COMPARISON OF IDENTIFICATION AND RANKING METHODOLOGIES FOR SPEED-RELATED CRASH LOCATIONS

Final Report

SPR 352

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by

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16. Abstract

Over 60,000 crashes were reported on the Oregon state highway system from 2000–2002. Of these, speed was a primary causal factor in 27% of total crashes and 36% of all fatal crashes. Excessive speed is a driver behavior that can be influenced by a wide variety of countermeasures. However, different methods for analyzing crash data often result in setting different priorities for safety improvements. The state of Oregon currently does not have a developed methodology for prioritizing locations for review of countermeasure deployment. When making decisions about countermeasure deployment with limited resources, it is important they be allocated to locations that will result in the greatest impact. The objective of this study was to improve the procedures used to select locations for speed-related safety countermeasures. The report includes a literature review focused on the relationship between speed and crashes, as well as past research on speed reduction techniques. An analysis of speed-related crash data indicated that a number of variables such as ice, curves, and others are overrepresented in speed crashes. Based on these findings, the study then developed and compared alternate ranking methods for speed/ice crash locations, including a unique refinement of the rate quality control (RQC) method, using climate data that helps identify road segments that exhibit statistically significant high speed/ice crash patterns. The results of the method were highlighted with a case study of identified highway sections using a new zonal RQC. To demonstrate the feasibility of this analysis technique, the top 20 sites identified by the refined screening technique were reviewed for possible countermeasures.

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°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
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
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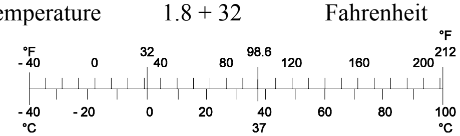
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



***** SI is the symbol for the International System of Measurement

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COMPARISON OF IDENTIFICATION AND RANKING METHODOLOGIES FOR SPEED-RELATED CRASH LOCATIONS

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1.0 INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) reported that speeding was a contributing factor in approximately 32% of motor vehicle fatalities nationwide in 2002 (*FARS 2004*). Speeding is defined here as a driver charged with a speeding citation, racing, driving too fast for conditions as indicated by police officer, or exceeding the posted limit. For Oregon, NHTSA reported that 31% of Oregon motor vehicle fatalities were speeding-related, and only 6% of those were on interstates (*FARS 2004*). The Oregon Department of Transportation (ODOT) Transportation Safety Division reported that 52% of 2002 fatalities involved speed (excessive speed or speed too fast for conditions) (*ODOT 2002*). This difference is due to slightly different definitions of speeding. In both cases, speed was a contributory factor in a substantial number of fatal crashes. In addition, drivers who speed often participate in other risky behavior such as not wearing a seat-belt, alcohol abuse, or aggressive driving. Furthermore, during the period 1996-2000, excessive speed was a contributing factor in 15% of all crashes on the Oregon state highway system, accounting for approximately 16% of the injury and 41% of fatal crashes during that five year period. Clearly there is a need to attempt to reduce the number of speed-related crashes.

The physical contribution of speed, as a mechanism in individual crashes, is well understood. Driver speed contributes to multiple vehicle crashes by creating differences in vehicle speeds and increasing the distance required for crash avoidance maneuvers. For single-vehicle crashes, speed often contributes to a loss of control when combined with other driver errors and environmental effects. Speed also determines the severity of injuries to occupants in a crash. All else being equal, crashes at higher speeds are almost always more severe as a result of the greater energy involved. These concepts have been well-documented through past research efforts and are understood intuitively by most drivers.

Excessive speed is a driver behavior that can be influenced by countermeasures including, but not limited to, roadway design improvements, intelligent transportation system (ITS) technologies such as dynamic message signs, and enforcement and education programs. Each of these possible strategies is appropriate at certain locations, though there is currently no statewide system in Oregon to prioritize or understand the potential benefits of various forms of countermeasures at different locations. This is clearly evident with ITS technologies. A wide array of ITS countermeasures exists, which are primarily aimed at reducing speed and improving safety. However, there is no systematic process for determining which of these technologies to apply at specific locations. The absence of such a process is in part due to a lack of a long track record in systematically and continually measuring benefits of speed reduction countermeasure technologies in Oregon. As a result, this has led to heightened interest in this subject.

There are various ongoing techniques for analyzing crash data toward improving highway safety, including ODOT's Safety Priority Index System (SPIS) and Safety Investment Program (SIP). Other agencies and researchers have developed and applied procedures that are markedly different from those used in Oregon. These different methods may result in better project selection for safety improvements. When making decisions with limited resources, it is important they be allocated to locations where the improvement will result in the greatest impact.

A companion to this research report – *Field Evaluation of the Myrtle Creek Advanced Curve Warning System* – describes a system which measures the speeds of vehicles approaching a tight horizontal curve and reports the vehicle's speed via a dynamic message sign (*Bertini, et al. 2006*). The broader motivation for this research was to develop methods for a statewide prioritization technique for technologies similar to the Myrtle Creek project. This report compares a number of techniques for selecting countermeasures to speed-related crashes, while the results of the Myrtle Creek project are published in a separate report.

1.1 RESEARCH OBJECTIVES

The objective of this research is to improve the procedures used to select locations for speed-related safety countermeasures. This is accomplished by comparing various methodologies for identification and ranking of speed-related crashes in the state of Oregon. The analysis will recommend an optimal method which will be adequately documented to allow ODOT to repeat the procedures used to identify areas for countermeasure deployment. This report presents the first step towards a more robust method of identifying highway locations based on crash type, using speed-related crashes and other important crash variables as a model. It is hoped that the results of this project will contribute toward ODOT's safety prioritization systems and will provide documentation of the efficacy of alternate prioritization methods. These results can be extended to statewide relevance and will also be useful to counties and cities throughout Oregon when making safety improvement decisions. Ultimately, a better understanding of the possible relationships between different types of countermeasures and safety outcomes will enhance the safety and mobility of all users of the transportation system.

1.2 ORGANIZATION OF REPORT

Chapter 2 presents an extensive literature review that first discusses the relationship between speed and crashes. The literature review continues by examining past research on speed reduction techniques, including geometric roadway modifications, traffic control devices, operations and ITS, and enforcement. Educational issues are not discussed in this study. Chapter 3 includes an analysis of crash data for Oregon between the years 2000-2002 (three years' data, robust enough for a statistically significant analysis). In this chapter the statewide crash data are analyzed with a particular focus on those crashes deemed to be speed-related. Other contributing factors such as light and surface conditions are also examined. Chapter 4 describes the development of four crash ranking methods. Chapter 5 describes a comparison of the selected ranking methods, including a statistical comparison and a comparison of the top 20 crash sites based on a zonal rate quality control method. Chapter 6 discusses case study selection of appropriate countermeasures for those crash locations, including anti-icing systems and ice-detection systems. This is followed by conclusions, recommendations and a brief discussion of suggestions for future research.

2.0 LITERATURE REVIEW

A detailed literature review was conducted in order to examine past research that focused on the relationship between speed and crash occurrence. This included research that focused on the impact of speed on vehicle operating characteristics, as well as studies that included very detailed post-crash investigations in an attempt to pinpoint the key causal factors. Studies that examined the impact of speed on crash severity were also reviewed and are discussed below. Over the past few decades, changes to vehicles have been made that have impacted highway safety. At the same time there have been numerous programs aimed at making some kind of infrastructure-based improvement in order to reduce crash frequency. This chapter thus includes a review of past literature that studied the impacts of speed reduction techniques, including geometric modifications to roadways, traffic control devices, operations and ITS, and enforcement. Educational programs are not reviewed in this report. This chapter concludes with a review of research aimed at developing and improving roadway network screening techniques for safety improvements.

2.1 RELATIONSHIP BETWEEN SPEED AND CRASHES

It has been established that speed plays an important role in individual crash occurrence, and all else being equal, in the severity of crash outcomes in terms of damage severity, both to persons and property. The research and knowledge of these issues is fairly unanimous. This section discusses ways that speed changes the operating characteristics of cars and trucks, the relationship between speed and crash severity, the analysis of speed-related crashes in databases, and the results of post-crash investigations documenting speed as a contributing factor.

The research is less clear on how speed can affect overall crash occurrence, primarily because of the challenges in isolating the role of speed in aggregate studies. The research is not conclusive, but generally indicates that speed has a negative impact on safety. Crash occurrence (or more accurately, crash risk) was generally found to be near the minimum for vehicles traveling near the mean traffic speed. The risk of crash involvement was shown to have nearly equal increases for vehicles traveling significantly above the mean speed as well as below (*TRB 1998*).

2.1.1 Operating characteristics

While speed can affect other operating characteristics such as handling and stability of passenger cars, most often the safety impacts of speed are associated with the additional braking distance required at higher speeds. In the design of highways, stopping sight distance is often calculated for a “design” vehicle which includes assumptions about driver reaction time, pavement conditions (wet), driver, vehicle and object height, and vehicle deceleration capabilities. This distance consists of two components: 1) the distance traveled from the time the driver first perceives a hazard to when he or she first applies the brakes; and 2) the distance traveled during braking. Drivers at higher speeds travel greater distances during the reaction component, and the distance required for braking increases as a function of the square of speed.

For trucks, the size and configuration of the vehicle affects how much speed changes its operating characteristics. Like cars, braking distance for trucks is longer with increased speed. Heavy vehicles use hydraulic and air brakes (trucks are primarily equipped with air brakes). Federal Motor Vehicle Safety Standards (FMVSS) have required anti-lock brakes (ABS) on new trucks and trailers since 1997. Roughly 43% of the trucking fleet is estimated to have anti-lock brakes (*Harwood, et al. 2003*). The widespread use of ABS has resulted in improved stability during braking (avoiding wheel-lock and jackknife conditions) and under some conditions, reduced braking distance (*ITE 1992*). Braking distance for trucks, however, is still longer than for passenger cars. Assuming a level roadway, dry pavement, and a truck weight of 80,000 pounds, a truck will take 60% longer to come to a complete stop at 65 mph compared to 55 mph (*Harwood, et al. 2003*).

Some of the longer stopping sight distance can be offset because truck drivers have an eye height advantage over passenger car drivers (8 feet as compared to 3.5 feet), which means that truck drivers can see farther down the road and over vertical sight distance impediments. Consequently, truck drivers have a slight advantage in reaction time. Truck rollover conditions are primarily related to loaded weight and load configuration, while speed plays a smaller role. For trucks with double or triple trailers, higher speeds may increase trailer rearward amplification.

2.1.2 Post-crash investigations

Some studies have been conducted in which trained investigators systematically studied crashes and assigned the most likely cause of the crash. These studies are categorized as "clinical." None of these studies focused specifically on interstate facilities. Acquiring the number of samples to develop an adequate data set for analysis is costly, and as such, there is not a significant body of literature to report. The benchmark comprehensive study, referred to as "Tri-Level," was conducted by Treat, et al. at Indiana University in the late 1970s (*Treat, et al. 1977*). The research team assembled data on three levels of crash detail: police reports (n=13,658), on-site investigations of crashes in Monroe County, Indiana by a trained team (n=2,258), and in-depth analysis by a multidisciplinary team (n=420). Crash causes were assigned in a rigorous manner independently at each level. The study found that human error was a definite cause for 64% and probable cause for 93% of crashes studied. Of those crashes, excessive speed (defined as speed different from the average driver on that road) was the second leading crash cause (after improper lookout). Speed was a definite cause for 7% and probable cause for 15% of crashes studied. Treat et al. also found that most excessive speed errors were associated with some road design feature, mainly horizontal curves. The Tri-Level study also found that the most common crash type associated with excessive speed was one involving a single vehicle.

Bowie and Walz used the NHTSA Crash Avoidance Research Data file (CARDfile) to determine speed crash causation (*Bowie and Walz 1994*). The CARDfile combined data from six states in a common format for analysis. Here, speed was coded as a causal factor when the police officer's judgment was that speed contributed to the cause of the crash. Up to three causes could be coded per crash, and they found speed to be a cause in 12% of total crashes and 34% of fatal crashes.

In 1996, Viano and Riddle studied a set of 131 data files for fatal crashes of seat-belted drivers for the purpose of developing vehicle-based crash avoidance technologies. The detailed investigation of the crash was required as part of a General Motors incentive program that offered a $10,000 insurance policy in case of a fatality of a belted driver. Viano and Ridella found that the second most common crash type involved single vehicles departing the roadway at high speeds (14%) (*Viano and Ridella 1996*). Here, as in Treat, et al. (*1977*), nearly all of these crashes were related to curves.

More recently, Hendricks, et al. studied specific driver behaviors and unsafe driving acts (UDAs) that led to crashes (*Hendricks, et al. 2001*). Using the National Automotive Sampling System (NASS) protocol, a sample of 723 crashes involving 1,284 drivers was investigated from four different sites in a one-year period from 1996 to 1997. In-depth data were collected and evaluated on the following: condition of the vehicles, the crash scene, roadway conditions, driver behaviors and situational factors at the time of the crash. Trained investigators used a repeatable process to assign the primary crash causation factor and other contributing factors. In results similar to the Treat study, human error causes were attributed to 99% of crashes investigated. Of those human errors, driver inattention was the primary cause assigned (27%). Vehicle speed was the second largest contributing factor to crash causation (19%), followed by alcohol impairment (18%), and perceptual errors, e.g., looked, but didn't see (15%). Vehicle speed causes typically involved drivers exceeding the posted speed limit, but in a few cases the causal factor assigned was a driver traveling below the speed limit but too fast for conditions. Speed was the single causal factor in 7% of crashes. Like the other clinical studies, speed was related to single vehicle crashes in curved roadway sections.

There are few clinical studies of truck crashes. The Michigan State Police Fatal Accident Complaint Team (FACT) investigates fatal crashes involving trucks (using a clinical type approach). Analysis of their data by Blower and Campbell indicated that nearly one-third of trucks involved in fatal crashes would have been placed out of service due to an inspection failure if they had been inspected prior to the crash. In the FACT data, the crash cause "lost control due to speed" was listed for 2.4% of total fatal crashes (*Blower and Campbell 2002*). A comprehensive study of truck crashes funded by NHTSA is currently underway. Preliminary results of the Large Truck Crash Causation Study have recently been published by NHTSA (*Thiriez, et al. 2002*). Trained investigators analyzed truck collisions and gathered data about each crash, much like the studies described in Treat and Hendricks. The preliminary results reported the initial findings of 116 truck crash investigations, and found the critical event in 15 out of 116 crashes (13%) was too fast for conditions. Caution is urged when interpreting these preliminary results since the study is incomplete.

In summary, these clinical studies have investigated individual crashes in great detail. In these studies, trained crash investigators reviewed each crash, visited the scene, interviewed drivers, and made subjective judgments about the primary causal factors of crashes. Considering all crashes, these studies have found excessive speed to be an important causal factor in crashes. However, while important, speed was the primary causal factors in a relatively small (10-15%)

percentage of total crashes. In addition, a common crash type associated with high speed crashes was the single-vehicle type.

2.1.3 Crash severity

A clear relationship exists between vehicular speed and the severity of injury resulting from a crash. In a crash, the physics of motion explain a great deal about this relationship. A vehicle occupant continues in motion at pre-crash speed for a short time after impact, until collision with another surface within or outside the vehicle occurs and completely halts the motion of the person (*Evans 1991*). Seat belts, airbags and vehicle materials and structural design can moderate some of these impacts, but greater vehicular speed upon impact usually results in faster motion of an occupant into vehicle surroundings and a higher chance of serious injury or death.

Empirical evidence shows that the rapid decrease in velocity during a crash, known as Delta-V, correlates non-linearly with the severity of injury upon impact. Solomon found a clear relationship between speed and injury as shown in Figure 2.1. Research shows that an 18% increase in speed upon impact, from 55 mph to 65 mph, increases the energy which must be absorbed in a crash by approximately 40% (*Solomon 1964*). A study by O'Day and Flora shows that the likelihood of a fatality resulting from a crash increases exponentially with Delta-V; a fatality is twice as likely at 50 mph as at 40 mph (*O'Day and Flora 1982*). The increase of risk of fatality relating to speed at impact is sometimes called the fourth power rule.

Pedestrians are especially vulnerable in higher speed collisions. In the event of a crash with a pedestrian on an interstate, the results are especially severe. While only 5% of pedestrians are likely to be fatally injured as a result of a collision with a vehicle at 20 mph, at 45 mph, the pedestrian faces an 85% chance of death. In a collision with a vehicle traveling 50 mph, the survival rate is close to zero (*TRB 1998*).

Not surprisingly, the larger mass of trucks usually means that in car-truck collisions occupants of the passenger vehicle sustain more serious injuries than the occupants of large trucks. NHTSA reports that in 2002 a total of 8.1 % of vehicles involved in fatal crashes in Oregon were large trucks and a total of 77% of injuries and 79% of fatalities in collisions involving a truck and car are sustained by occupants of the passenger vehicle (*FARS 2004*).

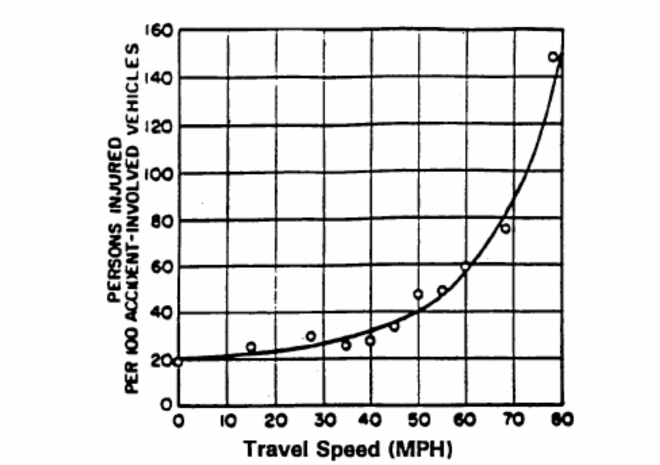


Figure 2.1: Persons injured per 100 involvements versus travel speed (daytime)[1]

2.2 SPEED REDUCTION TECHNIQUES

Numerous strategies, or countermeasures, are available to address excessive speed. This section provides a literature review of effective speed reduction countermeasures deployed on highways, and in some cases major arterials and rural collectors. Such conditions requiring speed reduction countermeasures include downhill grades, horizontal curves, adverse weather, and work zones.

While multiple speed countermeasures are typically used at the same time to control speed at identified risk locations, each countermeasure is described in this section as a separate entity. Furthermore, countermeasures that have been implemented and evaluated as effective strategies to reduce excessive speeding are addressed. Finally, all countermeasures are organized into four categories: geometric roadway modifications, pavement markings, signage, and operational/enforcement strategies.

2.2.1 Geometric roadway modifications

Geometric modifications are roadway improvements that can be used to reduce speeds by recommending and encouraging a speed based on the design and function of the roadway. Although costly to implement, geometric roadway modifications, such as traffic calming strategies are often considered because they do not require supplemental enforcement.

2.2.1.1 Pavement and lane widths

Modifying the geometry of pavement and lanes or narrowing their widths may be an effective way to reduce speeds. In a National Cooperative Highway Research Program (NCHRP) study in which a survey was completed by 45 directors or managers of state

[1] Source: From Solomon (*1964*) in Managing Speed – A Review of Current Practice for Setting and Enforcing Speed Limits (*TRB 1998*).

transportation agencies, speed data were collected in seven cities located in six states and included a variety of roadway types. The study concluded that overall, larger total pavement widths were associated with fewer lower speeds (*Torbic, et al. 2004*). With regard to lane widths, despite respondents' comments that narrow lane widths were effective in causing the motorist to drive slower on freeways, a field study conducted in the same study found no relationship between lane width and speed.

2.2.1.2 Chicanes/chokers

Chicanes and chokers are two similar types of traffic calming measures which typically involve roadway narrowing and curb extensions. Chokers are used to narrow the width of the roadway by widening sidewalks or medians. Chicanes are similar, but require obstacles to be placed at both sides of the road, thereby creating a curving S-shaped roadway to slow traffic. Chicanes have been known to be more effective than chokers in reducing speeds. However, little research has been conducted on the effectiveness of chicanes and chokers on major arterials in reducing speeds.

2.2.1.3 Traffic circles/roundabouts

Traffic circles or roundabouts are circles located in the middle of intersections used to reduce speed and crashes from left-turn maneuvers. Roundabouts are a modern form of traffic control for intersections which have some traffic calming effects by decreasing the speed at which motorists must safely navigate the roundabout. In a study conducted of the Route 67 corridor in Saratoga, NY, simulations of roundabout alternatives were explored for their effects on keeping the corridor in use, but at reduced speeds. The study concluded that roundabouts were effective not only in reducing speeds from 40–45 mph to 30 mph, but also to accommodate the 2024 forecasted traffic volumes (*Turner 2003*). In another study by Persaud, et al. found that, of all modern roundabout installations, crashes were reduced by 40%, with speed as the most likely explanation of the reduction (*Persaud, et al. 2001*).

2.2.1.4 Speed humps

Speed humps are short sections of raised roadway surface, typically 3 to 4 inches high, that are meant to calm traffic, or reduce both the speed and volume of traffic. Speed humps are often used to calm traffic because they can be installed and maintained at low cost. In the United States, speed humps are often installed on low-volume residential streets. Little is known about the effectiveness of speed humps on roadways with higher volumes and speeds. However, for low-volume streets, in a study conducted by Ewing for the Institute of Transportation Engineers and the Federal Highway Administration, speed humps were found to be the most effective traffic calming measure for reducing speeds. The study evaluated hundreds of before/after traffic calming studies. Speeds were reduced an average of 7 mph to 20 mph. In another study in Portland, Oregon, the installation of a 14 foot-wide speed hump resulted in a reduction in the 85th percentile speed from 32 mph to 21 mph (*Ewing 1999*).

2.2.1.5 Raised pavement markings/rumble strips

In general and as a long term solution, rumble strips or raised pavement markers in the travel lane are not effective devices for lowering vehicle travel speeds. Raised pavement markings include raised sections of rough or dot covered markings on the roadway. Rumble strips can be raised sections of bands placed on the roadway and perpendicular to the direction of traffic, or bands of undulations or indentations formed or grooved in the pavement and typically placed at the shoulder or center of the roadway in the same direction of traffic. The function of raised pavement markings and rumble strips are to produce an audible and vibratory warning to inattentive motorists.

Rumble strips have been successfully applied in work zones. The effectiveness of rumble strips in reducing speeds was demonstrated by Meyer in New York. Six wide, bright orange rumble strips were applied 12 inches apart and perpendicular to the direction of traffic on a rural two-way highway. Average speeds were decreased by 1 to 2.3 mph (*Meyer 2000*). Similar results were documented in a study conducted by Fontaine and Carlson, with speed reductions for trucks of 3 to 4 mph and for passenger cars of less than 2 mph (*Fontaine and Carlson 2001*). However, in a study conducted by Zech, et al., where two different types of rumble strips applied on different interstates were evaluated, only one of the two strips was found to be effective in reducing speeds by about 2.7 mph. The other strip had no significant reduction of vehicle speeds (*Zech, et al. 2005*). Zaidel, et al. also conducted a rumble strip test in a low volume rural intersection, where the distance between strips decreased as the intersection was approached, and found a reduction of 2 mph in average speed (*Zaidel, et al. 1984*). Furthermore, more vehicles stopped at the intersection than before the rumble strips were implemented. Overall, rumble strips are effective in slightly reducing speeds by 1 - 3 mph.

2.2.2 Traffic control devices

A second type of treatment that can be aimed at influencing drivers to reduce speed is the use of traffic control devices. National and state standards are developed and maintained by the traffic engineering profession that govern the design and use of traffic control devices, in order to maintain consistency from state to state (and among various jurisdictions) and to provide drivers with confidence that they can expect similar types of control devices as they travel around the transportation network. Research focusing on several types of traffic control devices has revealed impacts on speed reduction.

2.2.2.1 Static warning signs

Static warning signs are commonly used to notify motorists of changes in roadway conditions, traffic conditions, upcoming work zones, and weather conditions so they may be able to reduce speeds accordingly. Signs come in a variety of shapes and sizes, and use a variety of different notifying features, such as flashing beacons. The intended effects of these signs include an increased awareness and behavioral change.

Vehicles entering a curved roadway section typically do so at the speed driven in the preceding section, which can result in excessive speed in the curved roadway section. To reduce excessive speed in horizontal curves, roadway signs, such as a winding road sign, often with a recommended speed, can be placed ahead of the curve. No research has suggested one particular sign being more effective than another, nor have sign treatments at curves been consistently shown to be effective countermeasures. One research study found that pre-curve signs increased speeds (*Torbic, et al. 2004*), while another concluded that the signs decreased speed (*Fitzpatrick 2003*).

2.2.2.2 Pavement markings

Pavement markings consist of lines, words, arrows and other markings painted on the roadway. A major benefit of pavement markings is that they keep the driver focused on the roadway, where the problem area is located, compared to signs that are located above and off the roadway. Pavement markings are usually placed before the roadway hazard in order to provide motorists sufficient reaction time. The Manual on Uniform Traffic Control Devices (MUTCD) explains that the two most common types of pavement markings are longitudinal and transverse markings. The longitudinal category typically consists of center and edge line markings and lane lines. The transverse category typically includes crosswalk lines, intersection stop lines and similar markings.

Longitudinal pavement markings have been found to have statistically significant speed reductions by Cottrell, who evaluated the lateral placement of 8 inch edge lines compared to 4 inch edge lines at 12 different locations on a 55.2 mile two-lane rural highway segment (*Cottrell 1985*). Fitzpatrick, et al. concluded in a study analyzing free flow speed data at 79 sites in seven cities and six states that the absence of centerline or edge line markings was associated with lower speeds (*Fitzpatrick, et al. 2005*). Other studies have found little or no effect of longitudinal lane markings.

Transverse markings, or optical speed bars, are stripes or chevrons oriented perpendicular to the direction of travel and typically located at horizontal curve tangents, roundabout approaches, intersection approaches, construction areas, and freeway off ramps. Transverse markings have been used in numerous applications aimed at reducing vehicle speed. There are two main types: lane width reductions and optical speed bars.

2.2.2.2.1 Optical speed bars

Optical speed bars are typically transverse markings on the pavement used to slow vehicles down. They are typically located at a freeway exit ramp, stop sign or traffic signal. The theory is that by gradually decreasing the distance between markings, motorists will be induced to slow down because of a perceived speed increase.

Liebel and Bowron evaluated the effectiveness of optical speed bars applied to a major freeway exit ramp. In their before/after implementation study, average speeds decreased from 39.5 mph to 38.1 mph. Furthermore, the percentage of vehicles exceeding 50 mph decreased from 5.45% to 4.05% (*Liebel and Bowron 1984*). In another study by Jarvis, it was concluded that optical bars placed farther from the intersection reduce speeds more than bars placed closer to the intersection. Conclusions on crash reduction were not available (*Jarvis 1989*). Finally, Zaidel, et al. tested the use of optical speeds bars at a rural intersection, compared to rumble strips of a similar pattern. The optical speeds bars resulted in a 2 mph reduction in average speed over the rumble strips (*Zaidel, et al. 1986*).

Backus evaluated the implementation of transverse pavement markings across two lanes of traffic on a four-lane highway. The highway approached a horizontal curve, and the speed was measured 100 feet from the point of curvature. Before the pavement markings were implemented, the 35 mph speed limit was exceeded 60 percent of the time, and 18 percent of the traffic exceeded 40 mph. After the installation of the markings, the percentage of traffic exceeding 35 mph decreased by 35 percent, and the percentage of traffic exceeding 40 mph decreased by 10 percent. The experiments also yielded a decrease in average mean speed of 2.5 mph. Backus concluded that the decreases were statistically significant (*Backus 1976*).

Vest and Stamatiadis evaluated several speed reduction techniques, including pavement markings, at problematic rural horizontal curves. Three curves were studied and speed data were collected over two-day periods at three locations approaching the curve over approximately 350 meters. The results indicated that the most effective techniques for reducing speeds are flashing lights and transverse lines, with 3.4 percent and 2.9 percent speed reductions, respectively. Significant reductions occurred with higher operating speeds (*Vest and Stamatiadis 2005*).

In Wisconsin, the effectiveness of chevrons stenciled on the roadway was studied on a highway off-ramp on I-94 (*Drakopoulos and Vergou 2003*). The intention of the chevrons, as shown in Figure 2.2, which were placed closer together on the ramp the farther a vehicle was from the ramp entrance, was to give the perception that the speed at which the vehicle was traveling was faster than the actual speed. With an entering speed of 65 mph and a desired speed of 50 mph exiting the 610 foot long ramp, loop detectors at four different points recorded a decrease in vehicle speeds of up to 15 mph, with the exception of the last point showing an increase in speeds of 2 mph. Although speeds were reduced, due to limitations in the methodology, the study concluded that more research was necessary.

