Install chip seal
- Install open graded asphalt concrete

Night Accident Treatments

- Install/improve street lighting
- Install/improve pavement markings
- Install/improve warning signs
- Upgrade signing
- Provide illuminated signs
- Install pavement markings
- Provide raised markers
- Upgrade advance warning signs