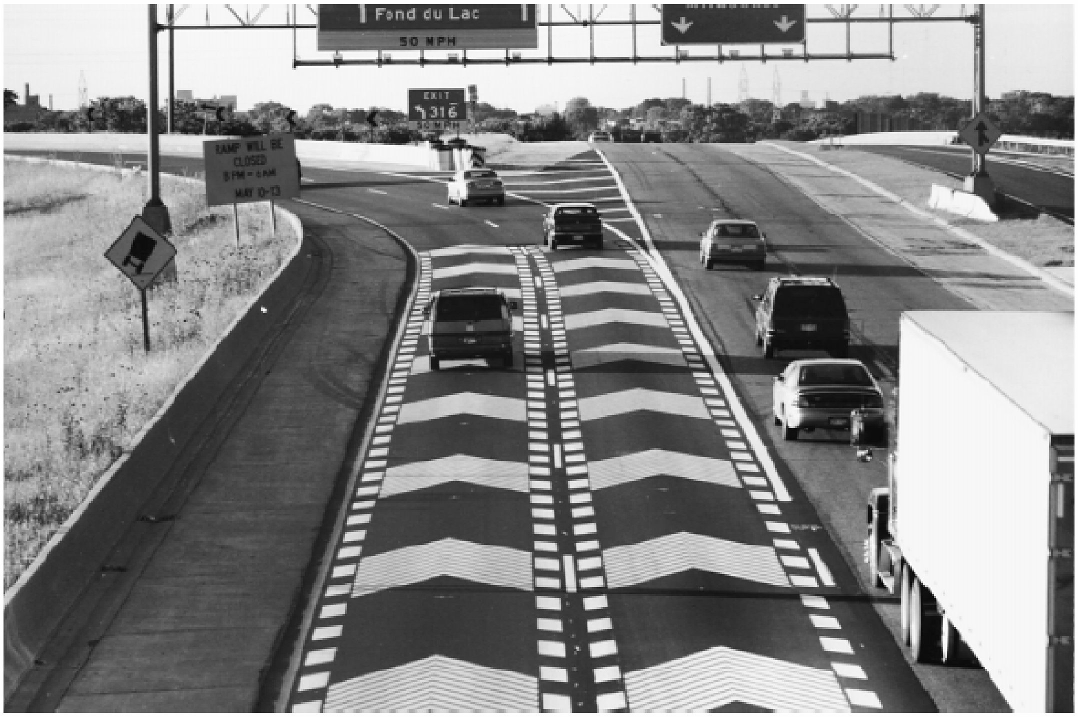


Figure 2.2: Chevron pavement markings from northbound I-94 to westbound I-894 in Milwaukee[2]

2.2.2.2.2 Effective lane width reduction

Effective lane width reduction with pavement markings attempts to influence perceived speed by narrowing the travel lane, causing an increase in driver attentiveness. Most studies claim that lane width reduction is effective by using obstacles such as pylons, but not effective by using just pavement markings. Effective lane width reduction was examined by Richards and Dudek. They concluded that moderate speed reductions are possible with lane width reductions. Moreover, effects tend to last over the long term. Certain problems are inherent with lane reductions however, including disruption of traffic flow, difficulty of implementation and removal, and the possibility to increase certain types of crashes. They found the average reduction in speed from lane width reductions to be 7% (*Richards and Dudek 1986*).

2.2.3 Operations and ITS

Intelligent Transportation Systems (ITS) apply well-established technologies of communications, control, electronics and computer hardware and software, along with improved management activities, to improve the surface transportation system. In recent years, advancements in sensors, communications, computing and management systems have resulted in improved

[2] Source: Wisconsin Traffic Safety Reporter, January/February 2000, Bureau of Transportation Safety, Wisconsin Department of Transportation

techniques for measuring vehicle speeds at points and over roadway segments, and on communicating information about roadway and traffic conditions to travelers. This new focus has led to an increasing emphasis on "operations" as a key strategy to manage transportation systems in addition to the more traditional construction and maintenance activities.

One of the technologies that prompted this study was the design and implementation of a dynamic message sign coupled with a speed measurement system in advance of a tight horizontal curve. Speed sensors coupled with a systems to communicate with drivers plus a management plan is a great example of an ITS application of promise. Several speed reduction systems will now be discussed.

2.2.3.1 Variable speed limit systems

Variable speed limit (VSL) systems display appropriate real-time advisory or enforceable speed limits based on the geometry of the road and the surrounding conditions which necessitate reduced speeds. Such conditions may include work zones and hazardous environmental or weather conditions. The purpose of these signs, displayed on a speed trailer or on fixed signs, is to inform motorists of the conditions that lie ahead of them.

The displayed speed limit values are maintained from a central control location using an appropriate remote communications or local control system. Although the speed values may be preset for a given hazardous condition, VSL signs may be equipped or coupled with fiber-optic, LED, or electromagnetic based sensors which monitor working conditions, traffic, roadway, and/or weather conditions to identify changes in the monitored condition. The sensors can quickly send the information to the central control location where it is processed. A new speed limit value can be determined and communicated back, to be displayed on the VSL sign.

Variable speed limit technology can be used to advise motorists of adverse weather or environmental conditions, such as wet or icy pavements, landslides, fog, floods, hurricanes, or fire hazards. Speed limit values are determined based on road geometry, surrounding terrain and/or weather condition. VSL signs have been used in Germany and Sweden to advise motorists of weather conditions, particularly in areas where ice is present. Using a variety of weather sensors for rain, condensation, wind, temperature, or light and video sensors or radar detectors for fallen rocks or smoke, their efforts have resulted in a decrease in average speed by 10% and anticipated reduction of crashes by 25–50% (*Panter 2002*).

The Florida Department of Transportation implemented a warning system using VSL signs and flashing beacons at an exit ramp on Interstate 595 known to have a high incidence of crashes during times of rain. Sensors were installed to measure wet conditions. Flashing beacons were installed on top of the speed limit sign and set to activate as pavement moisture was detected, to signal motorists to slow down. In light rain, the 85th percentile speed decreased by 8% from 49 mph to 45 mph. In heavy rain, the 85th percentile speed decreased 20% from 49 mph to 39 mph. Speed variance decreased by 8% to 15%, thereby reducing the risk for crashes. Although four crashes occurred during the week after installation and testing, no crashes occurred in the following 9 weeks (*Janson 1999*).

2.2.3.2 Dynamic message signs

Both variable speed limit signs and variable message signs (VMS) can be coupled with radar devices in a Dynamic Message System (DMS). Dynamic Message Systems are typically used in high hazard conditions such as in down grades and dangerous curves, but they can also be used in work zones.

There are many examples of using dynamic message signs to reduce vehicle speeds on steep inclines. The state of Oregon is using a dynamic downhill warning system on I-84 in the northeast corner of the state. The I-84 system uses a DMS to display advised speeds to trucks based on their weight, which is obtained by a weigh-in-motion detector. If vehicle weight cannot be determined, a default "Steep Downgrade" message appears. The system has more advanced capabilities as well. Trucking companies can subscribe to a service which uses the DMS to relay personal messages to trucks. Although data analysis results are not available at this time, the system is expected to reduce speed-related crashes on the downgrade (*Bertini, et al. 2006*).

In Colorado, a DMS is used for a downhill section following the Eisenhower Tunnel on I-70. The area was historically known for 125 truck-related crashes along the 10 mile downgrade between 1980 and 1998. Comparing two days where a DMS was in use to two days when they were not in use, speeds for trucks above 40,000 lbs. were significantly reduced. However, speeds on all days were above the advised speed limit (*Bertini, et al. 2006*).

Numerous studies show support for the ability of a DMS to enhance the safety of dangerous curves. Dynamic Message Systems are used on curves, such as dangerous exit ramps or sharp turns, to prevent truck rollover or other vehicles from running off the road. For truck rollovers on ramps, an in-road detection warning system using a DMS is used to automatically warn truck drivers turning a curve at excessive speeds. In this application they are also known as Dynamic Curve Warning Systems or Advanced Curve Warning Systems.

Such a system is in use on a tight horizontal curve on Interstate 5 in southeast Oregon near Myrtle Creek (Figure 2.3). The Myrtle Creek system uses radar to detect the speed of the largest approaching vehicle and provides a custom warning to drivers with the measured speed. The variable message signs provide individualized postings, such as "YOU ARE SPEEDING, SLOW DOWN" or "EXCESSIVE SPEED, SLOW DOWN."

In Colorado, a radar speed detection system and DMS is being used to warn motorists, particularly truck drivers, of a dangerous curve on I-70. A radar detection system was installed to detect truck speeds. If a speeding truck is detected, a DMS warns the driver of the dangerous curve. Prior to installation, the 85th percentile of truck speed was 66 mph. After installation this reduced to 48 mph, greatly improving the overall safety of the curve (*Inform 2004*).

Figure 2.3: Example of a dynamic message sign for speed reduction, northbound, I-5, MP 108, Oregon

In California, Dynamic Message Signs are used on Interstate 5 in the Sacramento River Canyon to reduce speeds in an area known for high traffic volumes and mountainous terrain where there have been a high number of crashes specifically related to heavy trucks. Five static or variable message signs and a radar detection system were installed. Researchers at the Western Transportation Institute collected and analyzed before and after data at each site. Results of the study show reductions in both vehicle speed and crash frequency at about half of the test locations. In other locations, speeds did not change. Although speeds were reduced, it was unclear whether the speed decreases were a result of the static or dynamic message signs (*Mounce, et al. 2000*).

The Minnesota DOT used a radar detection system in conjunction with a DMS to study the difference between static and dynamic signs in their ability to reduce the speed of high-speed vehicles. Researchers found the overall effect of a dynamic curve warning sign on vehicle speed to be somewhat small. However, the dynamic sign did have a strong effect on high speed vehicles and improved their ability to navigate through a curve (*Preston and Schoenecker 1999*).

Researchers at the Texas Transportation Institute analyzed a series of Dynamic Speed Display Signs (DSDS) at various locations, including school zones, signalized intersections, and sharp horizontal curves (*Ullman and Rose 2005*). Data were collected before the signs were installed, one week after installation, and again after four months. Researchers used a data collection method that allowed for tracking of vehicles at two specified locations in the study site. This allowed researchers to correlate initial approach speeds to speeds at the DSDS and thus assess how the sign impacted motorists' speed-changing behavior. Furthermore, researchers analyzed the influence of the DSDS upon passenger vehicles and large trucks separately at the horizontal curve location, just as was done in the Myrtle Creek study. The signs were most effective in school speed zones, where speeds were reduced by 9 mph. At the two horizontal curve sites, small decreases in speeds were evident in passenger vehicles approaching those curves. In general, motorists traveling faster than the posted speed reduced their speed more significantly than other motorists.

It has been well established by research that motorists respond well to work zone speed limits under identified circumstances. In Nebraska, researchers evaluated the Work Zone Speed Advisory System (WZSAS), an en route traveler information system displaying real-time speed advisory information by means of portable VMS strategically located in advance of diversion points upstream of a work zone. The objective of the WZSAS is to advise drivers of the speed of traffic in advance of a work zone and thereby encourage them to divert to an alternate route with less congestion. The WZSAS is comprised of a video detection system, two portable VMS, and a control system (*Pesti, et al. 2002*).

The video detection system was used to measure the speeds of traffic at two selected points in advance of the work zone. Average speeds measured at the two points were displayed on the two portable VMS which were placed upstream of diversion points in advance of the work zone. The control system coordinated communications between the video detection system and the portable VMS in order to display the appropriate speed messages. Nebraska Department of Roads (NDOR) personnel were alerted when speeds dropped below the selected threshold of 15 mph, which enabled them to display incident-related messages when necessary. In a four week before/after study of implementation the WZSAS, traffic speed and volume data were measured via video detection at two locations where the WZSAS was installed. It was found that the total peak-period demand did not change significantly in response to the speed messages. NDOR did note that the system might be more effective under heavier traffic demands and more severe congestion (*Pesti, et al. 2002*).

2.2.3.3 Automated enforcement

One of the most important tools available to reduce speeding is the use of automated enforcement of speed by mobile photo radar. The photo radar equipment includes a radar device to measure vehicle speed and photo device to capture the driver's image and license plate. The equipment is installed in standard vans and is operated on the same side of the street as traffic. A speed reader board is placed in the back window to inform the driver of his or her vehicle's measured speed. While a police officer is present in the van to operate the equipment, the citations are issued automatically to every vehicle that passes the van above a certain threshold speed, which depends on the jurisdiction's enforcement and judicial environment. In Oregon, the citation is issued to the registered owner of the vehicle. The photo radar program in Portland, Oregon has been administered by a private vendor (ACS) since 1996, who processes the citations by matching the license plate images to motor vehicle records. If the owner was not operating the vehicle at the time of the citation, he or she can return the citation with a copy of his/her driver's license and a certificate of innocence.

Although a formal evaluation of the photo radar program in Portland has not yet been completed, the majority of the literature supports the claim that automated enforcement practices have positive influences on safety. A thorough study in British Columbia evaluated the effect of the photo radar program on traffic speed and collisions at photo radar locations and found both speed and crash reductions (*Chen, et al. 2002*). Other studies summarized in a meta-analysis have found reductions in crashes from photo radar programs (*Zaidel 2002*).

2.2.4 Enforcement

The influence of enforcement on driver speed choices works mainly through the principle of deterrence. Deterrence affects human behavior by making the likelihood of penalties for certain actions (i.e., exceeding the speed limit) credible. When the general perception is that punishment is likely, some drivers will modify their behavior and comply with the posted speed limit. Posted speed limits are only one input drivers use to select a reasonable speed. Weather, lighting, traffic, road geometry, and enforcement activities also play an important role. Regardless, the majority of drivers select a speed they find reasonable for the existing roadway conditions. How much enforcement activities influence an individual driver's speed choice depends on his or her perception of the likelihood of being subject to enforcement and the swiftness and severity of penalties.

In speed enforcement, law enforcement officers can use tools such as general deterrence, whereby a trooper attempts to impact the driving speeds of the general public by apprehending individual drivers, or by specific deterrence, in which troopers target an individual in the hopes that he or she will not violate the speed law in the future. In either case, the key to successful speed enforcement is adequate, visible police presence.

Because enforcement resources are limited, it is usually advantageous to set speed limits that are considered reasonable by a majority of the public. Research has shown that compliance is generally poor with speed limits that are not considered reasonable (*TRB 1998*). When this is true, a large proportion of the traveling public will violate the speed limit. Enforcement officers are generally reluctant to enforce limits that the majority of drivers consider unreasonable and that they know will not be upheld by judges. In response, they typically develop thresholds above the posted speed at which they will begin writing citations. This practice, although necessary when faced with large numbers of drivers exceeding posted speed limits, undermines the effectiveness of the deterrence theory because it conditions the public to not expect enforcement until they exceed posted speeds by some threshold.

The effectiveness of police presence as a deterrent to speeding can be difficult to determine. The research indicates that the effect of enforcement on speeds has a spatial and temporal component. Police enforcement presence in the targeted area or section affects speeds for a short distance around the officer and the effect decreases as motorists leave the target area. This is sometimes termed the "halo" effect. One study evaluated the "halo" effect of the presence of enforcement officers on a rural interstate (I-96 in Michigan) (*Sisiopiku and Patel 1999*). In this study, the speed limit on I-96 had recently been raised from 65 mph to 70 mph. The authors concluded that speeds decreased by about 5 mph to the posted speed limit immediately upstream from a visible enforcement officer, but speeds increased by about 2.7 mph shortly after passing the patrol vehicle. Other research confirms these results (*Shinar and Stiebel 1986*). That research demonstrated the effect of distance from a trooper vehicle on vehicular speed. Compliance with the posted speed limit was greatest near the patrol vehicle, and decreased as distance from the enforcement officer increased.

While the behavior of the majority of drivers may be affected by the presence of enforcement officers, the effect of enforcement on those drivers who greatly exceed the posted speed limit seems to be negligible. Even with the presence of patrol vehicles, another study found speeds returned to pre-enforcement levels within 3 days after the first exposure (*TRB 1998*). Some research finds that deterrence reduces overall speeds by small amounts, but that drivers who consistently operate vehicles at relatively great speeds, such as 20 mph in excess of the limit or more, will continue to violate the law (*ODOT 2002*). Because speeds far in excess of the average vehicle speed cause a safety concern, this situation may only be remedied by the availability of an extremely robust enforcement team.

The frequency of enforcement is effective in further reducing the speed at which motorists drive. A 2003 Oregon Department of Transportation (ODOT) Research Unit study quantified the effect of enhanced enforcement on speeds at six locations on non-interstate highways (*Haas, et al. 2003*). For the study, additional speed enforcement labor was deployed over a period of 18 months at 6 study sites. Enforcement presence was categorized as light (10 additional hours per week), medium (15 additional hours per week) and heavy (25 additional hours per week). Three sites (one each of the light, medium, and heavy enforcement) were patrolled with a random schedule, and three other sites used a fixed schedule. The study concluded that there was a decrease of median and 85th percentile speeds in five of the six locations with any degree of additional enforcement. The greatest reduction in speed occurred at locations with heavy enforcement.

When the deployment of law enforcement personnel is not feasible, radar drones may be a possible enforcement strategy. Radar drones, a device that can be installed on the trailers of variable speed limit signs can simulate law enforcement personnel by continuously emitting radar signals. Vehicles with radar detectors thus detect the signals and may slow down. Studies conducted on radar drones pertain particularly to its effectiveness in work zones. A study on radar drones was conducted by Freedman, et al. at 12 different work zone sites with over 20,000 vehicles (*Freedman, et al. 1994*). Speeds were reduced on average of 3.6 mph near the drone and continued for 0.2 to 0.8 miles downstream of the drone location for long term work zones and 0.2 to 0.5 miles downstream for short term work zones (*Freedman et al. 1994*). Turochy and Sivanandan found similar results. Their study found average speed reductions of 0.8 to 2.3 mph and reductions in speed variance (measured by the standard deviation) of 0.1 to 3.9 mph (*Turochy and Sivanandan 1997*).

2.3 NETWORK SCREENING TECHNIQUES

In recent years, the techniques for screening transportation networks to identify high crash locations have become more sophisticated. However, many transportation agencies lack sufficient data, either in timeliness, completeness or accuracy to implement many of the more recent advances. In general, networks can be screened and locations ranked based on frequency, severity value, crash rate, some combination weighting, by potential for improvement, or trend or pattern analysis. The more sophisticated methods are typically included in the potential for improvement, or trend or pattern analysis.

Many agencies still routinely rely on simpler methods to identify candidate locations for safety improvement. For example, Hallmark, et al. recently completed an evaluation of the Iowa Department of Transportation (Iowa DOT) method in its safety improvement candidate list (SICL) process (*Hallmark, et al. 2002*). A survey of 17 other state departments of transportation was conducted to determine the state of the practice in other areas and found they all used frequency, rate, severity or a combination of methods. A common concern for rankings that include severity scores is that this ranking is often skewed by the presence of fatal crashes, given the relatively high value normally assigned to those crashes. In Hallmark's evaluation, she found that fatalities did overwhelm the current Iowa DOT high crash location process.

Agent, et al. conducted a similar study for Kentucky to evaluate the current procedures for identifying high-crash locations and evaluating and prioritizing roadway safety improvements at high-crash locations, and to recommend improved methods (*Agent, et al.2003*). Kentucky currently identifies locations using the critical rate method. Sinha, et al. also demonstrated the use of the critical rate methodology for using a criterion including both above-norm number of crashes and confidence level (*Sinha, et al. 1998*). The method was illustrated using the county level data in the state of Indiana.

Hauer argues that the primary purpose of network screening should be to produce a list of candidate locations, that when subjected to a detailed engineering study, are considered cost-effective and produce the most return (*Hauer 1996*). If a given location can be expected to have a high number of crashes, either because of crash volume or other variables, it does not necessarily need to be ranked as hazardous. Further, if the network screening tool can estimate the likely types of fixes and costs, an improved list can be generated. Given the considerable expense and staff time involved in conducting these studies, the criteria for evaluating ranking methods are merited.

One ranking method that builds on this idea is the potential for improvement ranking methodology. Here, sites that are significantly above what is considered average or expected are ranked higher, since one might expect that improvements would bring the locations closer to average. A number of researchers including Sinha, et al. have demonstrated the potential crash reduction method, which attempts to directly meet the objectives of the identification stage using examples from the method for the rural intersections administered by the Indiana Department of Transportation (INDOT) (*Sinha, et al. 1998*).

Finally, Souleyrette, et al. reported on the integration of crash and roadway data to improve the methods for which high crash location segments are identified (*Souleyrette, et al. 2001*). Using GIS, roadway and crash databases were integrated to populate records with roadway characteristics, such as lane width, surface and shoulder type, and traffic volume, for all public roads. GIS-ALAS records contained data for crashes occurring on public roads during the past 10 years. These data included vehicles, road conditions, drivers, and crash severity. Using these data, high crash locations and the relationships between crash rates and selected roadway design characteristics were identified. As expected, a number of roadway variables were correlated with high crash locations. Of interest to this research (in later sections), analysis of curve-related crash data indicated that the degree of curvature had a direct impact on crash rates on horizontal curves.

2.4 SUMMARY

This section began with a summary of the current research on the relationship between speed and crash occurrence. It then reviewed a number of techniques that can be used to reduce speed. These include geometrical, operational, and enforcement techniques for reducing speed. The section concluded with a brief review of network screening techniques. The following chapter studies the Oregon crash data for speed-related trends.

3.0 ANALYSIS OF CRASH DATA

This chapter contains an analysis of Oregon reported crash data for the three years 2000–2002. This analysis of more than 60,000 crashes is somewhat limited by the fact that not all crashes are reported, especially property damage only crashes; some estimates are that approximately 50% of these crashes are not reported (*Malik, et. al 2003*). In addition, it is worth noting that this analysis relies on crash reports, which are subject to the interpretations of a variety of individuals completing the crash report form. Specifically, the fact that a crash has been identified as speed-related is not based on a scientific analysis, and may be the result of opinion or best judgment.

For example, within the crash database, two different variables can be interpreted as meaning that ‘speed was involved’ in a crash. One variable identifies ‘driving too fast for conditions’ as a contributing factor – a rather subjective notation. The reporting officer makes a determination as to whether a vehicle involved in the crash was ‘speeding’ relative to some ‘reasonable’ speed limit as determined by environmental factors. The other variable indicates that at least one vehicle was driving faster than the posted speed limit. Though this variable has clearly defined bounds (yes/no), it fails to acknowledge that the posted speed limit is not always the most reasonable speed at which one should drive. Further discussion of these variables can be found in the following sections. This chapter presents an important analysis of crash history that drives subsequent analytical steps.

3.1 BASIC ANALYSIS

ODOT has summarized motor vehicle crash records since 1941 and began publishing crash data in 1948. The ODOT Crash Analysis and Reporting (CAR) Unit compiles crash data from individual driver and police crash reports submitted to the Driver and Motor Vehicles (DMV) Services Division, as required by Oregon state law. These data are stored in a database referred to as the ODOT Statewide Crash Data System (CDS). This first step in analyzing the crash data was to perform a basic analysis on this database. The following sections describe this process. Included are a description of the ODOT Statewide Crash Data System, an explanation of the variables examined, the methodology used to identify speed-related crashes, and an analysis of variables deemed to be ‘overrepresented’ in speed-related crashes.

3.1.1 State crash data system

Two units in ODOT have responsibility and oversight for crash reporting, the Driver and Motor Vehicles (DMV) Services Division and the Crash Analysis and Reporting (CAR) Unit. In Oregon, private citizens are require to file an Oregon Traffic Accident and Insurance Report within 72 hours if they are involved in a crash that results in injury, death, more than $1500 damage to their vehicle, or more than $1,500 damage and towing of another vehicle. These reporting thresholds have changed over time as the value of motor vehicles and reporting practices have changed. If a police officer responds to the scene, he or she completes the Oregon

Police Traffic Crash Report which is more detailed than the citizen report. A citizen must file a report even if a police officer is present and completes a form. In general, however, nearly 70% of the crash data that is entered in the statewide crash file for crash records comes from citizen reports.

The state Crash Data System (CDS) is a relational database that contains three primary tables to describe a crash. There are approximately 50,000 motor vehicle crashes reported in the state of Oregon each year.

- The crash table contains summary information about the crash including road condition, location, time of day, day of week, and other variables. There is one record in the crash table for each crash event.

- The vehicle table contains data about each vehicle in the crash including information about movements of vehicles, possible vehicle-related errors (mechanical failures), actions of the vehicle during the crash and any objects hit by the vehicle causing injury or property damage. If more than one vehicle is involved there is one record for each vehicle.

- The participant table includes data about each participant that was present at the crash (unless data are not presented or recorded about them on the report). The participant table includes the sex of driver, residence status, driver's license status, injury level, data about the use of safety equipment, and other participant-related data.

All tables are related by a unique number assigned to each crash. In this research, the analysis was focused on crashes that occurred on state highways. The crash table was primarily used for the analysis and these data fields are shown in Table 3.1. Data fields that were evaluated in this research are highlighted in bold. A complete description of the codes can be found in ODOT's Statewide Crash Data System Motor Vehicle Traffic Crash Analysis and Code Manual (*ODOT 2004)*.

Table 3.1: Crash-level data fields in the crash data system

Data Field	Definition	Data Field	Definition
AGY_ST_NO	Code for street by agency	MEDN_TYP_CD	One digit code for type of median
ALCHL_INVLV_FLG	System generated code for indicating if an active participant in crash had been using alcohol	MLGE_TYP_CD	Code for mileage portion of highway where crash occurred (Regular, Temp., Spur, Overlapping)
CITY_SECT_ID	Two digit code for city	**MP_NO**	Milepost of crash
CITY_SECT_NM	Name of city where crash occurred	NHS_FLG	Code for crashes that occur on national highway systems
CMPSS_DIR_CD	Direction of travel	OFF_RDWY_FLG	Yes or no field for whether the crash occurred outside travel portion of roadway
CNTY_ID	Two digit code for county	POP_RNG_CD	One digit code for population number of an area
CNTY_NM	Name of county where crash occurred	POST_SPEED_LMT_VAL	Posted speed on roadway were crash occurred
COLLIS_TYP_CD	Type of collision	RD_CHAR_CD	One digit code for profile of crash road (straight, curved, grade, level)
CRASH_CAUSE_1_CD	Two digit code representing circumstance most responsible for cause of crash	RD_CNTL_CD	One digit code for categorizing roadway by jurisdiction and location
CRASH_CAUSE_2_CD	Two digit code representing circumstance most responsible for cause of crash	RD_CON_NO	Connection number (if crash occurred on connection(
CRASH_CAUSE_3_CD	Two digit code representing circumstance most responsible for cause of crash	**RD_SURF_COND_CD**	Condition of road at time of crash
CRASH_DAY_NO	Day of the week crash	RDWY_NO	One digit code for Milepost type (Add, Non-add, Alignment, Couplet and Split)
CRASH_DT	Date of crash	RNDABT_FLG	Flag if crash involved a roundabout
CRASH_EVNT_1_CD	Three digit code representing event or object that caused injury or damage	RTE_ID	3 digit for route
CRASH_EVNT_2_CD	Three digit code representing event or object that caused injury or damage	RTE_NM	Route name
CRASH_EVNT_3_CD	Three digit code representing event or object that caused injury or damage	RTE_TYP_CD	Code for route
CRASH_HIT_RUN_FLG	Flag when responsible participant fled the scene	SCHL_ZONE_IND	One digit code for crashes occurring in school zones
CRASH_HR_NO	Hour in which crash occurred	SER_NO	Unique identifier assigned by DMV
CRASH_ID	Unique identifier for each crash	SPECL_JRSDCT_ID	Code used when crash occurs on road under agency jurisdiction other than city, county or state highway
CRASH_LAST_UD_DT	Date crash information was last update	ST_FULL_NM	Code for street or road where crash occurred
CRASH_MO_NO	Month in which crash occurred	**TOT_FATAL_CNT**	Total number of persons fatally injured in crash
CRASH_SPEED_INVLV_FLG	Flag when a driver was exceeding posted speed	**TOT_INJ_CNT**	Total number of persons injured in crash
CRASH_SVRTY_CD	One digit code for severest injury in crash	**TOT_INJ_LVL_A_CNT**	Total number of persons severely injured in crash
CRASH_TYP_CD	One character code recording first harmful event	**TOT_INJ_LVL_B_CNT**	Total number of persons moderately injured in crash
CRASH_WK_DAY_CD	2 digit code for day of the week in which crash occurred	**TOT_INJ_LVL_C_CNT**	Total number of persons with minor injuries in crash
CRASH_YR_NO	Year in which crash occurred	TOT_OCCUP_CNT	Total number of occupants in crash

Table 3.1 (continued): Crash-level data fields in the crash data system

DRUG_INVLV_FLG	Flag if active participant in crash was reported to have used drugs	TOT_PED_CNT	Total number of pedestrians involved in crash.
DRVWY_REL_FLG	Flag if crash involved a driveway or alley access	TOT_PED_FATAL_CNT	Total number of pedestrians fatally injured in crash
FC_CD	Two digit code for functional class of roadway	TOT_PED_INJ_CNT	Total number of pedestrians injured in crash
FROM_ISECT_DSTNC_QTY	Four digit code representing distance from an intersecting roadway	TOT_PEDCYCL_CNT	Total number of pedestrians involved in crash.
HWY_COMPNT_CD	One digit code characterizing the highway structure where crash occurred	TOT_PEDCYCL_FATAL_CNT	Total number of pedestrians fatally injured in crash
HWY_MED_NM	One character alphanumeric code indicating the category of mileage	TOT_PEDCYCL_INJ_CNT	Total number of pedestrians injured in crash
HWY_NO	Three digit code representing state highway index number	TOT_PER_INVLV_CNT	Total number of persons involved in crash
HWY_SFX_NO		TOT_SFTY_EQUIP_UNUSED_QTY	Total number of persons not using safety equipment in crash
IMPCT_LOC_CD	Two digit code describing where first impact occurred	TOT_SFTY_EQUIP_USE_UNKNOWN_QTY	Total number of persons using safety equipment in crash
INVSTG_AGY_CD	One digit code for law enforcement presence	TOT_SFTY_EQUIP_USED_QTY	Total number of persons using safety equipment in crash
ISECT_REL_FLG	Flag if crash is related to intersection	TOT_UNINJD_AGE00_04_CNT	Total number of persons less than age 4 with no injuries
ISECT_TYP_CD	1 digit code for type of intersection	TOT_UNINJD_PER_CNT	Total number of persons not injured injuries
ISECTG_AGY_ST_NO	5 to 15 digit code for intersecting street	TOT_UNKNWN_CNT	Total number of persons with unknown injuries
ISECTG_ST_FULL_NM	Full name of intersecting street	TOT_UNKNWN_FATAL_CNT	Total number of persons with unknown injuries
JRSDCT_GRP_CD	Code for agency with jurisdiction over the area of crash.	TOT_UNKNWN_INJ_CNT	Total number of persons with unknown injuries
LAT_DEG_NO	Degrees of latitude	TOT_VHCL_CNT	Total number of vehicles involved in crash
LAT_MINUTE_NO	Minutes of latitude	TRAF_CNTL_DEVICE_CD	Type of traffic control device present at the time of crash
LAT_SEC_NO	Seconds of latitude	TRAF_CNTL_FUNC_FLG	Flag if traffic control device was functional at time of crash
LGT_COND_CD	Amount of light available at time of crash	TURNG_LEG_QTY	Number of turning legs
LN_QTY	Number of lanes	URB_AREA_CD	Two digit code indicating city or urban area
LONGTD_DEG_NO	Degrees of longitude	WRK_ZONE_IND	One digit code to indicate crashes in a work zone
LONGTD_MINUTE_NO	Minutes of longitude	**WTHR_COND_CD**	Atmospheric conditions at time of crash
LONGTD_SEC_NO	Seconds of longitude		
LRS_VAL	Values (other than longitude and latitude) that describe a segment of roadway.		

3.1.2 Determining appropriate data to analyze

There are two methods for identifying speed-related crashes within the ODOT Crash Data System. The first involves querying the database at the crash level for the "**CRASH_SPEED_INVLV_FLG**" flag. This is a Boolean attribute of all crashes, where '1' signifies speed involved and '0' signifies no speed involved. Early analysis of the crash data focused on the use of this variable to identify speed-related crashes. Approximately 9,770 crashes of the 62,548 that occurred on Oregon highways from 2000–2002 are flagged as involving speed.

As mentioned, the "CRASH_SPEED_INVLV_FLG" flag is only coded when an automobile involved in the crash was traveling faster than the posted speed limit. This presented a problem in the analysis because many of the crashes that were of interest would have occurred in inclement weather conditions. Vehicles might not have exceeded the posted speed limit, nor even approached it. However, this does not mean that speed was not a contributing factor in the reported crash. To determine the crashes for which this was the case, the "Crash Level Causes" variables were used within the crash database. These columns contain up to three sets of two-digit codes, which represent the circumstances most responsible for the occurrence of the crash. The code '01' identifies "Speed too fast for conditions." The database was queried for all crashes which contained at least one "Crash Level Cause" code of '01'. This method produced 16,865 total speed-related crashes for further analysis.

Further review of the 16,865 crashes identified with the '01' cause variable focused on the participant level of the ODOT Crash Data System. Of greatest interest were the error codes within the participant table. This table lists all known participants involved in the reported crashes, and the error codes represent the action of a specific participant. Participants could have up to three different error codes associated with them, depending on their level of involvement and the number of citations received from the reporting officer. Also, participants may have no error code associated with them, or an error code of '000,' if it was determined that they took no action in the reported crash or that a citation was not warranted.

There were over 32,070 participants involved in the 16,865 speed crashes for the study period of 2000–2002. This indicates that many of the crashes involved multiple vehicles. Of those 16,865 speed-related crashes, at least one participant had an error code of '047' – "Driving too fast for conditions" – in 8,353 crashes. Figure 3.1 displays the participant error code breakdown for all crashes that did not have at least one '047' code. The participant error code '000', which has been identified as non-action or non-warranted, makes up a majority of the error codes associated with speed-related crashes where there was not at least one reported '047' participant error code (see Table 3.2). This would suggest that 7,841 participants of the total 32,070 involved in speed-related crashes took 'no-action' or did not warrant any citation. Error codes of '026' – Failure to avoid stopped or parked vehicles ahead – was also quite common among participant error codes. Indeed, an analysis of the types of collisions in which participant error codes '000' were involved shows that over 90% were classified as 'Rear-End.' A flowchart describing the above analysis is shown in Figure 3.2.

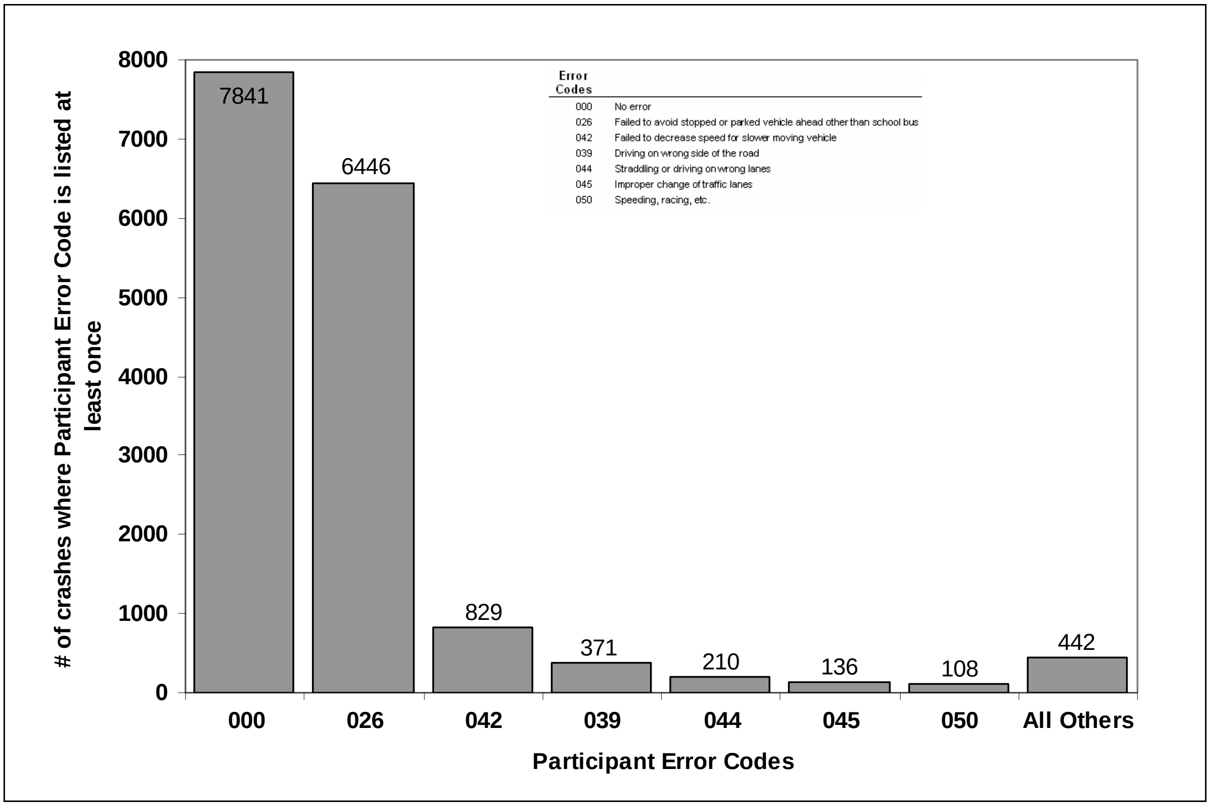


Figure 3.1: Participant error codes in speed crashes other than driving too fast for conditions

Table 3.2: Counts of collision type for crashes with participant error code '000'

Type	**Number**
Rear-end	7,103
Sideswipe overtaking	212
Turning movement	181
Head-on	141
Sideswipe meeting	121
Angle	35
Fixed-object or other-object	29
Miscellaneous	10
Non-collision	6
Parking maneuver	2
Backing	1
Total Crashes*	**7,841**
***19,520 Total Vehicles Involved**	

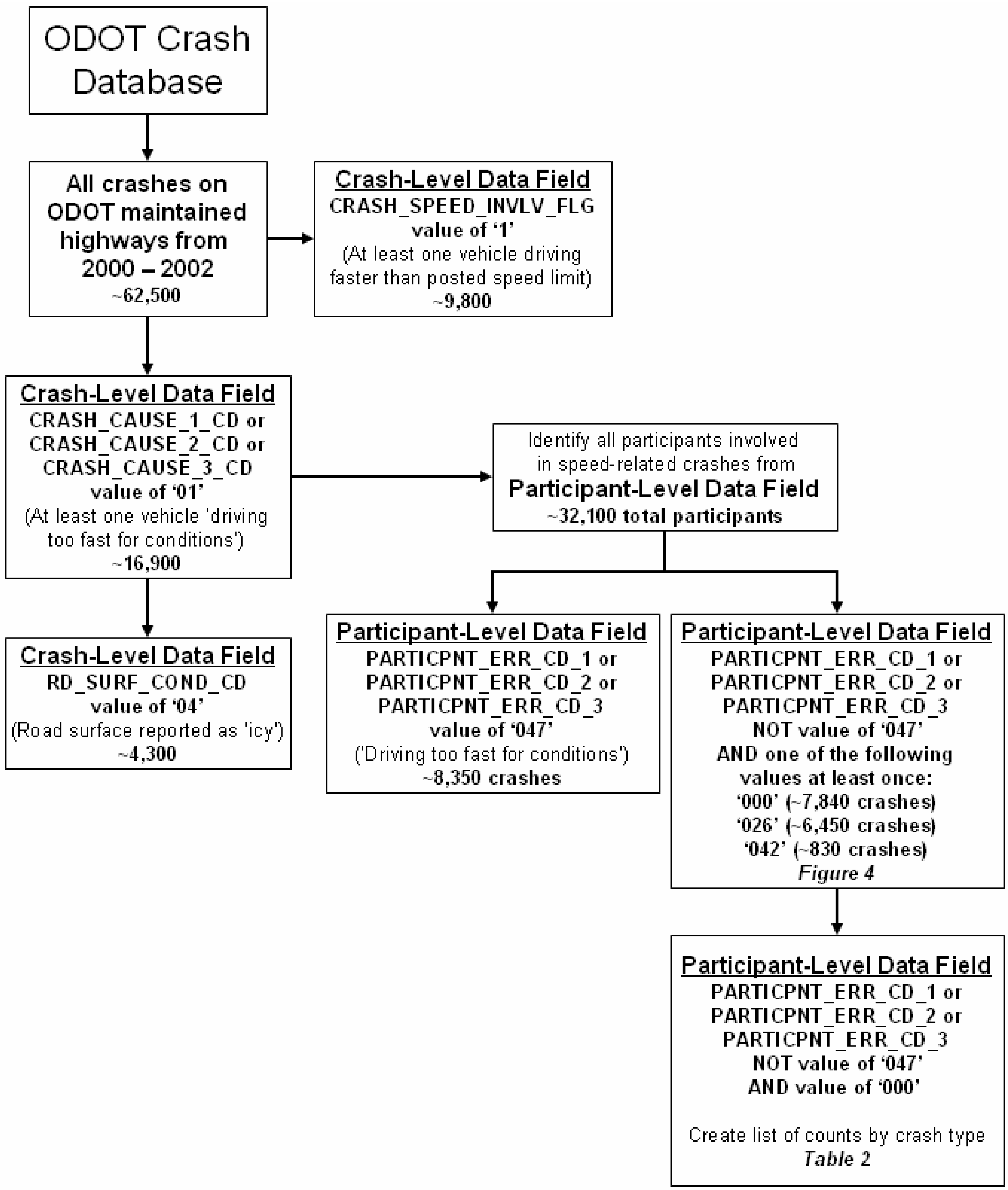


Figure 3.2: Flow chart of coding/selection process for crashes

3.1.3 Overrepresentation analysis

Many related causal factors were considered relating to speed crashes such as light condition, surface conditions, driver error and others. Each field variable in the crash database has sub-variables in order to better describe the specific type of crash. For example, the "RD_SURF_COND_CD" field variable is divided into the following categories: dry, wet, snowy, and icy. Crash ratios of the sub-variables were analyzed to determine which of the variables were overrepresented in speed-related crashes. A number of roadway, environment, or other conditions were analyzed in order to see if the representation of that variable was consistent in all crashes and those crashes that were speed-related. Variables that had a significantly higher presence in speed-related crashes than total crashes could be said to be overrepresented.

Figure 3.3 shows how the sub-variable "icy" was overrepresented in speed-related crashes, especially when compared to the other sub-variables. In the other categories (dry, wet, and snowy) speed-related crashes were approximately equal to or less than the percentages of all reported crashes. This analysis highlights what roadway, environment, or other conditions were more represented in speed/ice crashes. As shown in Figure 3.4, the majority of the crashes occurred during daylight hours (73%), which is expected because about 75 percent of total traffic volume also occurs during the daylight. When speed was considered as a crash factor, however, this percentage shifted slightly, decreasing the share of daylight crashes by 3 percent.

Figure 3.5 shows that when weather was considered as a factor, 68.8 percent of all crashes occurred when it was clear. Similar to the daylight example, the majority of driving occurs in clear conditions. When the weather was not clear – mainly cloudy, rainy, or snowy – speed increased as a factor by over seven percent. An examination of crashes by crash severity showed somewhat intuitive results, as shown in Figure 3.6. While property damage only (PDO) crashes accounted for 58.6 percent of all crashes, the percentage of speed-related crashes that were PDO were somewhat less (54.9%). Injury crashes, as a percent of the total, where higher for speed-related crashes. Surprisingly, fatal crashes made up 1.1 percent of all crashes, but only 0.5 percent of speed-related crashes.

Lastly, as shown in Figure 3.7, examining collision type also helped to understand the relationships between speed and crash types. Rear end collisions accounted for 40 percent of all crashes and 45.6 percent when speed was a factor. The difference in fixed object crashes was also noteworthy; fixed objects accounted for 15 percent of all crashes and 41 percent of speed-related crashes.

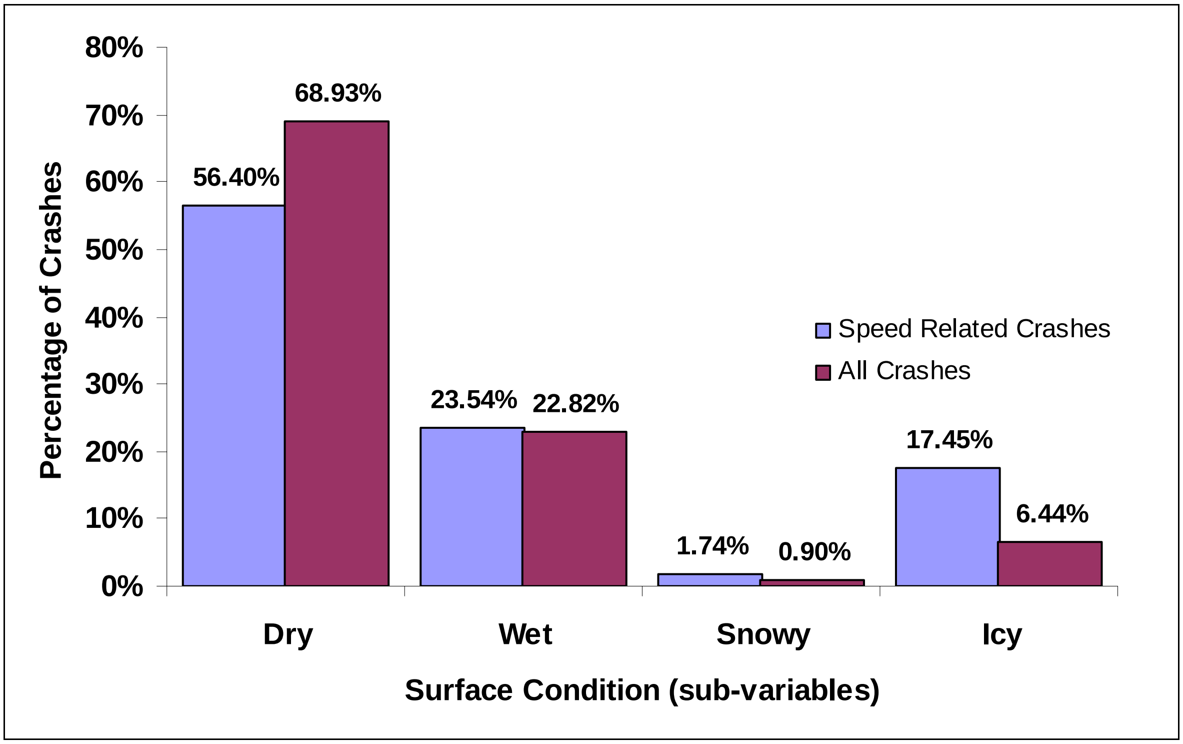


Figure 3.3: Histogram of crashes by road surface condition (2000–2002)

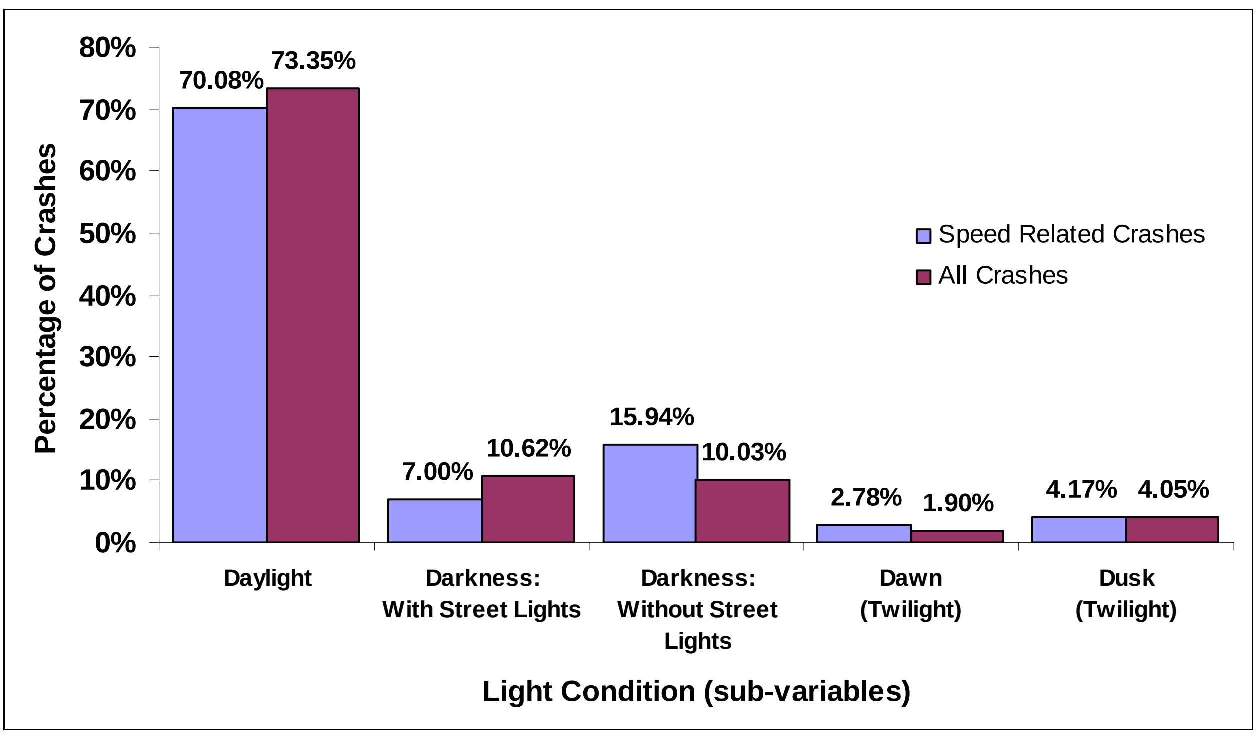


Figure 3.4: Histogram of crashes by light condition (2000–2002)

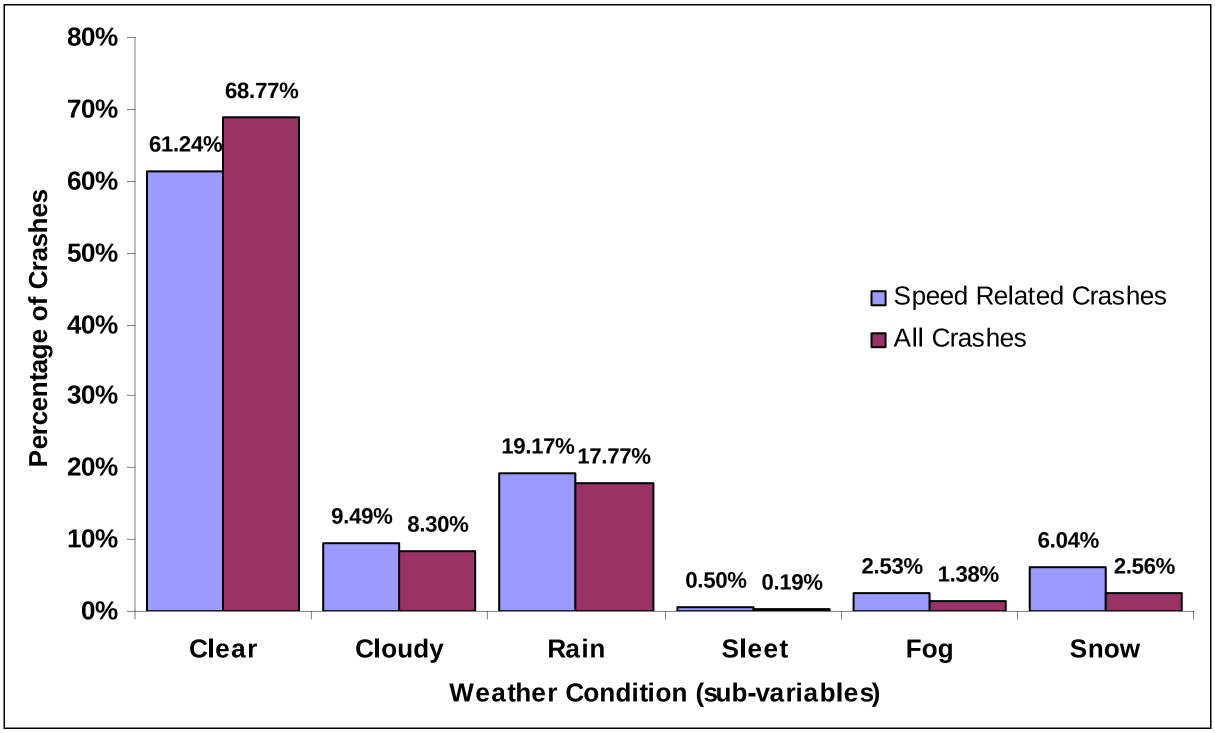


Figure 3.5: Histogram of crashes by weather condition (2000–2002)

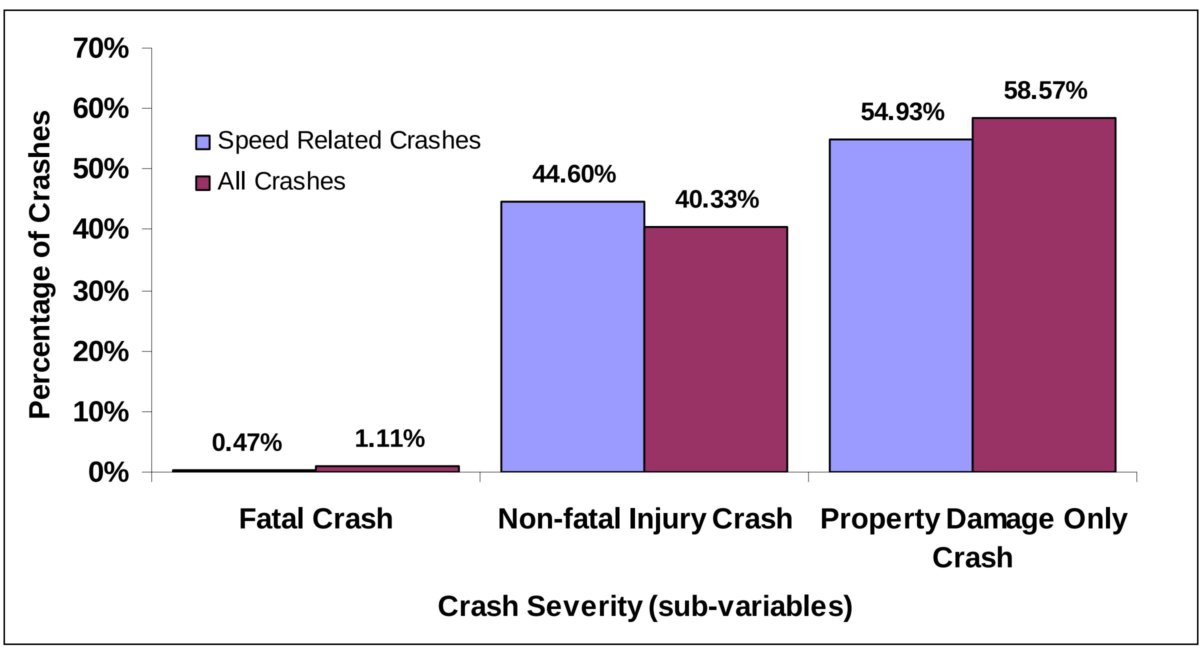


Figure 3.6: Histogram of crashes by crash severity (2000–2002)

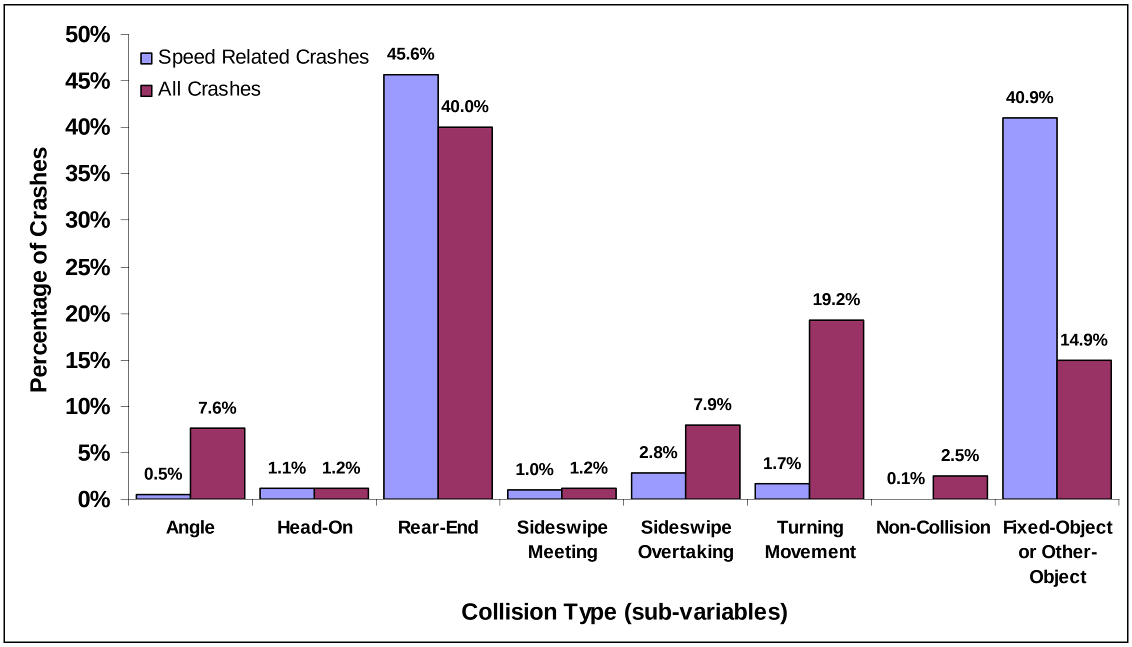


Figure 3.7: Histogram of crashes by collision type (2000–2002)

3.2 SPATIAL ANALYSIS

Geographical information systems (GIS) were heavily used in this project, with a particular emphasis on *linear referencing* methods, also known as *dynamic segmentation*. Dynamic segmentation allows events (crashes) stored in a database table (Crash Data System) to be associated with any portion of a linear feature (highway network shapefile). For this research, dynamic segmentation was used to relate a crash by milepost (MP), and display that location on the highway network with a marker. Highway points were aggregated by the number of crashes occurring in each one-mile segment. Figure 3.8 explains the dynamic segmentation process as it was used in ESRI's ArcGIS software package.

The first step in creating the model was to establish a unit of analysis. Since the study area included all roadways currently maintained by ODOT – 8,061 miles of state highway – it was determined that one-mile segments of roadway would be sufficiently small enough to compare crash sites across a statewide-region.

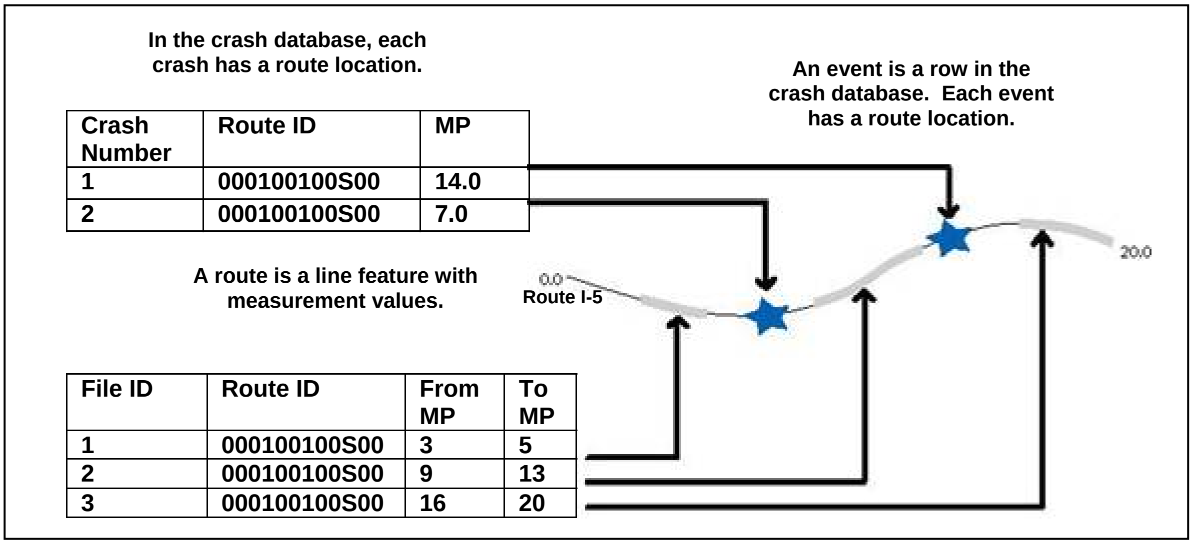


Figure 3.8: Dynamic segmentation process[3]

Next, as illustrated in Figure 3.9, using ODOT's highway network data files and spreadsheet software, a database was created that included unique 'network-able' one-mile segments of roadways for the entire ODOT system. Each segment contained a unique highway identifier, usually an LRS number, as well as *beginning* and *ending* milepost values. These one-mile segments were then attributed with average daily traffic (ADT) data using dynamic segmentation in ArcGIS. Counts of crashes occurring along each one-mile segment were tabulated using the linear referencing system and a spatial join. Finally, the resulting data file was exported to a geodatabase for analysis in Microsoft Access and Excel.

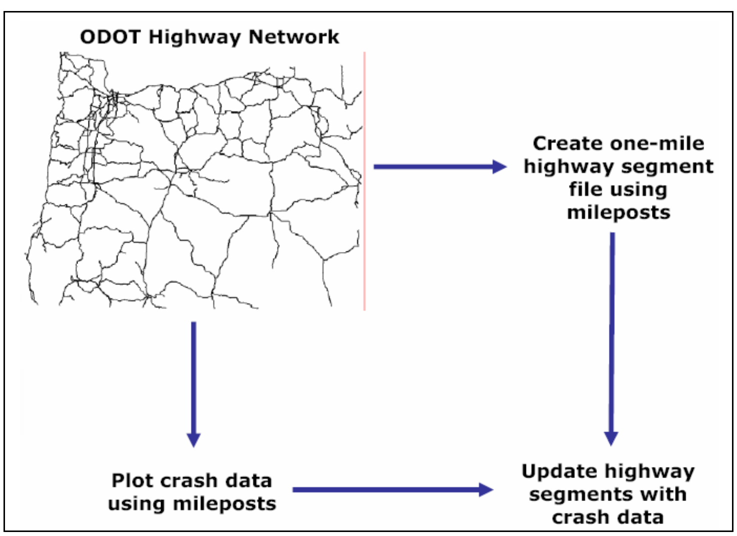


Figure 3.9: Diagram of GIS model used in research

[3] * Adapted from ArcUser, 2002

This entire process was also repeated for a ½-mile roadway segment file. However, later analysis showed little discrepancy between the one-mile and ½-mile segments. Therefore, only the one-mile segment file was used for the research in this report.

Figure 3.10 shows the one-mile roadway segments by total numbers of crashes on the map of Oregon's highway system, without considering traffic volumes. Spatial analysis in a GIS is greatly simplified by the use of dynamic segmentation and spatial joins. The following sections describe how these tools were further used to analyze the distribution and characteristics of 'high' crash locations – specifically those that pertain to speed-related crashes.

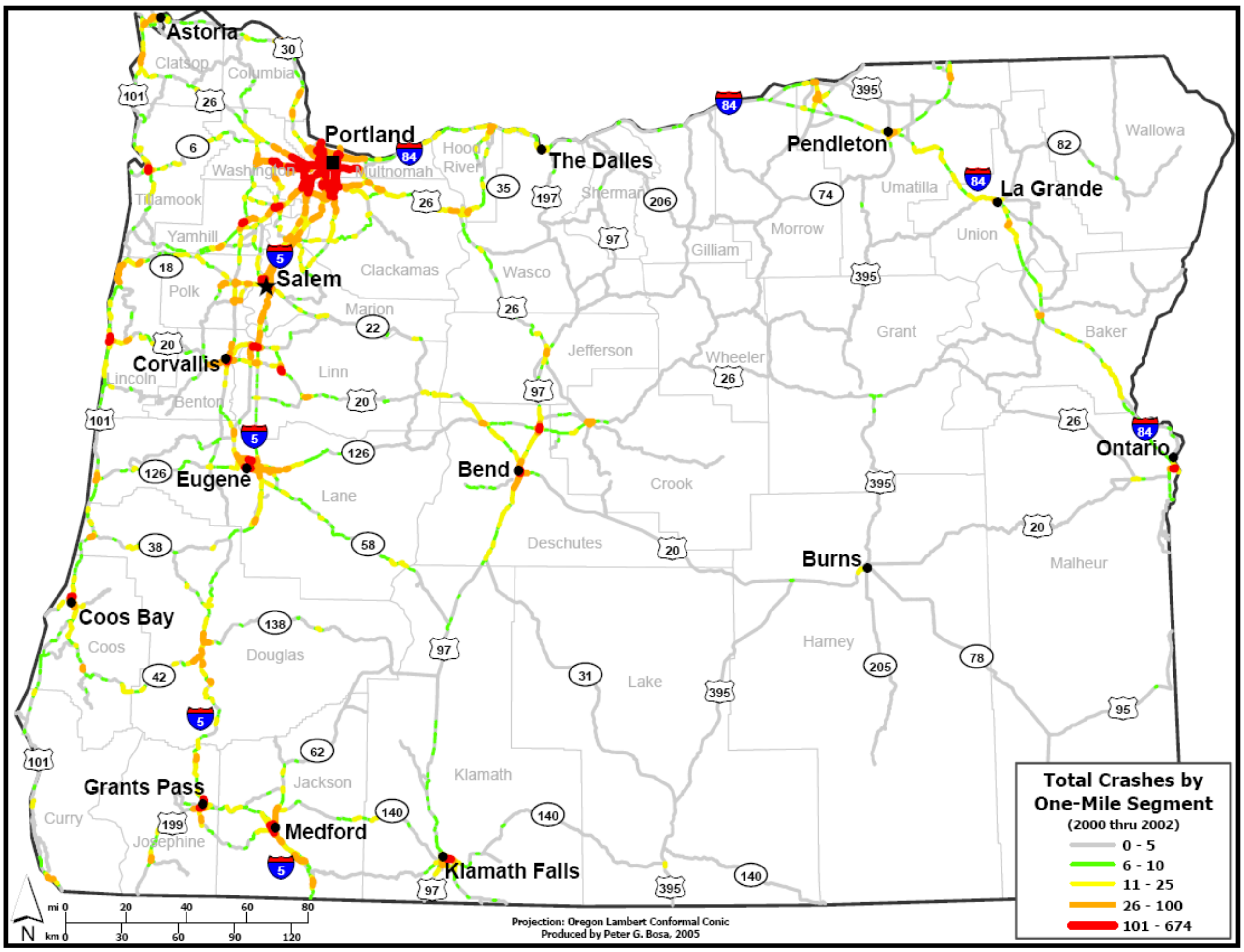


Figure 3.10: Total reported crashes by one-mile segment (2000–2002)

3.2.1 Speed-related crashes

In order to analyze the speed-related crashes in greater spatial detail, the first step was to filter the speed crashes from all crashes. Again, this was a simplified look at crash types, but it was an important first step in identifying locations that were vulnerable to speed-related crashes. Figure 3.11 highlights locations on the state highway system that had high numbers of speed-related crashes between 2000 and 2002.

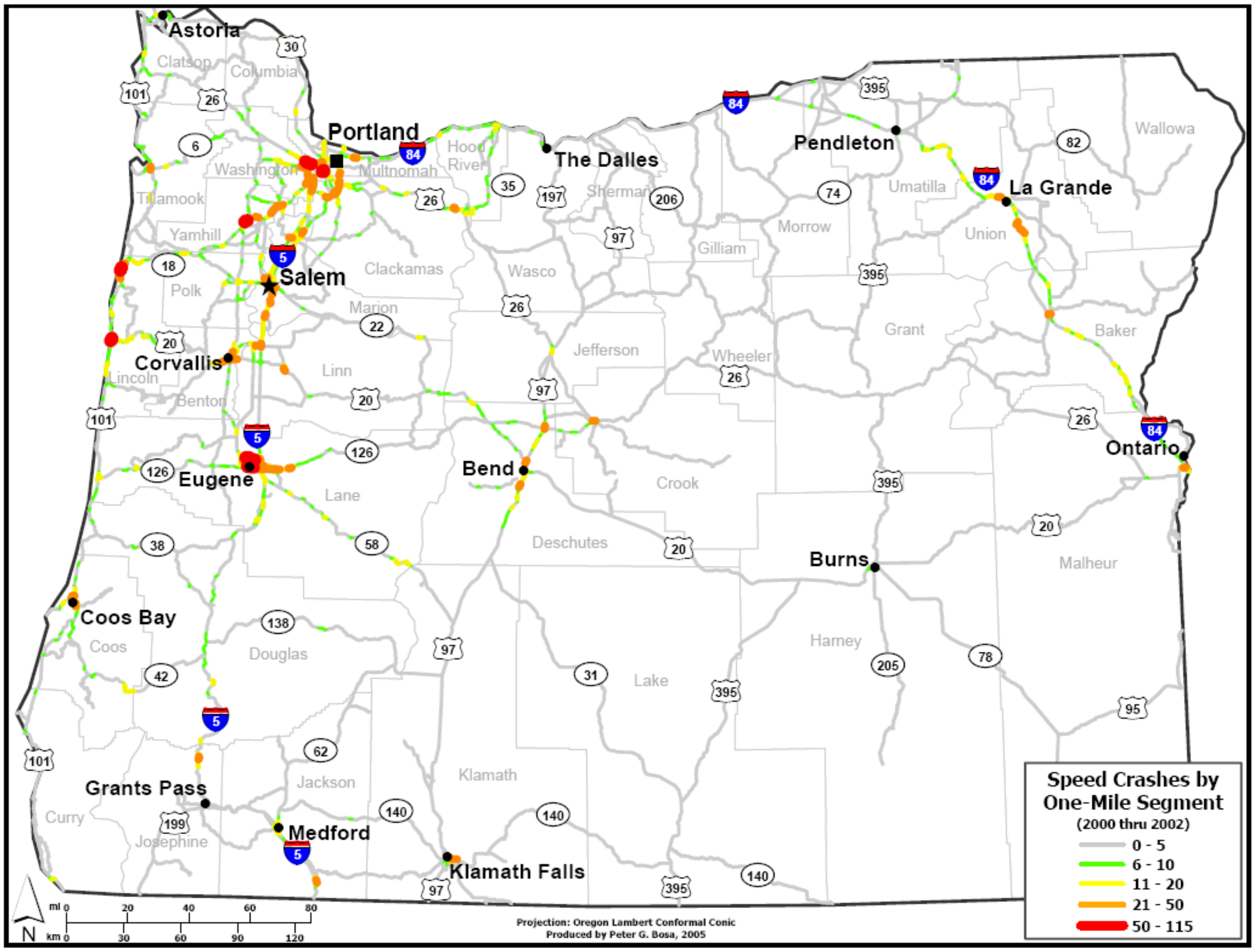


Figure 3.11: Speed-related crashes (2000–2002)

Although the majority of speed-related crashes were in western Oregon, they were dispersed throughout the state. The Eugene area had the four segments with the highest numbers of speed-related crashes, all on OR-126 and OR-99. One segment had 34 speed-related crashes and another segment just two miles away had 39 speed-related crashes. The same area produced two segments with 25 speed-related crashes each. In total, six one-mile sections clustered together on these two highways accounted for 151 speed-related crashes. At this first level of analysis, the Eugene area clearly stood out as an area for further investigation, analysis and potential application of countermeasures.

Other regions that stood out with respect to numbers of speed-related crashes over one-mile segments include two spots on US-101, directly west of Salem. Combined, those two locations accounted for 144 speed-related crashes over twelve miles of highway. Additionally, 84 speed-related crashes occurred in within a six-mile cluster of highway segments five miles west of Portland, on US-26. Central Oregon had a small concentration of speed-related crashes on US-97 outside of Bend. There was a cluster of high speed crashes in northeast Oregon to the north and south of La Grande, along I-84. There was also a small cluster of speed-related crashes 50 miles east of Portland on US-26, which is near the Mt. Hood ski resorts. The rest of the highway segments did not have substantially high numbers of speed-related crashes during the study period.

3.2.2 Speed and light conditions

Looking at speed-related crashes and lighting conditions served as a second example of using this method for identifying highway locations based on crash type. The sub-variable darkness (without street lights) was identified as being overrepresented within the set of speed-related crashes. Figure 3.12 shows locations where crashes caused by both speed and darkness were prevalent during the period 2000 – 2002 (3,381 total Speed and Darkness crashes).

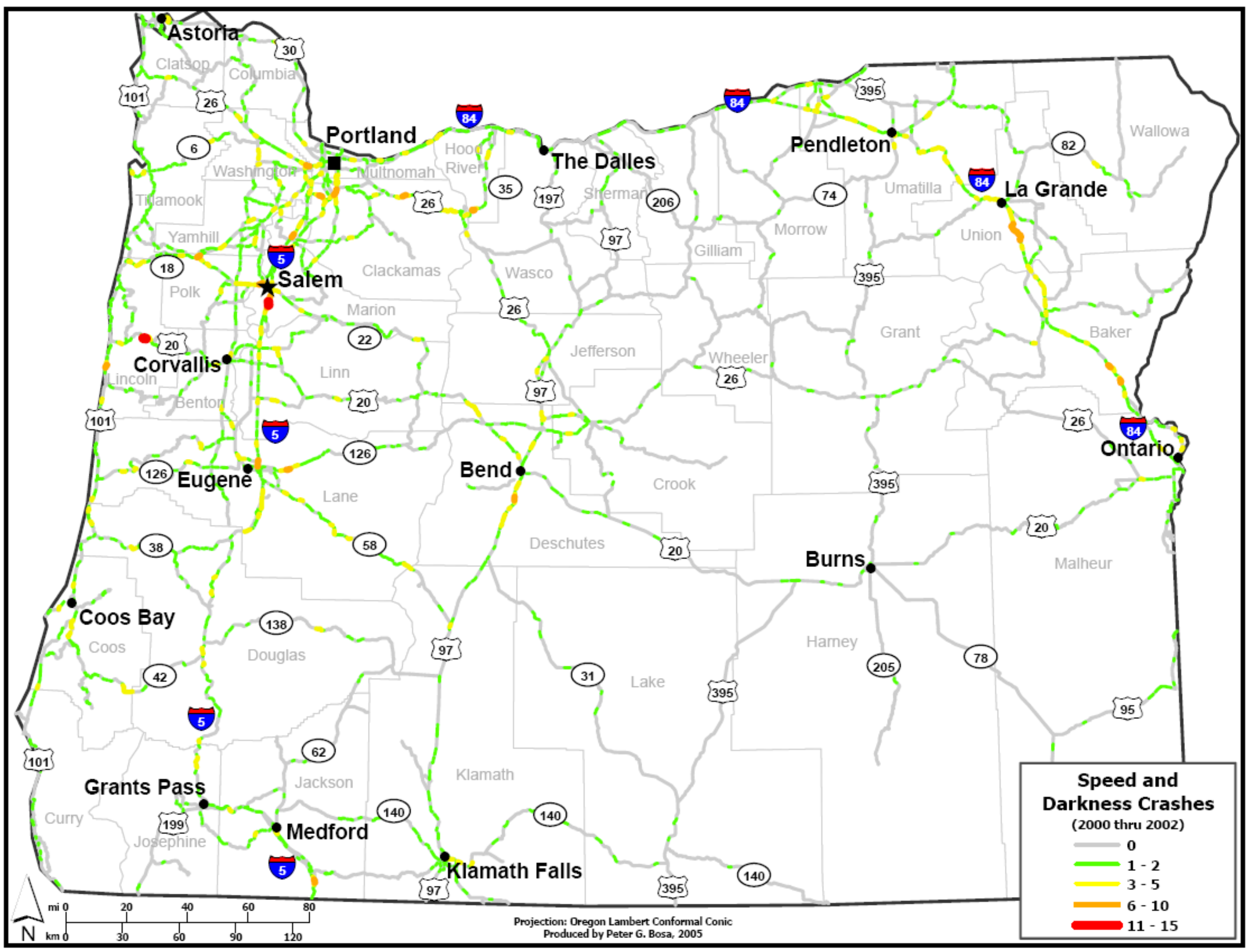


Figure 3.12: Speed and darkness crashes (2000–2002)

Several locations stood out from the rest as segments to be analyzed further. One of these segments was along I-5, just south of Salem. Another segment was located along US-20 between Newport and Corvallis. Other areas deserving further analysis with respect to speed and darkness were scattered across a few regions of the state. Numerous crash locations were identified throughout the Portland and Salem regions. More sites were located along I-84 east of La Grande and west of Ontario, outside Eugene along I-5 and OR-126, south of Bend on US-97, and along US-26/OR-35 near the Mt Hood area.

3.2.3 Speed and surface conditions

As shown in Figure 3.3, the surface conditions data analysis showed that speed-related crashes were found to be overrepresented in icy road conditions. Accordingly, a map was created to show highway sections that had high numbers of speed-related crashes coupled with icy surfaces. Figure 3.13 shows speed/ice crashes as a percentage of the total crashes. Most of the segments showing greater than 80% speed/ice crashes were located in rural areas, along sparsely traveled roadways. Many of these segments had only one or two crashes during the entire study period. Without 'normalizing' the data with a variable such as average daily traffic (ADT), the best this snapshot could do was to provide a window into where snow and ice crashes seemed most prevalent (as a percentage of all crashes) This type of mapping thus began to pinpoint problem areas based on a specific combination of possible crash causation factors.

There were several highway sections in the highest number category of speed/ice crashes, most of which were concentrated predominantly in two areas. These areas make logical sense for someone who is familiar with Oregon topography; they are located in the higher elevations of mountainous terrain where ice is more likely. The first these high elevation clusters was in northeast Oregon along I-84, south of Pendleton. This area is comprised of a 75-mile cluster of many problem areas for speed/ice crashes on I-84. A second area of speed/ice crashes was located on Highway 26/Highway 35 near the Mount Hood ski resorts. A cluster of medium and low frequency crashes occurred within 25 miles of Bend on Highways 20 and 97 as well as along Highway 58 near Willamette Pass. Again, most of these areas are in mountainous terrain.

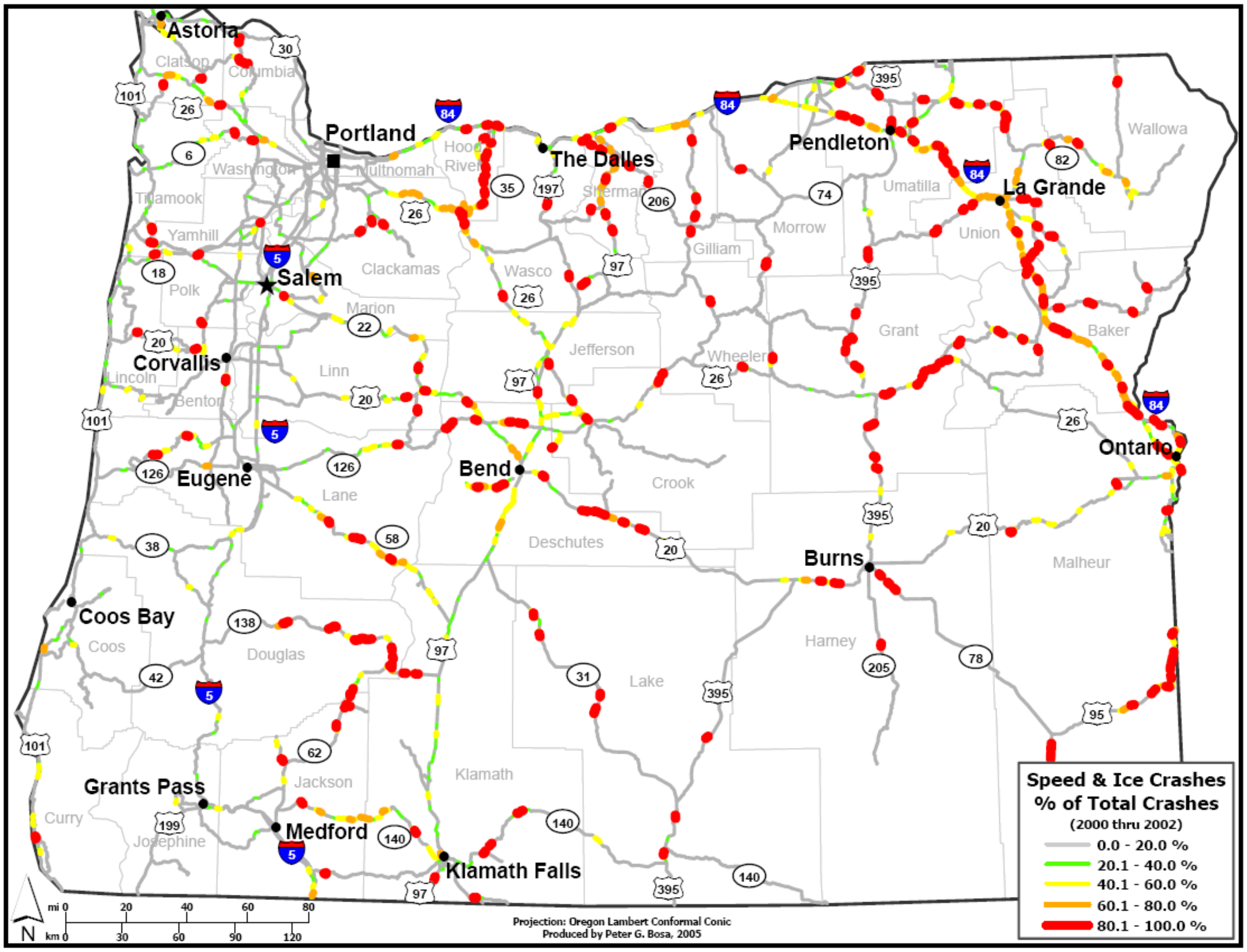


Figure 3.13: Speed and ice crashes as a percentage of total crashes per one-mile (2000–2002)

3.3 SUMMARY

This chapter has focused on an analysis of the number of crashes of different types that occurred on the Oregon highway system during the years 2000–2002. The description of the Statewide Crash Data System was followed by the discussion of the speed-related crashes and those crashes associated with icy conditions, extracted from the overall crash database. The overrepresentation analysis confirmed that speed-related crashes were overrepresented under icy conditions. Crash data analysis illustrated the distribution of speed-related crashes by different surface conditions, lighting conditions, weather conditions, crash severity, and collision type. The dynamic segmentation technique used to subdivide the Oregon highway network into one-mile segments was also described, followed by spatial presentations and discussions of the total reported crashes, speed-related crashes, speed and darkness crashes, and speed/ice crashes. Investigating numbers of crashes is valuable, but as will be described in the next chapter, there are better methods available for more informative analyses.

4.0 NETWORK SCREENING

This chapter describes more sophisticated and useful methods for analyzing speed-related crashes that are associated with icy surfaces. Data were analyzed at regional and state levels using Geographical Information Systems (GIS). Identification and ranking methods were used to explore one-mile and half-mile highway section lengths, frequency, rate, critical rate, severity, and index ranking methods. Specific tools included dynamic segmentation and spatial joins to develop the database for ranking. Techniques were developed to evaluate sites across the highway network that should be considered for countermeasure deployment.

4.1 FREQUENCY

A common way to screen networks for high crash locations is the frequency method. There are clearly more sophisticated methods for screening networks (as briefly reviewed in Chapter 2), but the frequency method provides a very good baseline for comparison to other methods. In the frequency method, sections were ranked by the total number of crashes that occurred at the observation level. Again, this analysis used three years of crash data (speed/ice related crashes), and the total number of speed/ice related crashes that occurred were determined. In Figure 4.1, the total number of crashes per one-mile section is displayed. For frequency, sections were ranked in descending order, with the most crashes in one mile being ranked first. The results of this analysis are in shown in Table 4.1 and graphically in Figure 4.2.

As can be seen in the figures, most segments were located along a few roadways (I-84, US-26/OR-35, OR-58), and all were rural, mountainous areas. In Table 4.1, the section that had the most speed/ice related crashes in three years was I-84 which had 21 crashes (7 per year on average). A number of sections were tied for the 15th rank with 11 crashes each; thus 24 locations are shown in the table rather than just 20. A vast majority of the crashes reported along major highways of central and eastern Oregon were related to the speed/ice variables. As expected, the majority of these roadways are high-volume facilities with a substantial amount of winter weather conditions. I-84 between Hermiston and the Idaho border and US-97 north and south of Bend have relatively high traffic volumes, and a high number of speed/ice related crashes. Also, OR-35 between Hood River and the intersection with US-26 had consistently high percentages of speed/ice crashes. While knowing the locations where there are a high number of crashes is useful, it does not consider traffic volumes does not necessarily identify above average or abnormal locations. These limitations are addressed by the next methods.

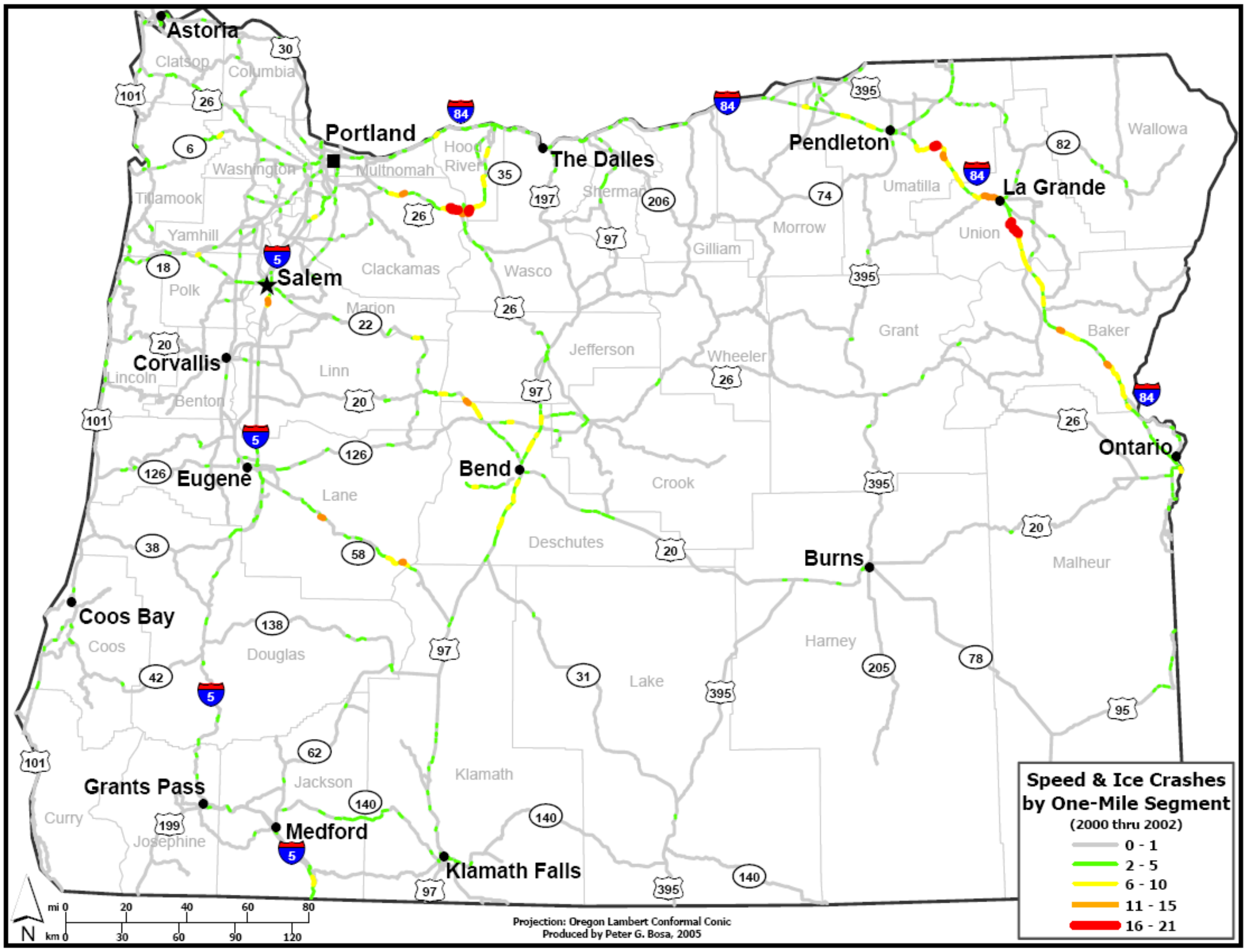


Figure 4.1: Crashes involving speed and ice on one-mile sections (2000–2002)

Table 4.1: Top 20 crash sites based on crash frequency (2000–2002)

Rank	Route	County	From MP	To MP	Total Speed/Ice Crashes	Percent Speed/Ice Crashes	Total Lanes	Total Surface Width (feet)
1	I-84	Union	274	275	21	87.5	2 *	38 *
2	US-26	Clackamas	51	52	20	80	4	66
2	I-84	Union	270	271	20	62.5	2 *	41 +
4	US-26	Clackamas	52	53	18	64.3	3	46
4	US-26	Clackamas	53	54	18	66.7	3	50
6	I-84	Union	273	274	17	70.8	2 *	38 *
7	OR-35	Hood River	61	62	16	61.5	2	38
7	I-84	Umatilla	228	229	16	66.7	2 *	40 +
9	I-5	Marion	248	249	15	34.1	3 *	56 +
10	OR-58	Lane	59	60	14	66.7	2	32
10	I-84	Umatilla	229	230	14	93.3	2 *	40 +
10	I-84	Union	258	259	14	60.9	2 *	38 +
13	US-26	Clackamas	57	58	12	66.7	2	40
13	I-84	Union	256	257	12	70.6	2 *	38 +
T-15	OR-58	Lane	24	25	11	78.6	2	30
T-15	US-26	Clackamas	32	33	11	78.6	4	68
T-15	OR-35	Hood River	60	61	11	64.7	2	38
T-15	OR-126	Jefferson	91	92	11	84.6	2	46
T-15	I-84	Umatilla	234	235	11	91.7	2 *	38 *
T-15	I-84	Union	255	256	11	57.9	2 *	38 +
T-15	I-84	Union	272	273	11	61.1	2 *	38 *
T-15	I-84	Union	275	276	11	78.6	2 *	38 *
T-15	I-84	Baker	312	313	11	91.7	2 *	40 +
T-15	I-84	Baker	332	333	11	91.7	2 *	40 +

Note: * EB and WB values the same
+ maximum of EB/WB value

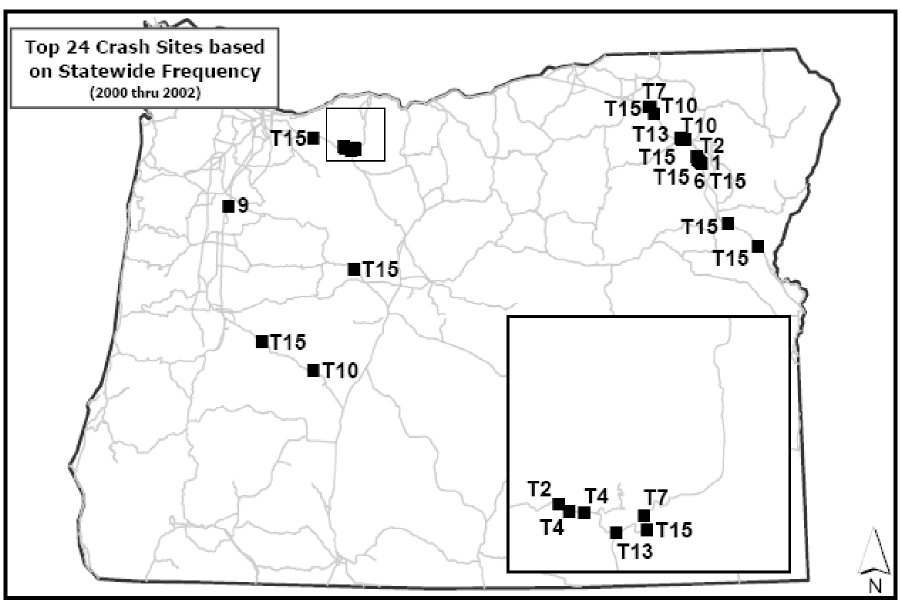


Figure 4.2: Top 24 crash site locations - statewide frequency

4.2 RATE

Network screening with the rate method requires that the number of crashes be normalized by the volume on the section. Using the spatial techniques described in Chapter 3, the average daily traffic (ADT) for each one-mile section was determined. ADT values for 2001 were used rather than an average volume. (This year represented the midpoint for the study period 2000 through 2002). To determine the crash rate of a given segment, R_{SEG}, (expressed as crashes per million vehicle miles traveled), the following formula was used:

$$R_{SEG} = \frac{C * 1{,}000{,}000}{V(D)(L)}$$

Where:
C = number of crashes in study period
V = volume, in Average Daily Traffic
D = number of days in study period
L = length of segment

In Figure 4.3, the rate per million VMT for the one-mile sections is shown. For the rate method frequency, sections were ranked in descending order with the highest rate in one mile being ranked first. The results of this analysis are in shown in Table 4.2 and graphically in Figure 4.4. A comparison of Tables 4.1 and 4.2 reveals that only three sites ranked in the top 20 by frequency also appear in the top 20 by the rate method. OR-35, MP 61-62 had 16 speed/ice related crashes and a rate of 8.12 crashes per MVMT. OR-35, MP 60-61 and OR-58, MP 59-60 are the other two sections that appear in both rankings.

The remaining sections ranked by the rate method had much lower frequencies of speed/ice related crashes (<6) but had relatively high rates. Most of these locations are low-volume 2-lane rural sections. In the rate method, sections with few crashes can still be ranked high if the volume is relatively low. In a sense, the "risk" of these locations is higher, but they may not necessarily be locations where one might invest in safety improvements, because the total number of crashes to be addressed is low. The rate method can be improved by comparing the rate to the average rate, which is described in the next section.

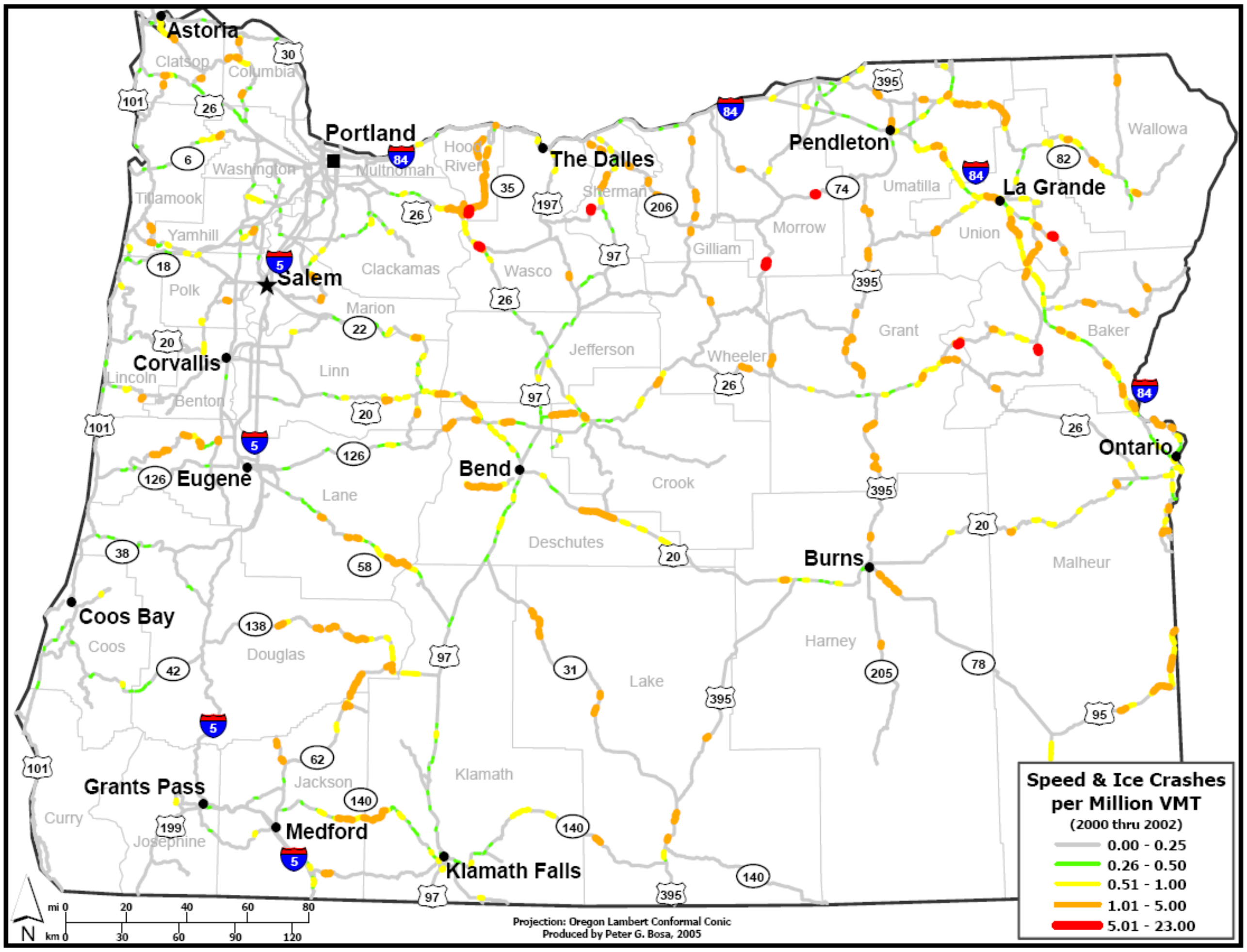


Figure 4.3: Speed and ice crashes per million VMT (2000–2002).

Table 4.2: Top 20 crash sites based on statewide rate method (2000–2002)

Rank	Route	County	From MP	To MP	Total Speed/Ice Crashes	Percent Speed/Ice Crashes	MVMT	Crash Rate	Total Lanes	Total Surface Width (feet)
1	OR-216	Sherman	22	23	1	100	0.04	22.83	2	22
2	OR-35	Hood River	61	62	16	61.5	1.97	8.12	2	38
3	OR-74	Morrow	58	59	1	100	0.13	7.61	2	22
4	OR-207	Morrow	19	20	1	100	0.15	6.52	na	na
5	OR-35	Hood River	60	61	11	64.7	1.97	5.58	2	38
6	OR-7	Baker	9	10	3	100	0.55	5.48	2	32
7	US-26	Union	71	72	2	33.3	0.37	5.37	2	31
7	OR-203	Wasco	8	9	2	100	0.37	5.37	na	na
9	OR-207	Morrow	20	21	1	100	0.20	5.07	na	na
9	OR-245	Baker	33	34	1	100	0.20	5.07	2	20
11	OR-35	Hood River	74	75	7	63.6	1.42	4.92	2	36
11	OR-35	Hood River	65	66	7	53.8	1.42	4.92	2	32
13	OR-35	Hood River	62	63	9	50	1.97	4.57	2	32
13	OR-35	Clackamas	58	59	9	75	1.97	4.57	3	44
15	OR-58	Lane	59	60	14	66.7	3.18	4.41	2	32
16	OR-35	Hood River	52	53	1	100	0.23	4.35	2	20
17	OR-35	Hood River	75	76	6	100	1.42	4.21	2	36
17	OR-35	Hood River	67	68	6	85.7	1.42	4.21	2	42
19	OR-395	Union	64	65	1	100	0.24	4.15	2	32
19	US-30	Lake	28	29	2	66.7	0.48	4.15	2	22

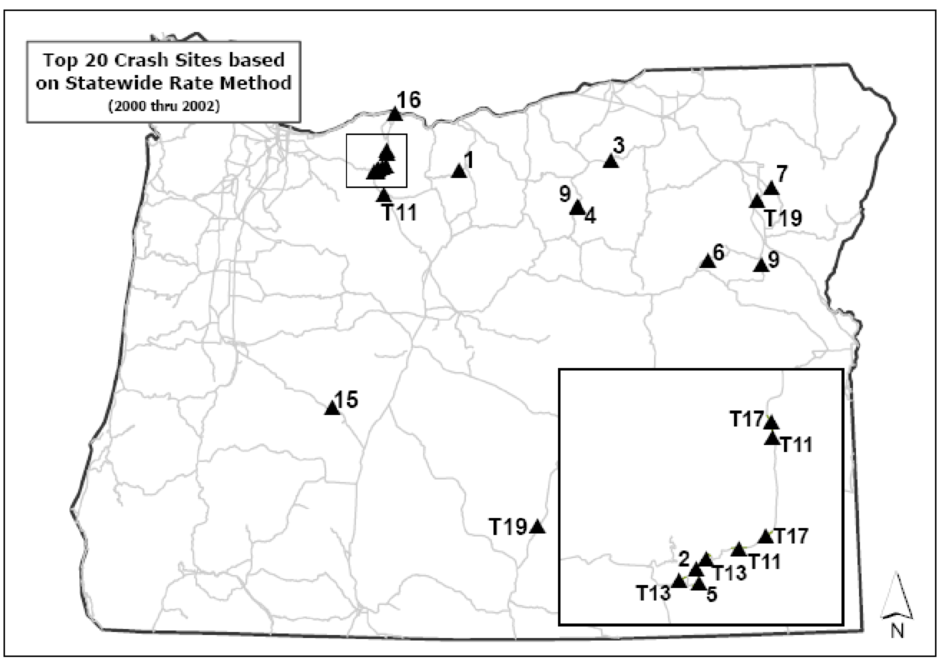


Figure 4.4: Top 20 crash site locations - statewide rate method

4.3 RATE QUALITY CONTROL

In the rate quality control (RQC) method, the calculated rate for each segment is compared to a critical rate to determine whether the crash rate along a segment exceeds some mean value by a statistically significant margin. If the observed rate for a section exceeds the critical rate for that section, one can conclude that the crash rate is above average. In our analysis, sections were ranked in ascending order by the percent the observed rate exceeded the critical rate. The critical rate, R_C, was calculated with the following formula:

$$R_C = R_A + K\sqrt{\frac{R_A}{M}} + \frac{1}{2M}$$

R_C = critical rate
R_A = the average rate for similar facility
K = probability constant based on desired level of significance (1.645 for 95%)
M = millions of VMT or entering vehicles = $(V*D*L)/1{,}000{,}000$

In this analysis, the average rate for similar facilities was determined using each segment's crash rate and the statewide mean crash rate for all roadway types (0.152 crashes per MVMT). The average rate could also be determined by roadway type (freeway, arterial, urban, rural) or by other categories (as described in the next section). This approach is weighted by volume so that it more precisely estimates the critical rate for high volume sections. In this manner, sections with relatively low volumes are less likely to be ranked unless they have a significantly higher crash rate. The percentage by which sections exceeded their critical rates are shown in Figure 4.5. Table 4.3 shows the results of the ranking of the top 20 crash sites based on the statewide RQC method, while Figure 4.6 displays their locations on the Oregon map.

Inspection of Figures 4.5, 4.6 and Table 4.3 reveal that the RQC ranking more closely resembled the frequency method than the rate method. Ten (10) of the sections identified by the frequency method were also identified by the RQC method. The RQC method identified four key areas in the state that were high-volume and typically experience winter-weather type conditions - OR-35/US-26 near Mt. Hood, OR-58 near Willamette pass, and I-84 east of La Grande. However, the rank-order of these sections did change from one method to the other. In addition, a number of nearby sections in these areas were identified.

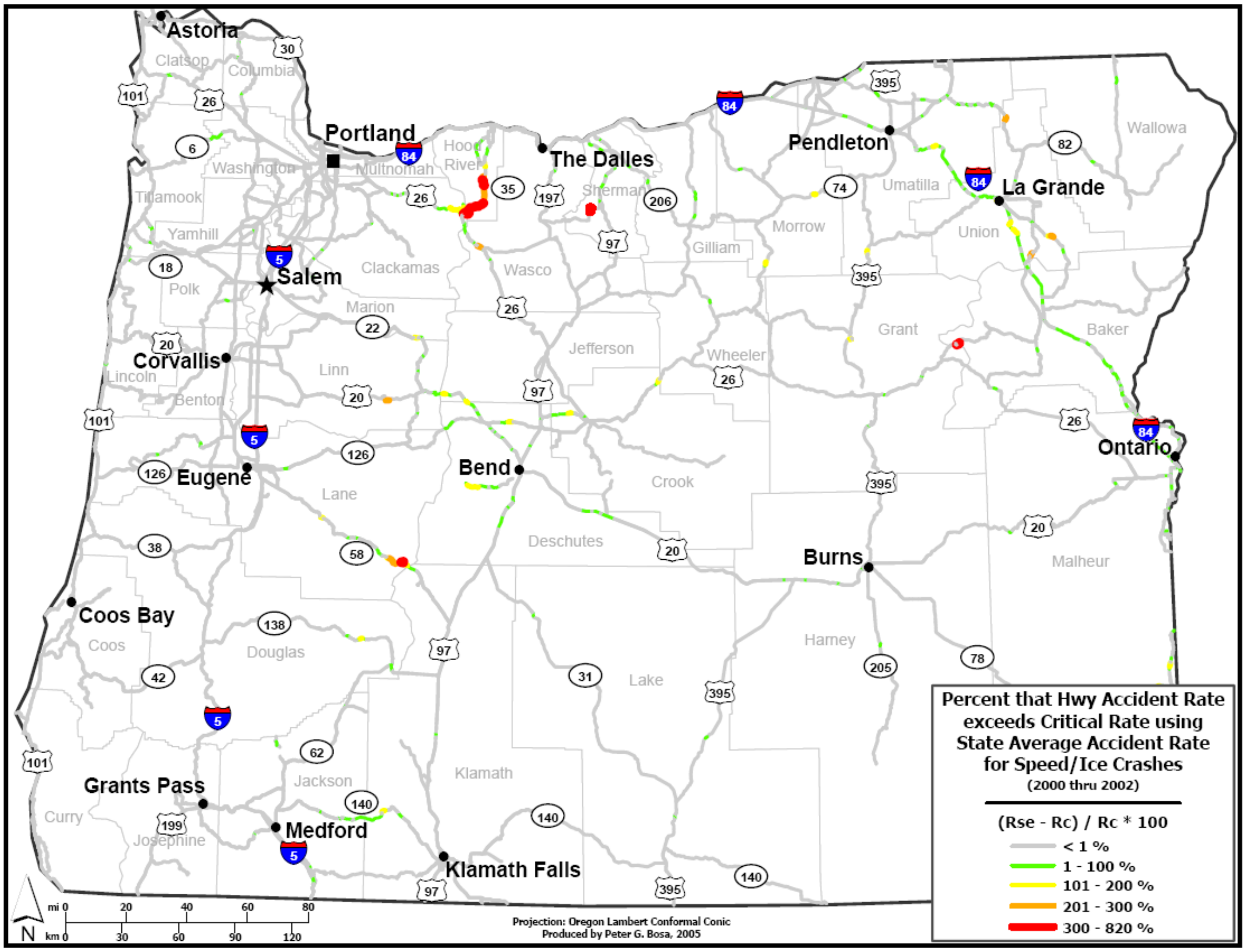


Figure 4.5: Percent that highway segment crash rate exceeds critical rate using state mean crash rate.

Table 4.3: Top 20 crash sites based on statewide RQC method (2000–2002)

Rank	Route	County	From MP	To MP	Total Speed/Ice Crashes	Percent Speed/Ice Crashes	MVMT	Crash Rate	Total Lanes	Total Surface Width (feet)
1	OR-35	Hood River	61	62	16	61.5	1.97	8.12	2	38
2	OR-58	Lane	59	60	14	66.7	3.18	4.41	2	32
3	OR-35	Hood River	60	61	11	64.7	1.97	5.58	2	38
4	US-26	Clackamas	51	52	20	80	8.43	2.37	4	66
5	OR-35	Hood River	62	63	9	50	1.97	4.57	2	32
5	OR-35	Hood River	58	59	9	75	1.97	4.57	3	44
7	I-84	Union	274	275	21	87.5	9.75	2.15	2 *	38 *
8	US-26	Clackamas	53	54	18	66.7	7.99	2.25	3	50
9	I-84	Union	270	271	20	62.5	9.75	2.05	2 *	38 *
10	US-26	Clackamas	52	53	18	64.3	8.43	2.13	3	46
11	US-26	Hood River	74	75	7	63.6	1.42	4.92	2	36
11	OR-35	Hood River	65	66	7	53.8	1.42	4.92	2	32
13	OR-35	Hood River	59	60	8	57.1	1.97	4.06	3	44
14	I-84	Union	273	274	17	70.8	9.64	1.76	2 *	38 *
15	OR-58	Clackamas	56	57	9	60	3.18	2.83	2	32
15	OR-58	Lane	55	56	9	64.3	3.18	2.83	3	44
15	OR-58	Lane	54	55	9	90	3.18	2.83	3	44
18	OR-35	Hood River	75	76	6	100	1.42	4.21	2	36
18	US-26	Hood River	67	68	6	85.7	1.42	4.21	2	42
20	OR-35	Hood River	57	58	12	66.7	6.24	1.92	2	40

Note: * EB and WB values the same
+ maximum of EB/WB value

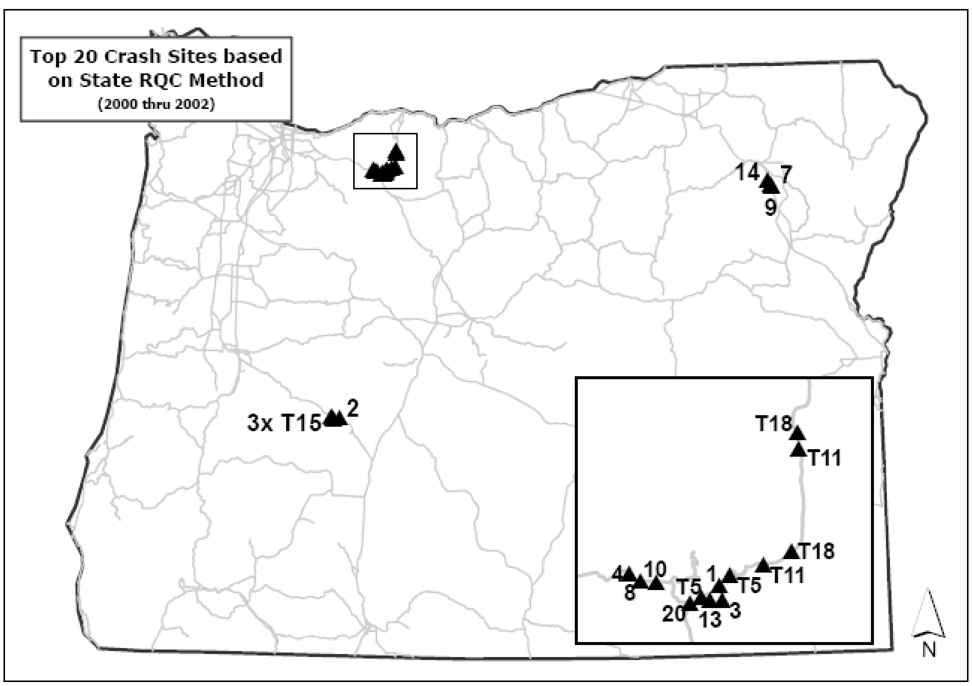


Figure 4.6: Top 20 crash site locations - statewide RQC method

4.4 RATE QUALITY CONTROL (WITH CLIMATE ZONES)

As mentioned, one improvement in the rate quality control method is to better define the categories that are used to calculate the average rate that is used in each section. By better defining what is "Average" it is more likely that true outliers will be identified. When comparing locations based on speed/ice crashes, one might expect that the frequency of crashes would be higher in mountainous areas where snow and ice are common than in more temperate locations. The diversity of Oregon's climate means that ice related crashes are much less likely in one region of the state than other. Sections that had crash rates significantly above average for similar weather conditions might be more likely to trouble spots. Identifying these regional 'outlier' locations would provide insight into the locations of true 'hotspot' sites for speed/ice crashes and is the focus of this section.

In order to further refine the rate quality control method, ranking with better categorization based on weather conditions needed to be identified. Two variables were analyzed in this model as potential indicators of areas prone to icy road conditions – the mean annual days of measurable snowfall exceeding 0.1 inch and the mean annual days when the temperature fell below freezing. These variables were collected using the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) CLIMAPS data. Coverage areas were presented as polygons, each polygon representing a range of days.

Two data sets were used in creating the Climate Zones. Both were obtained from NOAA's National Climatic Data Center, available for download from the NCDC website.[4] Each dataset consisted of GIS compatible shapefiles, which allowed for spatial overlays within ArcGIS. The first dataset contained polygons which represented one of nine categories for mean annual days with measurable snowfall exceeding 0.1 inch. The entire continental United States can be represented by polygons containing one of the nine categories shown in Table 4.4.

Table 4.4: Climate zone categories

Region Number	Mean Annual Days with >0.1" Snowfall	Mean Annual Days Below Freezing
1	< 0.5	< 0.5
2	0.5 – 2.4	0.5–30.4
3	2.5–5.4	30.5–60.4
4	5.5–10.4	60.5–90.4
5	10.5–15.4	90.5–120.4
6	15.5–20.4	120.5–150.4
7	20.5–30.4	150.5–180.4
8	30.5–60.4	180.5–240.4
9	> 60.4	> 240.4

[4] http://www.ncdc.noaa.gov/oa/ncdc.html

The second dataset contained polygons which represented one of nine categories for mean annual days with a temperature below freezing. Again, Table 6 shows the zonal categories represented by polygons for the entire continental U.S. Each of these data sets is based on 30-year averages. The resolution of each dataset was about one-half to one mile. Though this resolution was a bit coarse, it sufficed for the analysis here.

The next step of the analysis was to bring each of the CLIMAPS data sets into ArcGIS to produce unique 'climate zones.' By making one of the layers transparent, it was possible to visually merge the two layers. Individual regions were then digitized based on the results of the snow and freezing temperature layers, as well as guided by an understanding of the geographic features of the state. The result was a set of nine individual climate zones based on similar climate and geography characteristics. These zones were then used to categorize highway segments based on their location within each zone. The resulting classifications could then be used to compare the highway segments against one another using a rate quality control method discussed in the previous section. Figure 4.7 illustrates the process in which a map of the mean number of annual days with temperature below 32°F was merged with a map of the mean annual days with snowfall >0.1 inch, to produce the overall climate zone map. The zones, shown by color, are consistent with an general knowledge of the state's geography and climate.

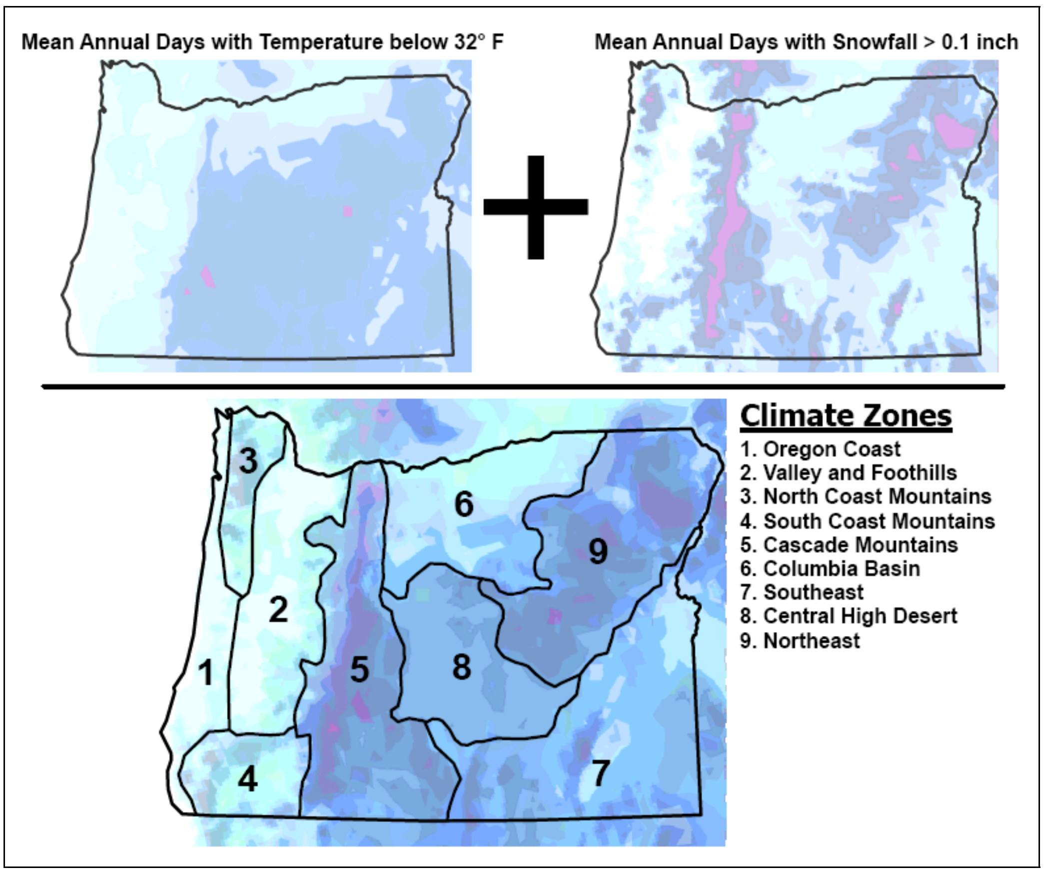


Figure 4.7: CLIMAPS data used to divide state into regions based on climate data

Next, the average crash rate for speed/ice related crashes for all roadway sections in each climate zone were determined. The results of this analysis are shown in Table 4.5. As shown in the table, it is clear that climate zones that experience more winter weather conditions on average have higher average crash rates in each zone. It should be noted that the climate zones that include the interstate highways are likely to have lower than average crash rates because of the relatively good safety performance of these facilities. In fact, the crash rate for road sections in the Cascade Mountains was 0.378, nearly double the statewide average and those for Zones 1, 2, 3 with much fewer winter weather conditions. This result was not unexpected, Zone 5 stood out with the highest crash rate, followed by Zone 9. Zones 3, 6, 7 and 8 had crash rates near to the state average and Zones 1, 2 and 4 fell well below the average for the state.

Table 4.5: Average rate values by climate zone (2000–2002)

Climate Zone	Zone Name	Average Rate (per MVMT)
1	Oregon Coast	0.061
2	Valley and Foothills	0.052
3	North Coast Mountain	0.138
4	South Coast Mountain	0.054
5	Cascade Mountains	0.378
6	Columbia Basin	0.129
7	Southeast	0.155
8	Central High Desert	0.157
9	Northeast	0.256
	Average Statewide	0.152

Using the average rate for each climate zone, a critical rate was calculated for each segment in the analysis region as described previously. Again, sections were ranked in descending order by the percent that they exceeded the critical rate. The results of this analysis are shown in Figure 4.8 and summarized by rank in Table 4.6 and Figure 4.9.

As shown, the sites were again located on OR-58 (4 locations), OR-35 (7 locations), I-84 (5 locations), US-26 (2 locations) and I-5 (2 locations). However, the rank-order of these sites changed. For example, the number 1 ranked site, OR-58, MP 24-25 was not identified in the statewide RQC method. It is likely that since this site is near the border for Zone 2 and Zone 5 but in Zone 2, it is identified as being significantly above average. Further investigation in Chapter 5 will reveal whether this site is indeed an outlier. In addition, two sites on I-5 in the Siskiyous near the California border were ranked in the zonal RQC method but not previously identified by other methods.

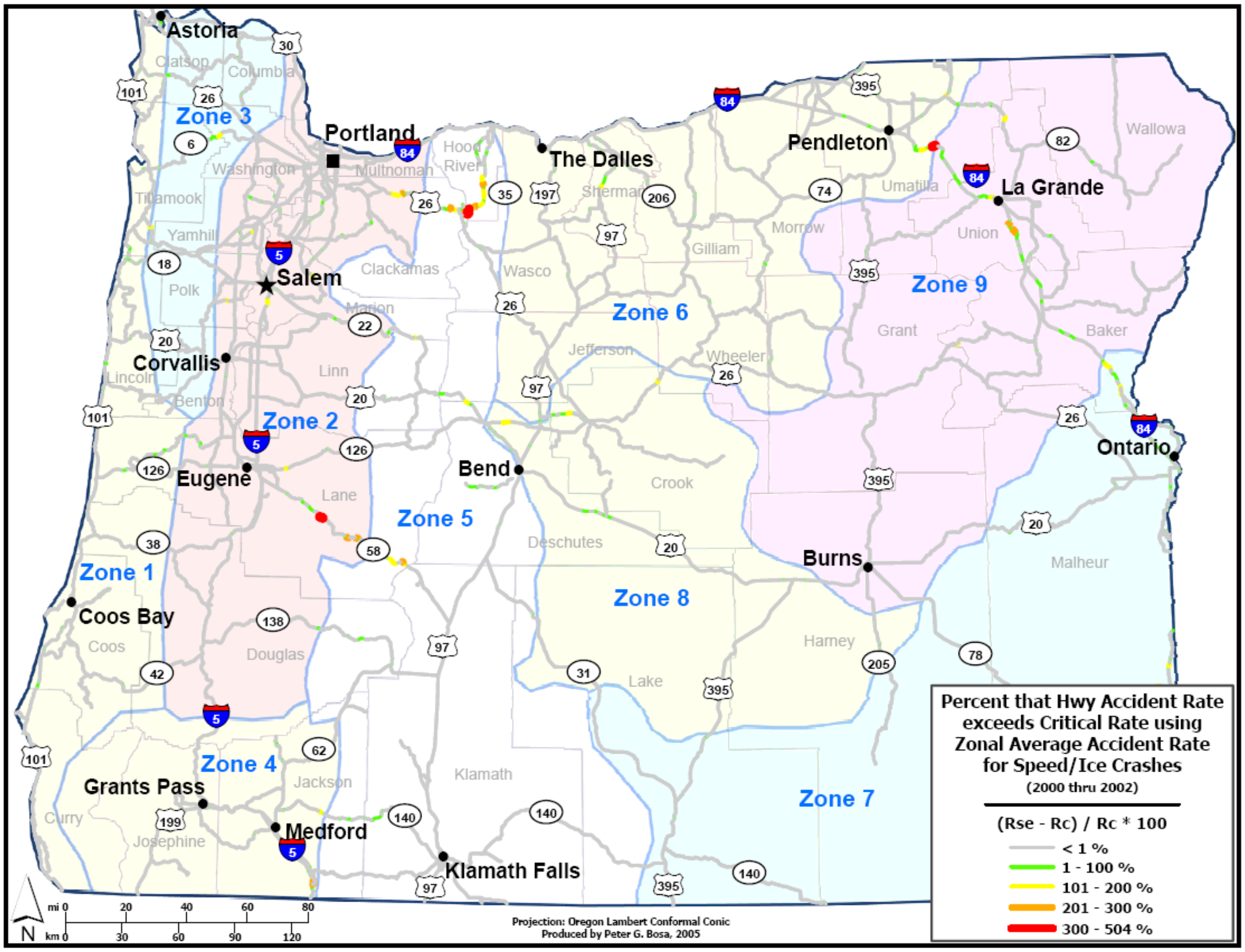


Figure 4.8: Percent that highway segment crash rate exceeds critical rate using zonal mean crash rates

Table 4.6: Top 20 crash sites based on zonal RQC method (2000–2002)

Rank	Route	County	From MP	To MP	Total Speed/Ice Crashes	Percent Speed/Ice Crashes	MVMT	Crash Rate	Total Lanes	Total Surface Width (feet)
1	OR-58	Lane	24	25	11	78.6	6.68	1.65	2	30
2	OR-35	Hood River	61	62	16	61.5	1.97	8.12	2	38
3	I-84	Umatilla	228	229	16	66.7	10.84	1.48	2 *	40 +
4	OR-35	Hood River	60	61	11	64.7	1.97	5.58	2	38
5	OR-58	Lane	59	60	14	66.7	3.18	4.41	2	32
6	I-84	Union	274	275	21	87.5	9.75	2.15	2 *	38 *
7	OR-58	Lane	40	41	5	83.3	3.18	1.57	2	32
8	US-26	Clackamas	32	33	11	78.6	17.19	0.64	4	68
9	I-84	Umatilla	229	230	14	93.3	10.40	1.35	2 *	40 *
10	I-84	Union	270	271	20	62.5	9.75	2.05	2 *	41 +
11	I-5	Jackson	5	6	10	38.5	15.22	0.66	2 *	44 *
12	OR-35	Hood River	62	63	9	50	1.97	4.57	2	32
12	OR-35	Clackamas	58	59	9	75	1.97	4.57	3	44
14	OR-58	Lane	37	38	5	55.6	4.71	1.06	2	32
15	OR-35	Hood River	74	75	7	63.6	1.42	4.92	2	36
15	OR-35	Hood River	65	66	7	53.8	1.42	4.92	2	32
17	I-5	Jackson	6	7	9	19.6	16.10	0.56	2 *	45 +
18	I-84	Union	273	274	17	70.8	9.64	1.76	2 *	38 *
19	US-26	Clackamas	51	52	20	80	8.43	2.37	4	66
20	OR-35	Clackamas	59	60	8	57.1	1.97	4.06	3	44

Note: * EB and WB values the same
+ maximum of EB/WB value

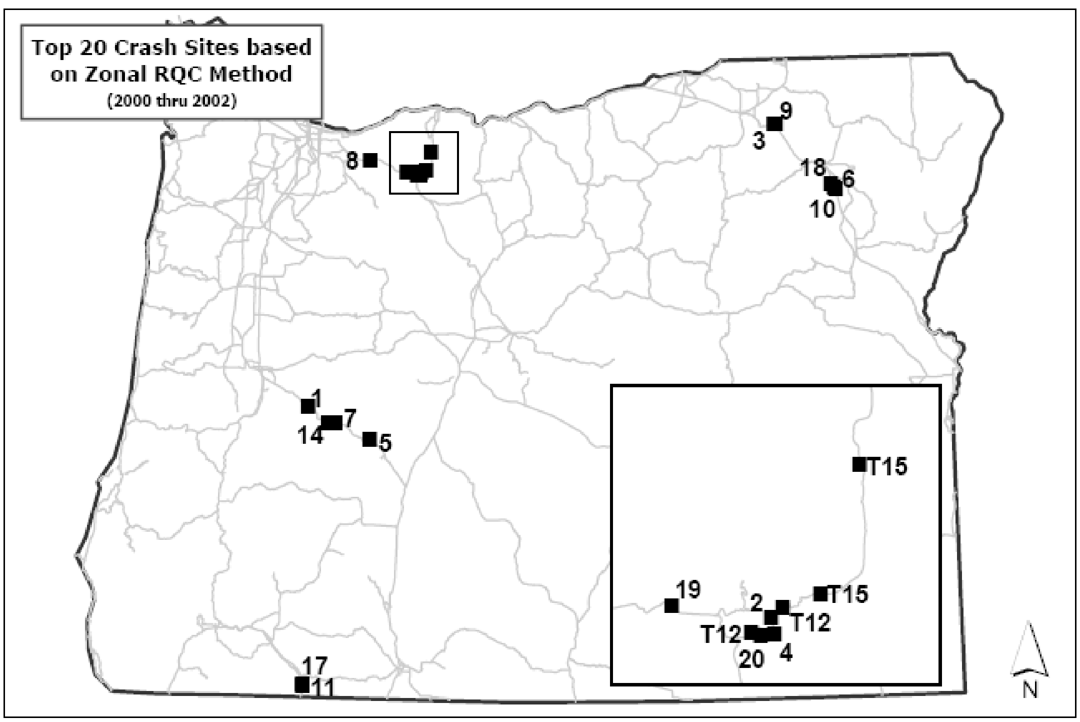


Figure 4.9: Top 20 crash site locations - zonal RQC method

4.5 COMPARISON OF SCREENING METHODS

In the previous sections, crash frequency, crash rate, rate quality control (RQC) and RQC with climate zones were presented as network screening methods. Table 4.7 presents a summary of all sections identified by any one of the 4 ranking methods as “Top 20.” This table produce shows the total of 49 top segments identified by the four ranking methods. This section will compare the prioritization techniques with the simple rate ranking or simple statewide RQC method.

Overall, only three sections were identified in the Top 20 by all three methods: OR-35, MP 61-62; OR-35, MP 60-61; and OR-58, MP 59-60. Additionally, the rate method identified 11, the frequency method identified 10, the statewide RQC identified 3, and zonal RQC method identified 4 sites that were only identified by that method. The statewide RQC and zonal RQC segments tended to be similar, yet both varied considerably from the simple crash rate and crash frequency rankings.

The use of the rate quality control method greatly clarified speed/ice crash data across the state, eliminating most highway segments as not statistically significant at the 95% confidence interval. The site ranking results from both the statewide and zonal RQC methods included high concentrations of sites in mountainous areas with high winter traffic volumes (I-84 has high year round traffic volumes, US-26/OR-35 provide major access to Mt. Hood ski areas and snow parks from Portland and Hood River, and OR-58 provides access to Willamette Pass ski areas and snow parks from Eugene).

The use of the statewide RQC method for speed/ice crashes eliminated most of the highway segments in Western, Southern, Southeastern Oregon. As shown in Figure 4.8, the method revealed the largest number of sites on US-26/OR-35 near Mt. Hood, OR-58 near the Willamette Pass, OR-216 near Wapinitia, and OR-7 near Bates. (The last two are extremely rural areas.) This provided further clarification in identifying areas with exceptionally high speed/ice crash rates.

There were several advantages with using the zonal RQC method. First, it included specific rates based on historical weather performance. Ranked in this manner, locations that were likely to include speed/ice crashes as normal conditions were ranked based on their deviation from other similar areas. As shown in Figure 4.9, the zonal RQC results were more “spread out” across the major concentration areas compared to the statewide RQC. The highest rates occurred on OR-35 south of Hood River, OR-58 east of Eugene (MP 24–25), and I-84 between Pendleton and Ladd Canyon, similar to the results of the statewide RQC method. Unlike the statewide RQC method, the zonal RQC method revealed high rates on the I-5 corridor south of Medford. The zonal RQC highest ranking site was not identified in the statewide RQC method. This was along OR-58 at MP 24–25. Along with site number from the zonal RQC method (see Figure 4.9 and Table 4.6), these were the only two sites that fell within Zone 2 (Willamette Valley). This suggests that despite exhibiting lower rates compared to the rest of the state, these locations had high rates compared to others in their zone. Thus the zonal RQC method was beneficial for identifying these speed/ice crash hot spots.

Table 4.7: All 'Top 20' segments identified by the four ranking methods (sorted by zonal)

Rank Zonal RQC	Rank Statewide RQC	Rank Frequency	Rank Statewide Rate	Route	County	From MP	To MP	Total Speed/Ice Crashes	Percent Speed / Ice Crashes	Crash Rate
1	27	15	175	OR-58	Lane	24	25	11	78.6	1.65
2	1	7	2	OR-35	Hood River	61	62	16	61.5	8.12
3	25	7	201	I-84	Umatilla	228	229	16	66.7	1.48
4	3	15	5	OR-35	Hood River	60	61	11	64.7	5.58
5	2	10	15	OR-58	Lane	59	60	14	66.7	4.41
6	7	1	82	I-84	Union	274	275	21	87.5	2.15
7	72	138	185	OR-58	Lane	40	41	5	83.3	1.57
8	126	15	583	US-26	Clackamas	32	33	11	78.6	0.64
9	32	10	233	I-84	Umatilla	229	230	14	93.3	1.35
10	9	2	102	I-84	Union	270	271	20	62.5	2.05
11	129	25	552	I-5	Jackson	5	6	10	38.5	0.66
12	5	37	13	OR-35	Clackamas	58	59	9	75	4.57
12	5	37	13	OR-35	Hood River	62	63	9	50	4.57
14	121	138	317	OR-58	Lane	37	38	5	55.6	1.06
15	11	71	11	OR-35	Hood River	65	66	7	53.8	4.92
15	11	71	11	OR-35	Hood River	74	75	7	63.6	4.92
17	172	37	650	I-5	Jackson	6	7	9	19.6	0.56
18	14	6	143	I-84	Union	273	274	17	70.8	1.76
19	4	2	71	US-26	Clackamas	51	52	20	80	2.37
20	13	54	21	OR-35	Clackamas	59	60	8	57.1	4.06
22	39	15	255	I-84	Baker	332	333	11	91.7	1.26
23	8	4	80	US-26	Clackamas	53	54	18	66.7	2.25
25	10	4	84	US-26	Clackamas	52	53	18	64.3	2.13
27	18	98	17	OR-35	Hood River	67	68	6	85.7	4.21
27	18	98	17	OR-35	Hood River	75	76	6	100	4.21
31	15	37	41	OR-58	Union	54	55	9	90	2.83
31	15	37	41	OR-58	Union	55	56	9	64.3	2.83
31	15	37	41	OR-58	Clackamas	56	57	9	60	2.83
36	43	288	6	OR-7	Baker	9	10	3	100	5.48
42	34	10	264	I-84	Union	258	259	14	60.9	1.23
47	21	15	105	OR-126	Jefferson	91	92	11	84.6	2.01
48	20	13	118	US-26	Clackamas	57	58	12	66.7	1.92
53	435	9	1125	I-5	Marion	248	249	15	34.1	0.23
73	47	15	287	I-84	Union	272	273	11	611.1	1.14
75	49	15	295	I-84	Union	275	276	11	78.6	1.13
79	48	13	303	I-84	Union	256	257	12	70.6	1.07
87	53	15	299	I-84	Umatilla	234	235	11	91.7	1.09
94	60	15	323	I-84	Baker	312	313	11	91.7	1.04
97	92	480	7	OR-203	Wasco	8	9	2	100	5.37
99	62	15	338	I-84	Union	255	256	11	57.9	0.98
116	116	480	19	US-30	Lake	28	29	2	66.7	4.15
136	192	859	1	OR-216	Sherman	22	23	1	100	22.83
137	92	480	7	US-26	Union	71	72	2	33.3	5.37
200	273	859	3	OR-74	Morrow	58	59	1	100	7.61
227	283	859	4	OR-207	Morrow	19	20	1	100	6.52
258	299	859	9	OR-207	Morrow	20	21	1	100	5.07
274	317	859	16	OR-35	Hood River	52	53	1	100	4.35
305	323	859	19	OR-395	Union	64	65	1	100	4.15
367	299	859	10	OR-245	Baker	33	34	1	100	5.07

4.5.1 Wilcoxon Signed Rank Test

In order to test if the different ranking methods produced different lists, a Wilcoxon Signed Rank Test was used to test the supposition that the median difference in ranks between two matched ranking methods were not statistically different from each other. The Wilcoxon Signed Rank Test is a non-parametric alternative to the one sample t-test. It is used when the data being analyzed are paired and cannot be assumed to have a normal distribution. The test works especially well on ordinal data such as the ranks of each road segment using the four ranking methodologies. Since the highway segments can be characterized as matched pairs that only differ by ranking, the two samples can be assumed to be dependent.

The procedures in a Wilcoxon Signed Rank Test are described in Table 4.8:

1. Calculate difference between pairs
2. Record the sign of the difference and the absolute value of the difference
3. Rank the absolute value of the difference from smallest to largest
4. Reattach signs to new ranks and calculate average of the new ranks ($\bar{r}$)
5. Calculate z-score using the following equation:

$$z = \frac{\bar{r} - ½}{\sqrt{(N+1)(2N+1)/6N}}$$: for $N \geq 20$, remove ½ from equation

H_0 : $\mu = 0$: No statistical difference between *Ranking Method 1* and *Ranking Method 2*

H_1 : $\mu \neq 0$: *Ranking Method 1* produces results statistically different than *Ranking Method 2*

Should the null hypothesis fail to be rejected, we can conclude that the two ranking methods are not statistically different. Rejection of the null hypothesis leads to acceptance of the alternative hypothesis and suggests the two ranking methods can be considered statistically different.

Table 4.8: Example of Wilcoxon Signed Rank Test

Pair	Rank 1	Rank 2	Sign	Diff.	Signed-Rank
1	1	27	-	26	-8
2	2	1	-	1	-1
3	3	25	+	22	6
4	4	3	-	1	-1
5	5	2	-	3	-5
6	6	7	+	1	1
7	7	72	+	65	9
8	8	126	+	116	10
9	9	32	+	23	7
10	10	9	-	1	-1
				$\bar{r}$ =	1.7
				z =	0.61
				two-tailed p =	0.35
				Reject Null =	No

Only those segments that ranked in the 'Top 20' of one of the four ranking methods (Table 4.7) were included in the analysis. The results (see Table 4.9) showed that the zonal RQC and statewide RQC ranks were not significantly different from one another at the 95% level of confidence (n = 49, Z = -0.190, p = 0.849). The zonal RQC method, however, was statistically different than both the statewide rate method and the frequency method (Z = -2.308, p = 0.021). Likewise, the statewide RQC method was statistically different from the statewide rate method (Z = -2.339, p = 0.019).

Table 4.9: Results of Wilcoxon Signed Rank Test (p=0.05)

Model	N	Results (Z, p)	Sig. (Y/N)
Zonal RQC – Statewide RQC	49	z = –0.190, p = 0.849	N
Zonal RQC – Statewide Rate	49	z = –2.308, p = 0.021	Y
Zonal RQC - Frequency	49	z = –2.308, p = 0.021	Y
Statewide RQC – Statewide Rate	49	z = –2.339, p = 0.019	Y
Statewide RQC - Frequency	49	z = –1.856, p = 0.064	N
Statewide Rate - Frequency	49	z = –0.637, p = 0.524	N

It should be noted that despite several of the ranking methods not being statistically different from each other, there still exists compelling evidence to closely review the methods used to prioritize high crash sites. Reviewing Table 4.7 shows that if one were to consider the Top 10 sites using the zonal RQC method, five of the sites would be completely different than using the statewide RQC method. Likewise, a review of the Top 20 sites using either of these methods would result in a list with eight non-concurrent sites (appearing on one list, but not the other). Clearly, while the methods were not statistically different, using either the statewide RQC or zonal RQC methods resulted in non-trivial differences in priority lists. These differences are great enough to warrant a recommendation for the zonal RQC method based on its theoretical appeal.

4.6 SUMMARY

This chapter considered several methods for ranking speed/ice crashes, including statewide frequency, statewide rate, statewide rate quality control and a zonal rate quality control using nine climate zones. For each method, the Top 20 identified sites were identified and a map showing the location was presented. A comparison of the methods showed that the rate method produced the list that had the least in common with other methods and that the frequency method, although simple, did identify sites that were flagged by the more complex methods. While the Wilcoxon Signed Rank Test did not reveal any statistical difference between the zonal and statewide RQC methods, the zonal ranking method was identified as the preferred method because of its theoretical appeal. In the next chapter, the link between road geometry and speed/ice crashes will be explored.

5.0 CASE STUDY OF SECTIONS IDENTIFIED BY SCREENING

Countermeasures pertaining to speed were addressed in Chapter 2; however, countermeasures pertaining to speed/ice crashes were not addressed. Thus, this chapter starts with a review of possible speed/ice crash countermeasures. This chapter then presents a review of the top 20 crash sites identified by the climate zonal rate quality control (RQC) method. Included in the profile of each crash site is a recommendation of countermeasures which could be employed to reduce the frequency and severity of speed/ice related crashes. Supplemental aerial photographs and ODOT digital video log images are included to help illustrate roadway geometry.

A wealth of research has consistently shown that certain environmental and roadway characteristics are important to consider in countermeasure selection procedures (*Strathman, et al. 2001*; *Strathman, et al. 2003*). Adverse weather conditions, sharp curves, steep grades, narrow shoulder width, and relatively high posted speed limits can all contribute to the number of crashes in a particular location. Understanding which combinations of variables are at play at a particular location is vital to determining the optimal countermeasure for use at that site.

5.1 SPEED/ICE CRASH COUNTERMEASURES FOR IDENTIFIED LOCATIONS

As shown in the previous chapters, there are a number of roadway and environmental variables that are strongly correlated with crash sites with a high frequency of speed/ice related crashes. Speed/ice countermeasures which pertain to these roadway and environmental variables are introduced. The list is not meant to be exhaustive, but rather suggestive of the types of improvements that might be considered for each of identified top 20 crash sites, building on those presented in Chapter 2.

5.1.1 Automated ice warning systems

In icy conditions, it may be appropriate to consider designing an automated ice warning system that can give a dynamic warning to motorists when conditions are sufficient for ice formation. In this system, a Road Weather Information System (RWIS) is utilized in which pavement temperature and other weather sensors, or Environmental Sensor Stations (ESS), collect data to accurately predict the formation of ice. If the risk of ice formation is detected, a message is transmitted to be displayed on a DMS, and/or a simple flashing beacon is activated by sensor technology. Response messages are also communicated to motorists via the internet.

An automated ice warning system was installed in Idaho on a 100 mile high-crash section of Interstate 84. Sensors with forward-scatter detection technology and other ESS were employed to measure visibility distance, wind strength, and pavement conditions. Warning messages were then displayed for motorists on DMS when sensors detected snowfall and pavement readings beyond a certain threshold. In an eight year evaluation period, crashes were reduced by 35% (*Lynette 2003*).

In Washington a warning system was installed at a 40-mile section of highway in the Cascade Mountains through Snoqualmie Pass, where winter crash rates were four times the annual average. The system consisted of ESS, radar vehicle detectors, DMS, and VSL signs. Weather conditions, such as temperature and humidity were detected and sent to a central computer system. This data was processed and safe speed limits and messages were communicated to alert motorists on DMS and VSL signs. Average speeds were reduced by up to 13% (*Lynette 2003*).

5.1.2 Automated anti-icing systems

In locations where ice routinely forms, automated anti-icing systems are a possible solution. Although anti-icing systems are installed on all types of roadways, they are typically installed on bridges. Moisture on bridge pavements tends to freeze prior to other sections of roadway due to the additional exposure from air blowing underneath the bridge. Anti-icing systems consist of liquid chemical sprays or frost-suppression chemicals. When applied to the roadway, the chemical works with the roadway to reduce the amount of freezing moisture and prevent ice from bonding to the pavement. Anti-icing systems are viewed as advantageous to winter maintenance operations, because the chemicals used are usually environmentally less toxic and do not act as a harmful abrasive to vehicles and the roadway. Also, because the system is automatic, it responds quickly once pavement and weather condition thresholds are met.

An automated anti-icing system was installed in 1999 on an elevated bridge in Minnesota. Moisture on the Interstate 35 bridge from the Mississippi River below and the nearby St. Anthony Falls was prone to freezing during the winter months. With the high volume of traffic on the bridge, the crash rate on the bridge was high. To reduce the crash rate and relieve crash-related congestion, an automated anti-icing system was installed. An illustration this system is shown in Figure 5.1. A total of 68 nozzles were embedded at points along the center of each of the eight lanes. Environmental sensor stations (ESS) were also embedded in the road to measure pavement temperature and precipitation. When environmental sensors detected wet pavement conditions, anti-icing potassium acetate was automatically sprayed onto the pavement. In addition, flashing beacons were automatically activated at bridge approach ramps to alert motorists. At the end of the winter season, water was sprayed on the pavement to clean off chemical residues. After the first year of installation, crashes in winter had been reduced by 68%. The benefit/cost ratio was 3.4 (*Johnson 2001*). A similar system and study was conducted in Utah, resulting in a 64% reduction in the number of accidents (*Khattak and Pesti 2003*).

A cost/benefit analysis was conducted by Robert Stowe of the Washington State Department of Transportation for various ITS systems on Interstate 90 near Vantage, Washington. Prior to installation, 19 accidents occurred within a three-year period (1994 – 1997), with 10 of the 19 accidents occurring in the winter. An automated anti-icing system and RWIS were installed. The RWIS monitored weather conditions, roadway surface temperature, and the presence and concentration of the chemical on the roadway. The cost benefit analysis included project costs ($599,500), operations and maintenance costs ($32,800 per year), safety benefits, collision costs, and service life / salvages value. The cost benefit analysis resulted in a ratio of 2.36 in favor of benefits. Net benefits totaled $1,179,274 (*Stowe 2001*).

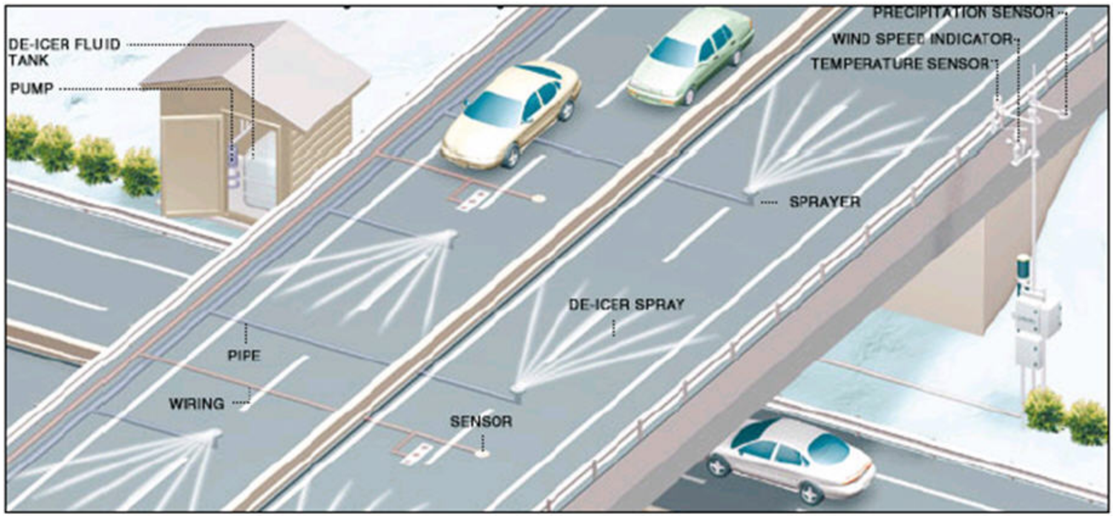


Figure 5.1: Minnesota automated anti-icing system - I-35

5.1.3 Pavement heating

In particularly troublesome locations, a transportation agency may consider heating the pavement to prevent ice from either forming or bonding to the pavement. Typically used for steep residential or commercial driveways, pavement heating or snowmelting systems can be utilized on public sidewalks and other heavy pedestrian areas, roadways and bridges. Snow melts when water/steam or antifreeze, such as a glycol solution, is heated by a heat exchanger and circulated through a closed plastic piping system placed within or below the roadway. The purpose of the antifreeze is to prevent freeze damage to the piping system (*Lund 2000*). Another pavement heating system involves the use of copper cables heated under the roadway.

Pavement heating has been used in many parts of the world and is not a new technique. In Klamath Falls, Oregon, a geothermal pavement heating system was installed in 1948 on a 450-foot long section of Esplanade Street. The ground remained clear in snowfall and in temperatures down to -10° F. In 1969, an antifreeze pavement heating system was used in Trenton, New Jersey with snow melting success rates of ¼ to ½ inches per hour when temperatures were between 20 and 35° F. In 1998 geothermal steam was used to heat streets in Argentina. The temperature of the roadway was raised from 10° F to 51°-60° F (*Lund 2000*).

A more recent installation by ODOT is on I-84 near one of the locations identified in the screening method. As part of the Ladd Creek Bridge deck project heating wires were installed in the eastbound Ladd Creek Bridge deck near mile point 270.8 (see Figure 5.2). Heating wires continue along the eastbound right lane to match truck wheel tracks, ending near the top of the vertical grade near mile point 272. According to ODOT[5], "the heating system is not designed to keep the freeway completely free of ice and snow, but it should reduce incidences of black ice

[5] http://www.oregon.gov/ODOT/HWY/REGION5/ladd_canyon_heating.shtml

when the air and roadbed are at near freezing temperatures. As the temperature drops, the heating system will loose its effectiveness and automatically shut off."

Figure 5.2: Pavement heating system under construction - I-84 near MP 271

A pavement heating system involving heated copper cables was installed on taxiways in 1994 at Chicago's O'Hare International Airport. Copper cables carrying an electric current were laid just below a two inch layer of conductive asphalt. Heat was generated from the current passing through the cables. The system was activated when the temperature was just above the freezing point. A cost/benefit analysis considering safety and operational factors concluded the operation as cost effective. Snow melted only 87% of the time, however. The system was later removed with reconstruction in 1998 (*Derwin, et al. 2003*).

Although none of these systems have been reported to result in a reduction in crashes, it is assumed that by removing the snow and ice off the roads, the potential for crashes is greatly reduced.

5.1.4 Horizontal curvature realignment

A long-term and costly way to improve the safety of a horizontal curve is to completely realign the horizontal curvature. This technique may require the acquisition of additional right-of-way as well as an Environmental Impact Statement (EIS). There are three main methods used to realign a horizontal curve:

- Increasing the radius of the curve
- Providing spiral transition curves
- Eliminating compound curves

Increasing the radius of a horizontal curve can be effective in improving the overall safety of the curve. Zegeer, et al. showed that increasing the radius of curvature can reduce total curve-related crashes by up to 80 percent (*Zegeer, et al. 1992*). A spiral transition curve is a horizontal curve with a continuously changing radius that provides a smooth transition between a tangent section and an adjacent circular curve. Zegeer, et al. reported that spiral transition curves are also effective in reducing crashes (*Zegeer, et al. 1992*). The findings are based on studies of spiraled versus unspiraled curves in one state. Lastly, NCHRP recommends that agencies be cautious in using compound curves, particularly if the radius of the first curve is significantly greater than the radius of the following curve. This is because the abrupt change in alignment requires considerable steering effort by motorists to travel safely through the successive curves.

5.1.5 Enhanced maintenance efforts

If an engineering or enforcement solution to the speed/ice related crash problem is not available or feasible, another approach may be to enhance available maintenance efforts. Such enhancement activities often include making maintenance operations more efficient. Sections of roadway or bridges can be identified through such systems as RWIS or Maintenance Decision Support Systems (MDSS), where road treatment recommendations are made based on weather patterns and predictions. In these sections, operations can facilitate maintenance operations ahead of snowfall, such as having trucks ready for de-icing, sanding, or plowing in these select areas. In the anti-icing process, applications of de-icing material can be made in higher concentrations or more frequently in hazardous locations than elsewhere. Another method is to remove trees or other features that provide shade and enable ice or snow to stay in locations longer than others, thereby removing the risk of a crash event.

5.2 PRELIMINARY INVESTIGATION OF IDENTIFIED SECTIONS

For each of the top 20 sections identified by the zonal rate quality control method, a detailed profile sheet was prepared. Each one presents a vicinity map showing the general location in the state, an aerial photograph illuminating the general horizontal alignment of the section of the section (ranked section is highlighted red), the mile point location of all speed/ice related crashes, and a number of summary variables about each section. The following sections briefly review the top 20 sites, located on five key highways (OR-58, I-84, OR-35, US-26, and I-5), discussing possible speed/ice crash countermeasures for each. Table 5.1 provides a summary of the possible countermeasures for the identified sites, sorted by route.

5.2.1 I-5

Two one-mile sections on I-5 were identified that cover milepost 5-7. These sections were not identified by any of the other methods so it appears that they are unique in that they exceed the average crash rate for other roadways in their climate zone. The sections have similar geometry, weather (<5 days with snowfall) and number of crashes (nine and ten, respectively). Both sections also have a long downgrade in the northbound direction. It appears that variable speed limits, automated enforcement, automated ice warning systems, and focused priority maintenance are countermeasures that should be considered.

5.2.2 I-84

Five one-mile sections of I-84 were identified by the network screening method. The five sections are essentially in two locations. The first group, sections (3) and (9) cover milepost 228-230. Both sections are in the Northeast climate zone, but each experiences a different number of mean annual days with snowfall. This may indicate that these sections are in an elevation transition area, and there may be some tendency for drivers to not expect snow or icy conditions. Given that the geometry does not appear to be a problem, these sections might benefit from automated ice warning systems, variable speed limits, or priority maintenance activities. If speed is consistently a problem, traditional enforcement should also be considered. The next three sections ranked (10), (18), and (6) cover mileposts 270-275. Interestingly, the eastbound section near milepost 271 was treated with pavement heating technology in the truck lanes. Additional countermeasures to be considered could include variable speed limits (based on weather) and priority maintenance activities.

5.2.3 OR-35

Six one-mile sections were identified by the screening method on OR-35. They cover from milepost 58 to 66 and another section at milepost 74-75. These sections are very similar in weather (>60 days of snow), curvature, and volume. Milepost 58-63 carries the majority of traffic using the Mt. Hood Meadows Ski Resort (near milepost 64); this volume of traffic is a possible reason for the large number of speed/ice related crashes on the roadway section. Given the amount of snowfall, automated anti-icing or pavement heating countermeasures are not an option. In the winter months there are limited shoulders or other locations for traditional enforcement. Variable speed limits, automated enforcement, or focused priority maintenance may be the only available countermeasures.

5.2.4 OR-58

Four one-mile sections on OR-58 were identified by the screening method. The highest ranked section (1) is at milepost 24-25. As shown in the aerial photograph on page 69, all of the speed/ice related crashes occurred at the southern end of the water feature. This section is in the Willamette Valley climate zone and is ranked high because ice related crashes are not common in this zone. As shown in Figure 4.8, no other speed/ice related crashes occurred in adjacent sections. One might surmise that the additional moisture from the water leads to ice formation on the roadway. This section might be a candidate for variable speed limit systems, automated ice warning systems, or priority maintenance activities. Because crashes seem to be clustered in a relatively short segment, this section may also be a candidate for automated pavement heating, if the experiment on I-84 proves successful.

The sections ranked (14) and (7) cover mile points 37-38 and 40-41. Rank 14 is in the Willamette Valley climate zone but section (7) is in the Cascade climate zone. The sections do not have unusual horizontal curves or other features that would suggest that substantial changes are required to the alignment. However, the crashes are clustered along curves. These sections might be candidates for automated ice warning systems, priority maintenance activities, or additional traditional enforcement. Finally, section (5) had a number of crashes directly related to a relatively sharp horizontal curve (also coupled with vertical grade). This site is in the

Cascade climate zone and experiences greater than 60 days with snowfall. As such, drivers should have an expectation of winter weather conditions, and speed too fast for conditions is the likely cause of many crashes, rather than unexpected ice or snow. This section may be a candidate for variable speed limits (based on weather), additional traditional enforcement, and priority maintenance activities. In addition, from the digital video log it appears that this section may benefit from additional static warning devices such as chevrons.

5.2.5 US-26

Two one-mile sections were identified by the screening method on US-26. Section (8) is at a lower elevation where the Mt. Hood Highway is a 4-lane section, is on a tangent, and experiences a few days of snow (<10). The authors have observed that the speeds in this section can be well above the posted limit of 55 mph. Again, drivers may not be expecting icy conditions as they begin their ascent up Mt. Hood or are coming down from more winter-like conditions. As such, variable speed limits (based on weather), automated or traditional enforcement or priority maintenance may be suitable countermeasures. On section (19) there is a notable horizontal curve, is very often snowy (>60 days), and is a 4 to 3-lane section. It appears that additional static warning signs (for curve), variable speed limits, automated enforcement, or focused priority maintenance may be the only available countermeasures. In the long term, curve realignment might be considered.

Table 5.1: Summary of possible countermeasures for identified sites (sorted by route)

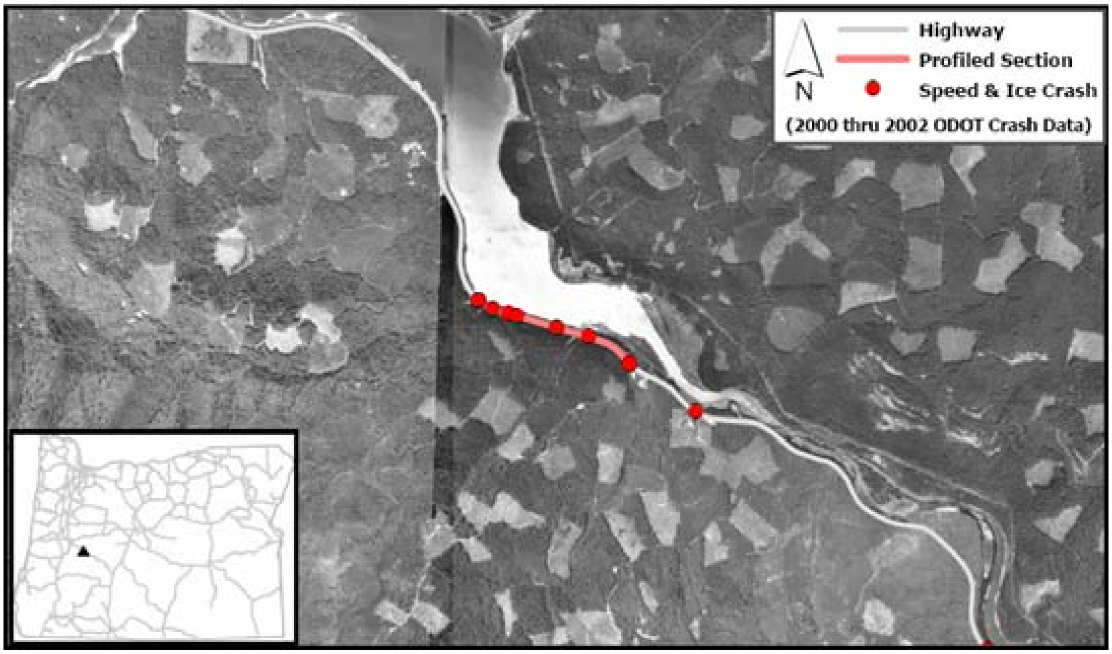
Site	Route	County	MP From	MP To	Additional Static Warning Signs	Variable Speed Limit Systems	Automated Anti-Icing Systems	Pavement Heating	Curve Realignment	Automated Ice Warning	Priority Maintenance	Increased Traditional Enforcement Activities	Automated Enforcement
11	I-5	Jackson	5	6		X				X	X		X
17	I-5	Jackson	6	7		X				X	X		X
3	I-84	Umatilla	228	229		X				X	X	X	
9	I-84	Umatilla	229	230		X				X	X	X	
10	I-84	Union	270	271		X		X			X		
18	I-84	Union	273	274		X		X			X		
6	I-84	Union	274	275		X		X			X		
12	OR-35	Clackamas	58	59		X					X		X
20	OR-35	Clackamas	59	60		X					X		X
4	OR-35	Hood River	60	61		X					X		X
2	OR-35	Hood River	61	62		X					X		X
12	OR-35	Hood River	62	63		X					X		X
15	OR-35	Hood River	65	66		X					X		X
15	OR-35	Hood River	74	75		X					X		X
1	OR-58	Lane	24	25		X	X	X		X	X		
14	OR-58	Lane	37	38						X	X	X	
7	OR-58	Lane	40	41						X	X	X	
5	OR-58	Lane	59	60	X	X					X	X	
8	US-26	Clackamas	32	33		X					X	X	X
19	US-26	Clackamas	51	52	X	X			X		X		X

Zonal Rank 1

OR 58, MP 24 - 25

Statewide Rank: 27
Speed & Ice Crashes: 11
MVMT: 6.68
Crash Rate: 1.65
Crash Rate Rank: 175
Zonal Exceedance: 504%

Number of Lanes: 2
Pavement Width (ft): 30
Maximum Central Curve Angle (degrees): 65
Mean Annual Days with Snowfall > 0.1 inch: 2.5 – 5.4

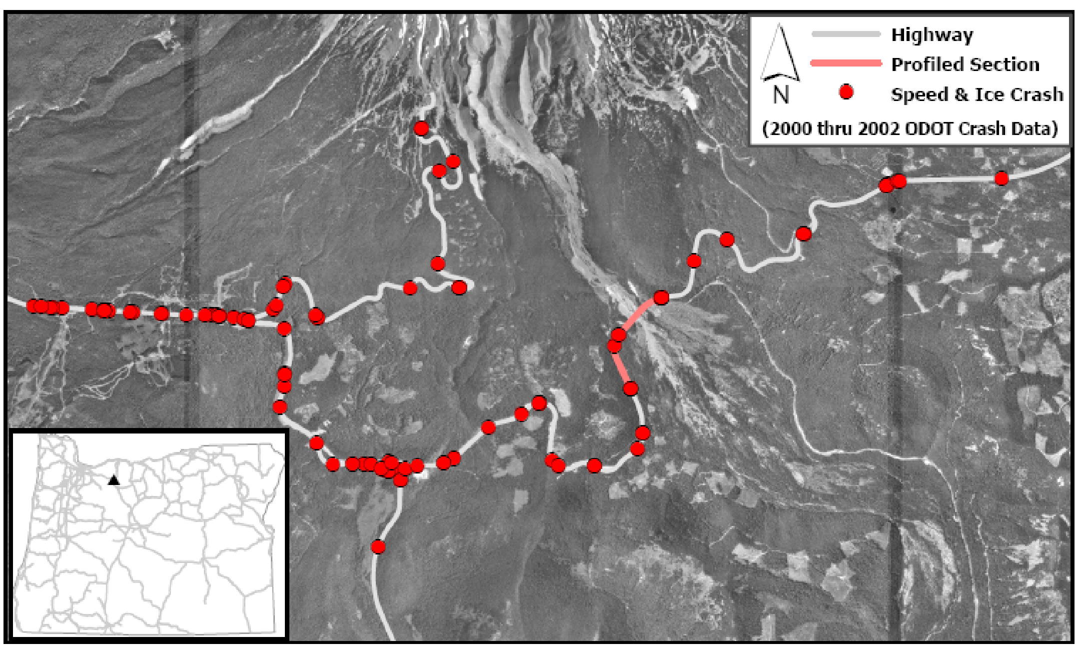


Zonal Rank 2

OR 35, MP 61 - 62

Statewide Rank: 1
Speed & Ice Crashes: 16
MVMT: 1.97
Crash Rate: 8.12
Crash Rate Rank: 2
Zonal Exceedance: 498%

Number of Lanes: 2
Pavement Width (ft): 38
Maximum Central Curve Angle (degrees): 55
Mean Annual Days with Snowfall > 0.1 inch: >60.4

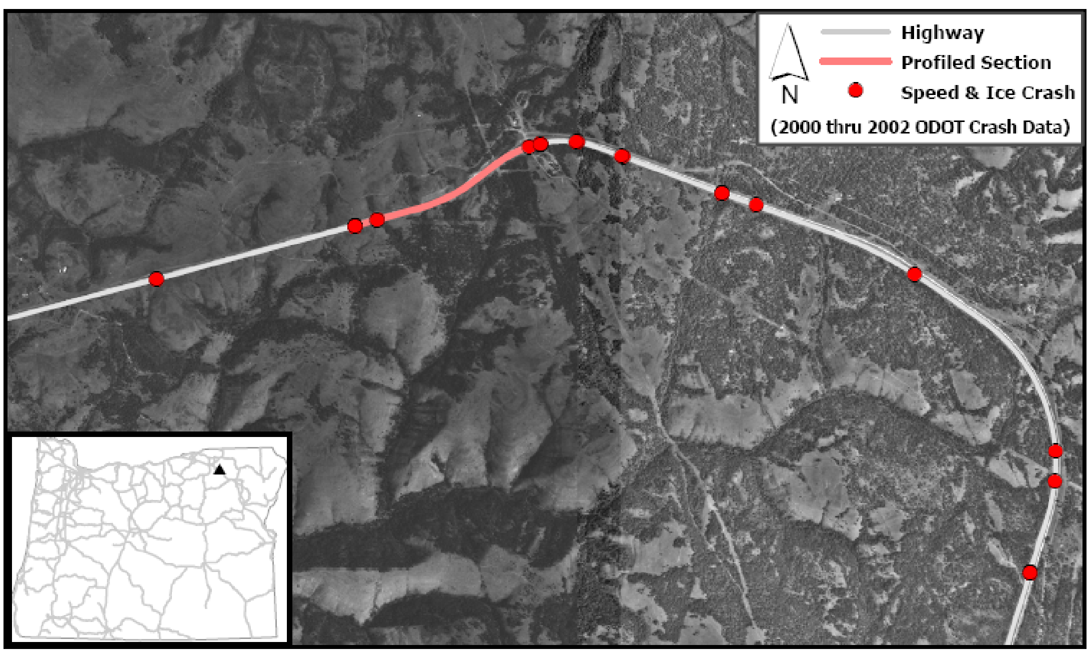


Zonal Rank 3

I-84, MP 228 - 229

Statewide Rank: 25
Speed & Ice Crashes: 16
MVMT: 10.84
Crash Rate: 1.48
Crash Rate Rank: 201
Zonal Exceedance: 315%

Number of Lanes: EB 2, WB 2
Pavement Width (ft): EB 37, WB 40
Maximum Central Curve Angle (degrees): EB 50, WB 50
Mean Annual Days with Snowfall > 0.1 inch: 20.5 – 30.4

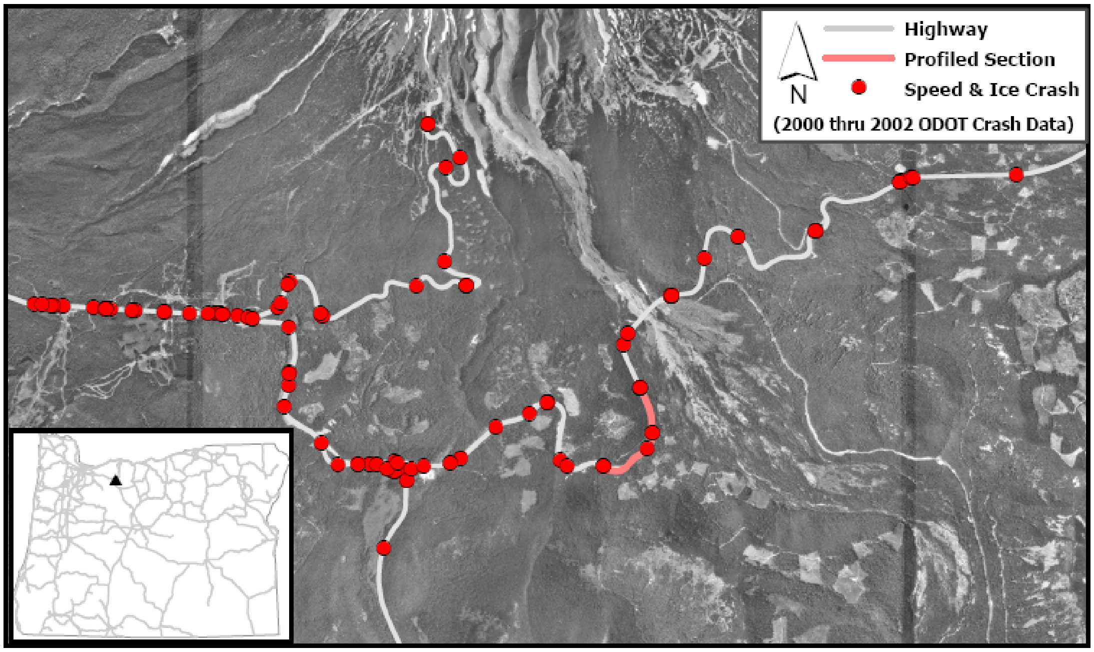


Zonal Rank 4

OR 35, MP 60 - 61

Statewide Rank: 3
Speed & Ice Crashes: 11
MVMT: 1.97
Crash Rate: 5.58
Crash Rate Rank: 5
Zonal Exceedance: 311%

Number of Lanes: 2
Pavement Width (ft): 38
Maximum Central Curve Angle (degrees): 46
Mean Annual Days with Snowfall > 0.1 inch: >60.4

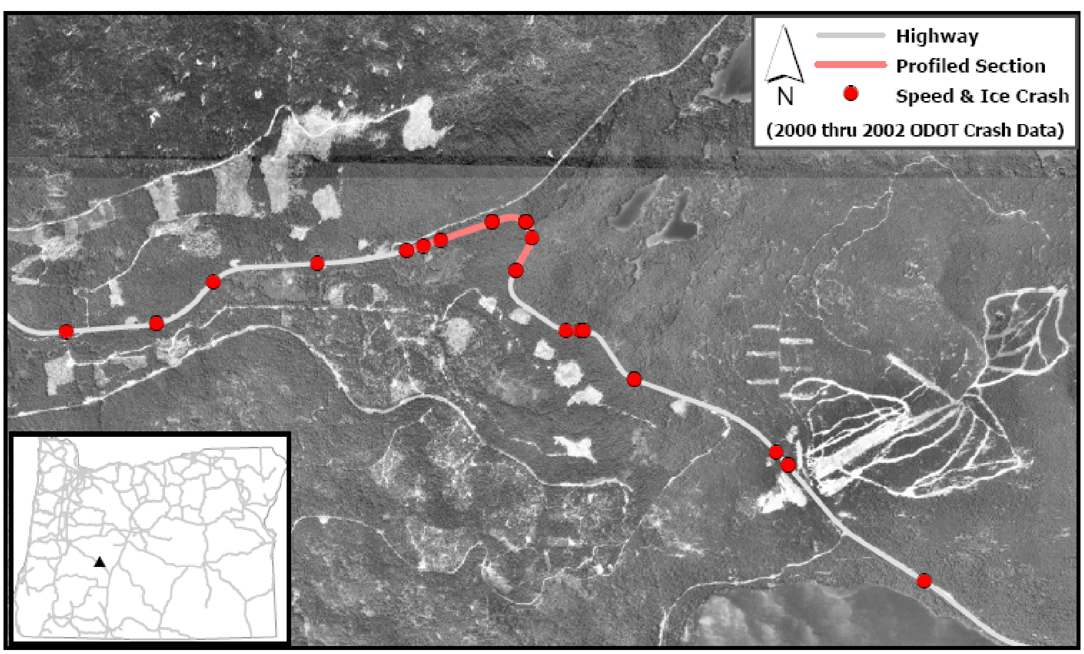


Zonal Rank 5

OR 58, MP 59 - 60

Statewide Rank: 2
Speed & Ice Crashes: 14
MVMT: 3.18
Crash Rate: 4.41
Crash Rate Rank: 15
Zonal Exceedance: 298%

Number of Lanes: 2
Pavement Width (ft): 32
Maximum Central Curve Angle (degrees): 99
Mean Annual Days with Snowfall > 0.1 inch: >60.4

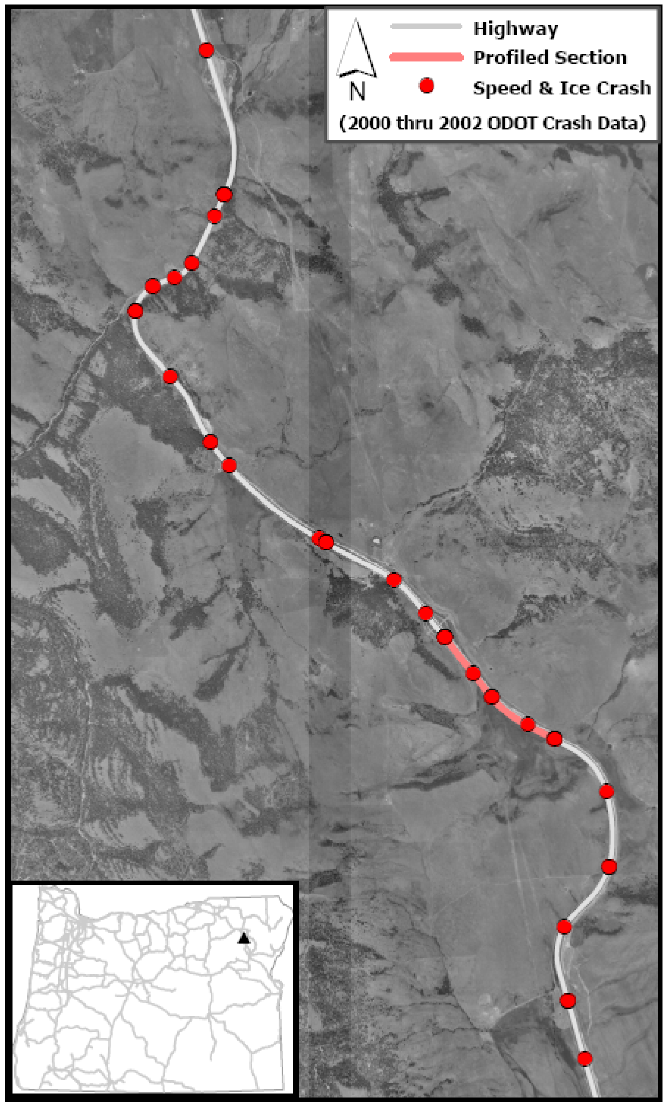


Zonal Rank 6

I-84, MP 274 - 275

Statewide Rank: 7
Speed & Ice Crashes: 21
MVMT: 9.75
Crash Rate: 2.15
Crash Rate Rank: 82
Zonal Exceedance: 275%

Number of Lanes: EB 2, WB 2
Pavement Width (ft): EB 38, WB 38
Maximum Central Curve Angle (degrees): est EB 20, est WB 20
Mean Annual Days with Snowfall > 0.1 inch: 20.5 – 30.4

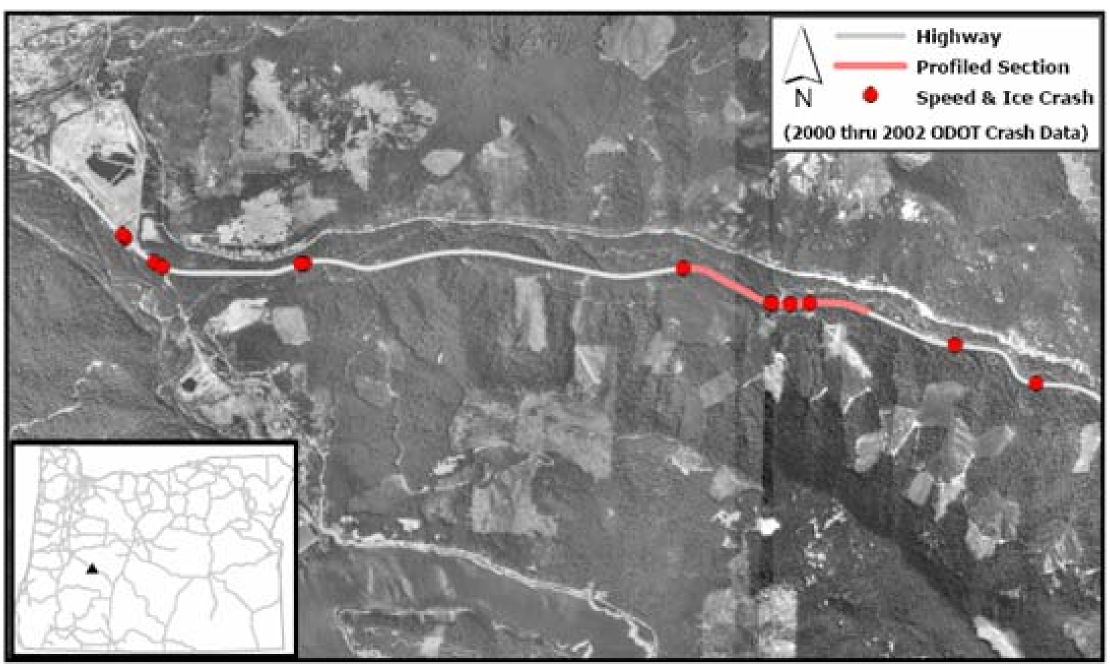


Zonal Rank 7

OR 58, MP 40 - 41

Statewide Rank: 72
Speed & Ice Crashes: 5
MVMT: 3.18
Crash Rate: 1.57
Crash Rate Rank: 185
Zonal Exceedance: 274%

Number of Lanes: 2
Pavement Width (ft): 32
Maximum Central Curve Angle (degrees): 22
Mean Annual Days with Snowfall > 0.1 inch: 10.5 – 15.4

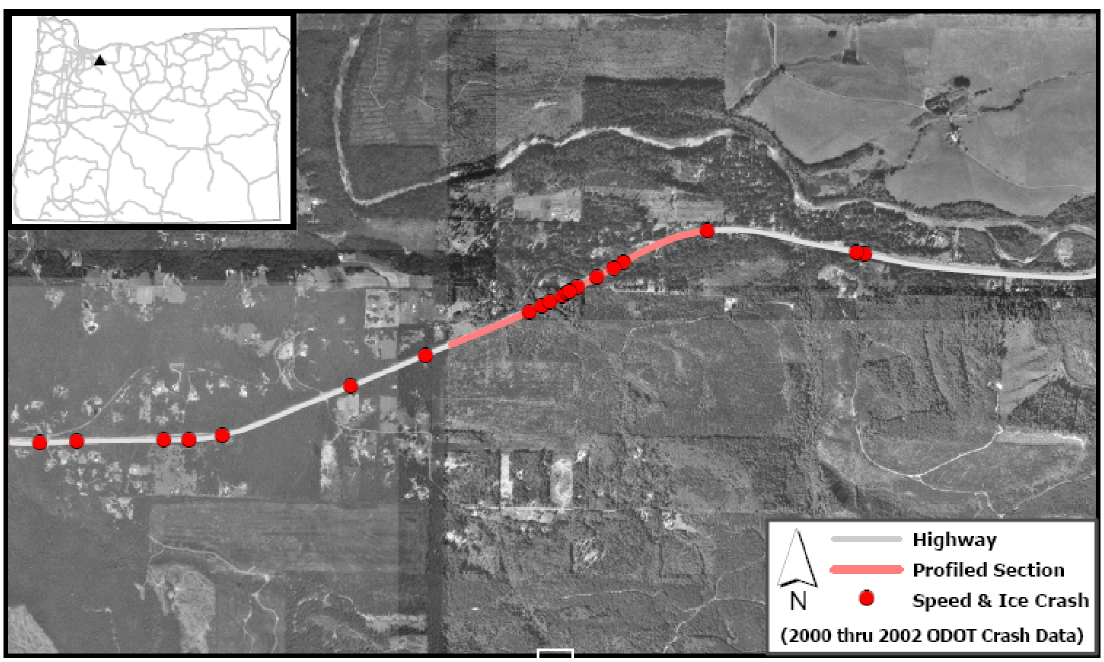


Zonal Rank 8

US 26, MP 32 - 33

Statewide Rank: 126
Speed & Ice Crashes: 11
MVMT: 17.19
Crash Rate: 0.64
Crash Rate Rank: 583
Zonal Exceedance: 272%

Number of Lanes: 4
Pavement Width (ft): 68
Maximum Central Curve Angle (degrees): 5
Mean Annual Days with Snowfall > 0.1 inch: 5.5 – 10.4

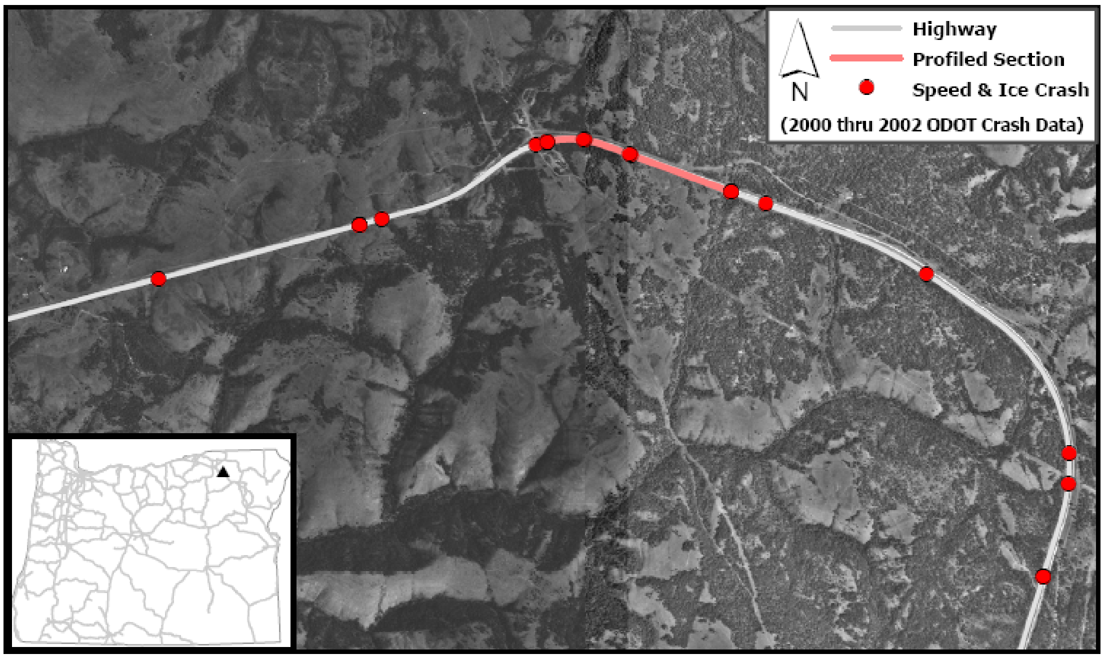


Zonal Rank 9

I-84, MP 229 - 230

Statewide Rank: 32
Speed & Ice Crashes: 14
MVMT: 10.40
Crash Rate: 1.35
Crash Rate Rank: 233
Zonal Exceedance: 272%

Number of Lanes: EB 2, WB 2
Pavement Width (ft): EB 32, WB 40
Maximum Central Curve Angle (degrees): EB 50, WB 50
Mean Annual Days with Snowfall > 0.1 inch: >60.4

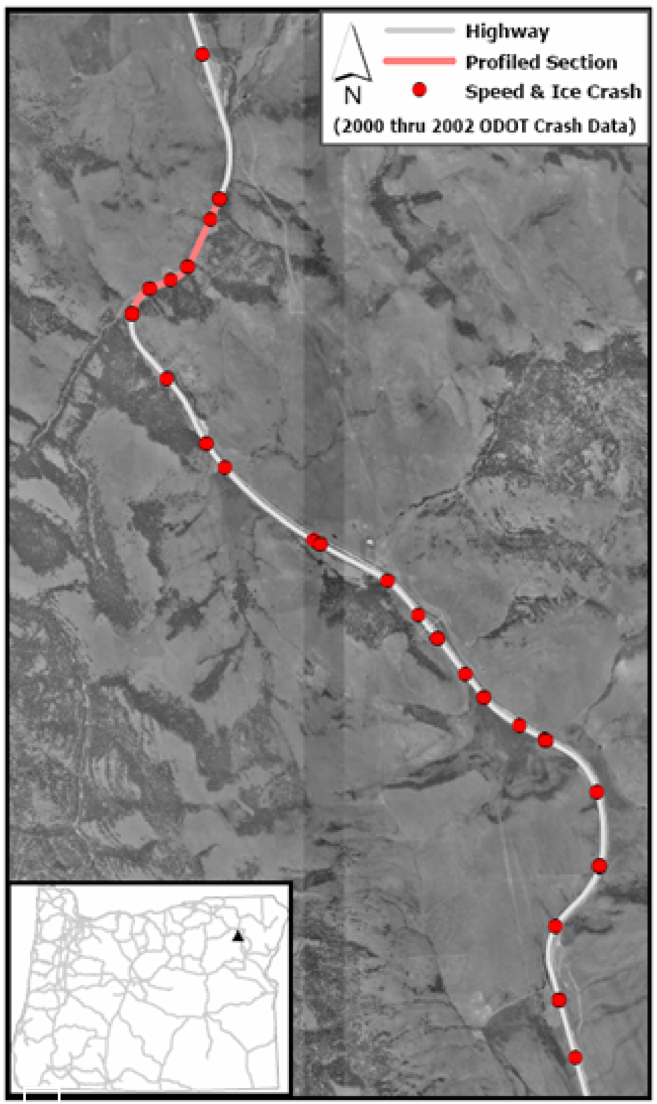


Zonal Rank 10

I-84, MP 270 - 271

Statewide Rank: 9
Speed & Ice Crashes: 20
MVMT: 9.75
Crash Rate: 2.05
Crash Rate Rank: 102
Zonal Exceedance: 257%

Number of Lanes: EB 2, WB 2
Pavement Width (ft): EB 41, WB 38
Maximum Central Curve Angle (degrees): EB 87, WB 87
Mean Annual Days with Snowfall > 0.1 inch: 15.5 – 20.4

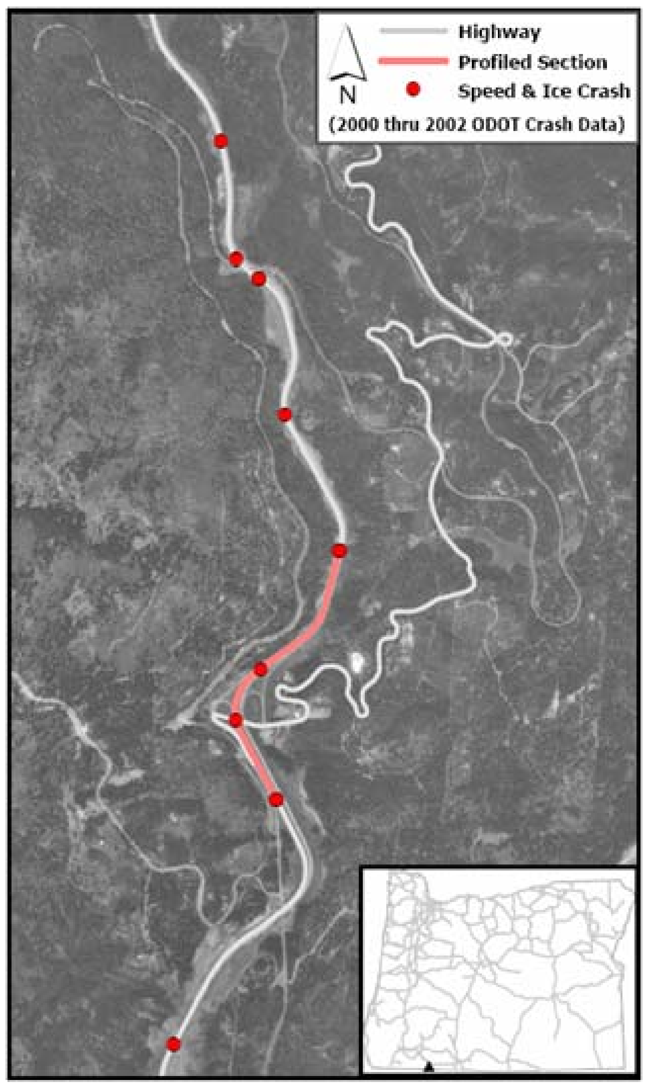


Zonal Rank 11

I-5, MP 5 - 6

Statewide Rank: 129
Speed & Ice Crashes: 10
MVMT: 15.22
Crash Rate: 0.66
Crash Rate Rank: 552
Zonal Exceedance: 254%

Number of Lanes: NB 2, SB 2
Pavement Width (ft): NB 44, SB 44
Maximum Central Curve Angle (degrees): NB 38, SB 35
Mean Annual Days with Snowfall > 0.1 inch: 2.5 – 5.4

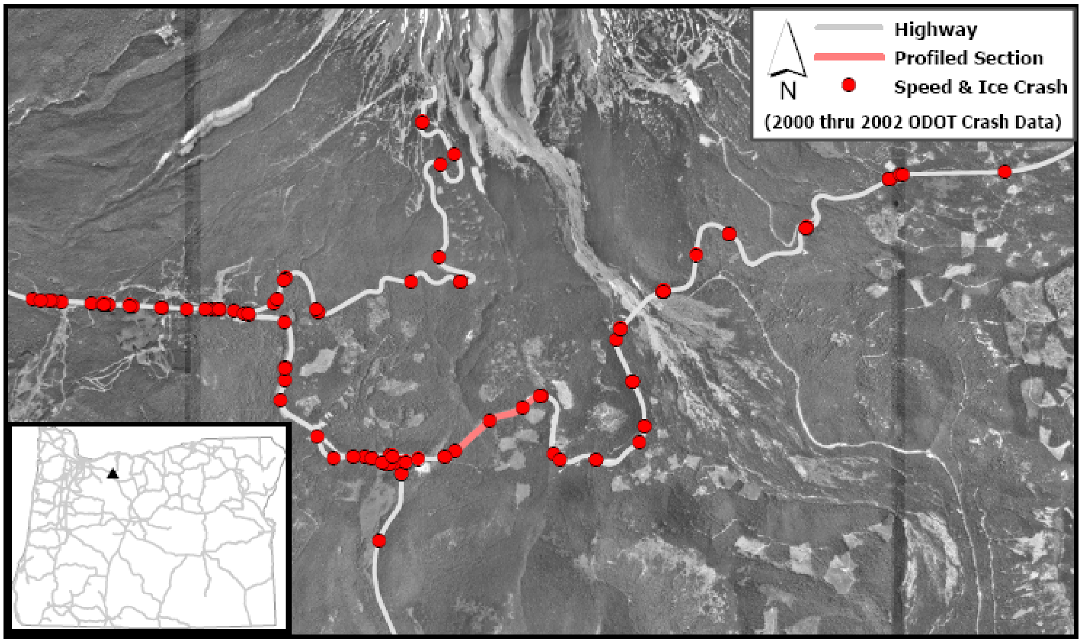


Zonal Rank T12

OR 35, MP 58 - 59

Statewide Rank: 5
Speed & Ice Crashes: 9
MVMT: 1.97
Crash Rate: 4.57
Crash Rate Rank: 13
Zonal Exceedance: 237%

Number of Lanes: 3
Pavement Width (ft): 44
Maximum Central Curve Angle (degrees): 107
Mean Annual Days with Snowfall > 0.1 inch: >60.4

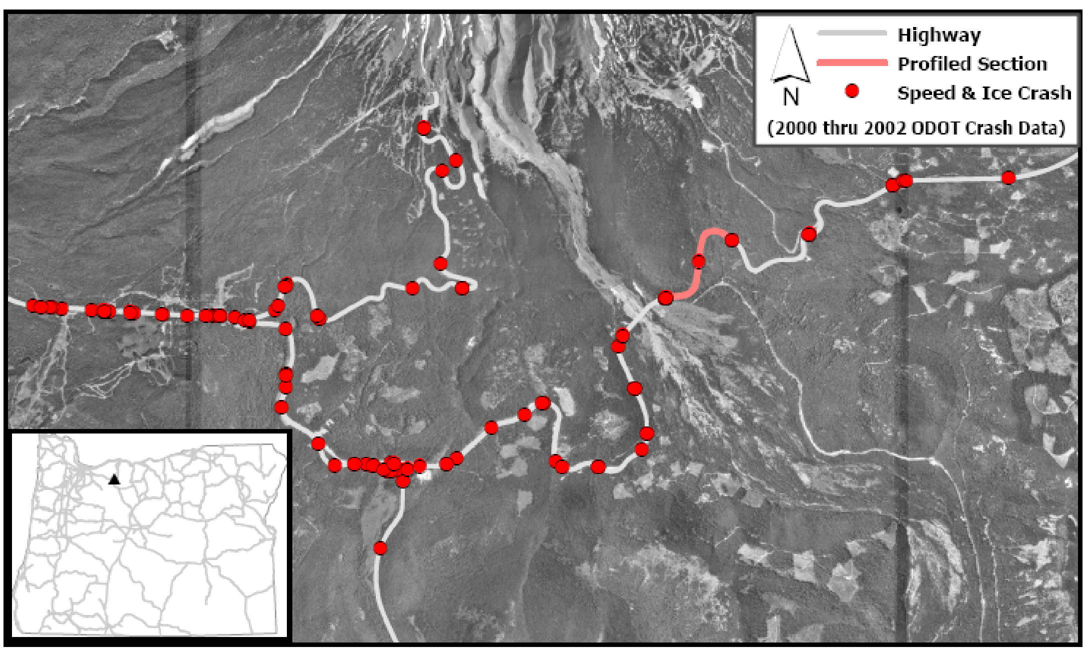


Zonal Rank T12

OR 35, MP 62 - 63

Statewide Rank: 5
Speed & Ice Crashes: 9
MVMT: 1.97
Crash Rate: 4.57
Crash Rate Rank: 13
Zonal Exceedance: 237%

Number of Lanes: 2
Pavement Width (ft): est 32
Maximum Central Curve Angle (degrees): est 100
Mean Annual Days with Snowfall > 0.1 inch: >60.4

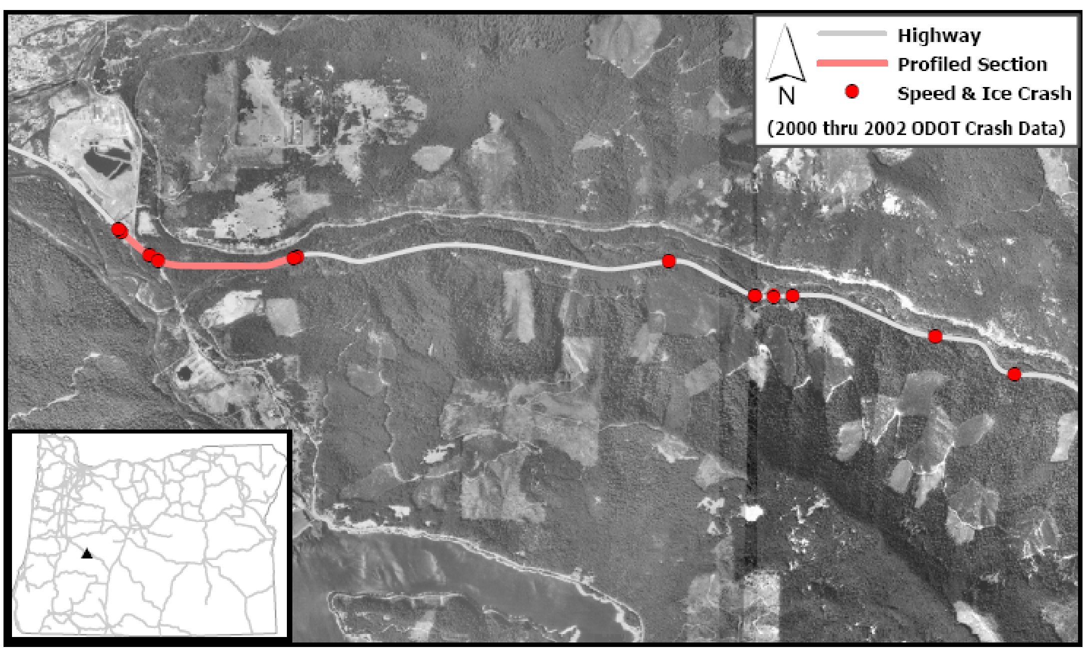


Zonal Rank 14

OR 58, MP 37 - 38

Statewide Rank: 121
Speed & Ice Crashes: 5
MVMT: 4.71
Crash Rate: 1.06
Crash Rate Rank: 317
Zonal Exceedance: 220%

Number of Lanes: 2
Pavement Width (ft): 32
Maximum Central Curve Angle (degrees): 34
Mean Annual Days with Snowfall > 0.1 inch: 5.5 – 10.4

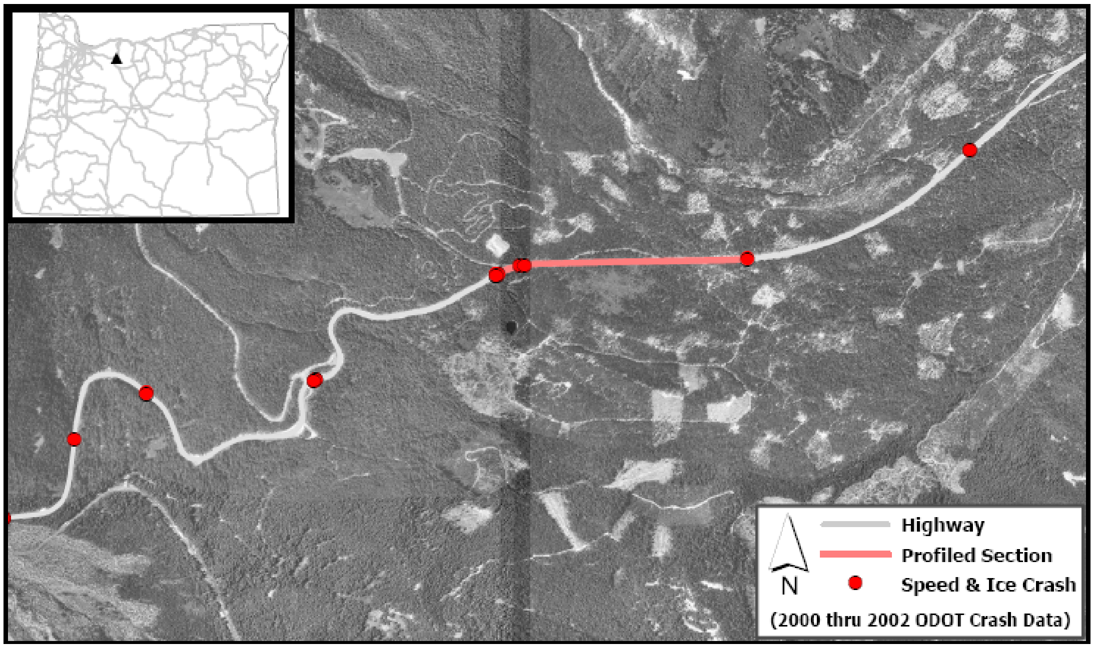


Zonal Rank T15

OR 35, MP 65 - 66

Statewide Rank: 11
Speed & Ice Crashes: 7
MVMT: 1.42
Crash Rate: 4.92
Crash Rate Rank: 11
Zonal Exceedance: 211%

Number of Lanes: 2
Pavement Width (ft): 32
Maximum Central Curve Angle (degrees): 38
Mean Annual Days with Snowfall > 0.1 inch: >60.4

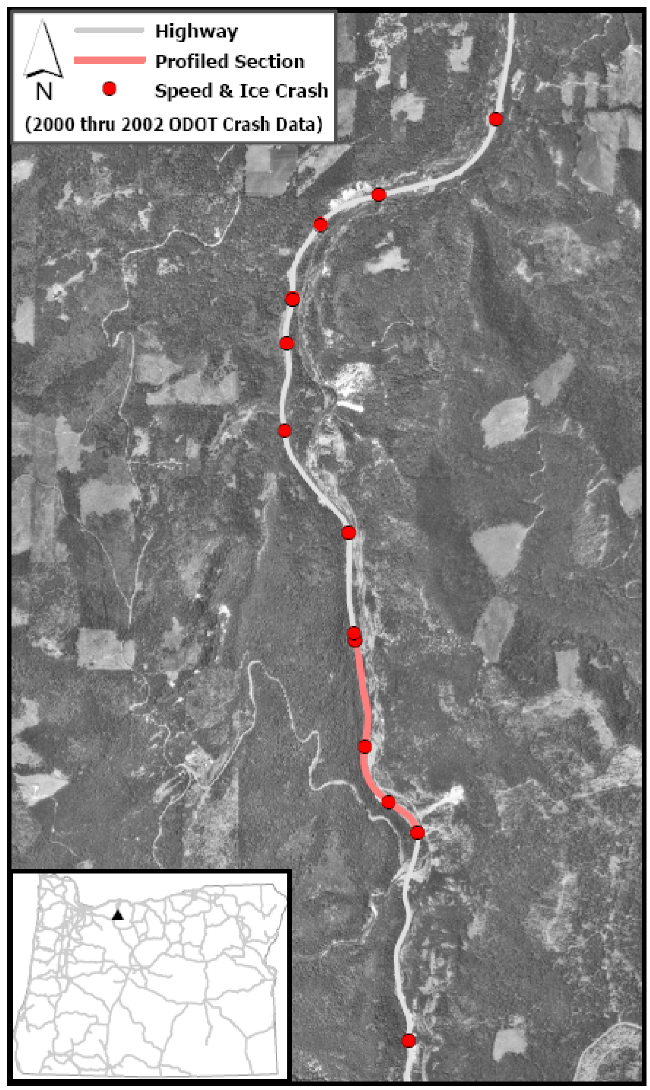


Zonal Rank T15

OR 35, MP 74 - 75

Statewide Rank: 11
Speed & Ice Crashes: 7
MVMT: 1.42
Crash Rate: 4.92
Crash Rate Rank: 11
Zonal Exceedance: 211%

Number of Lanes: 2
Pavement Width (ft): 36
Maximum Central Curve Angle (degrees): 49
Mean Annual Days with Snowfall > 0.1 inch: >60.4

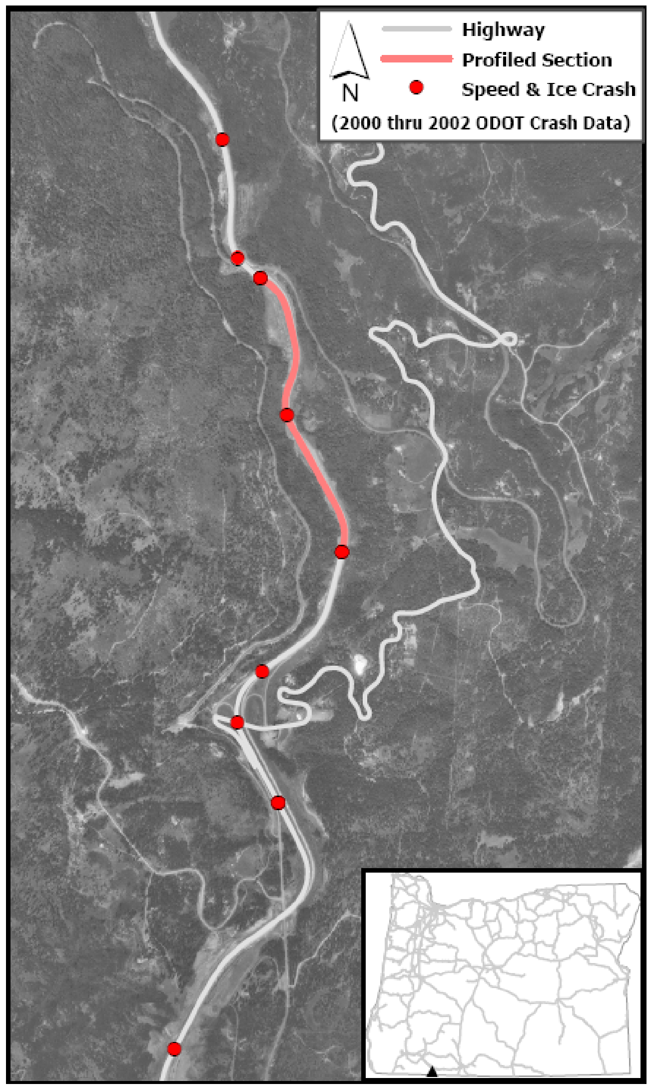


Zonal Rank 17

I-5, MP 6 - 7

Statewide Rank: 172
Speed & Ice Crashes: 9
MVMT: 16.10
Crash Rate: 0.56
Crash Rate Rank: 650
Zonal Exceedance: 208%

Number of Lanes: NB 2, SB 2
Pavement Width (ft): NB 45, SB 44
Maximum Central Curve Angle (degrees): NB 28, SB 28
Mean Annual Days with Snowfall > 0.1 inch: 2.5 – 5.4

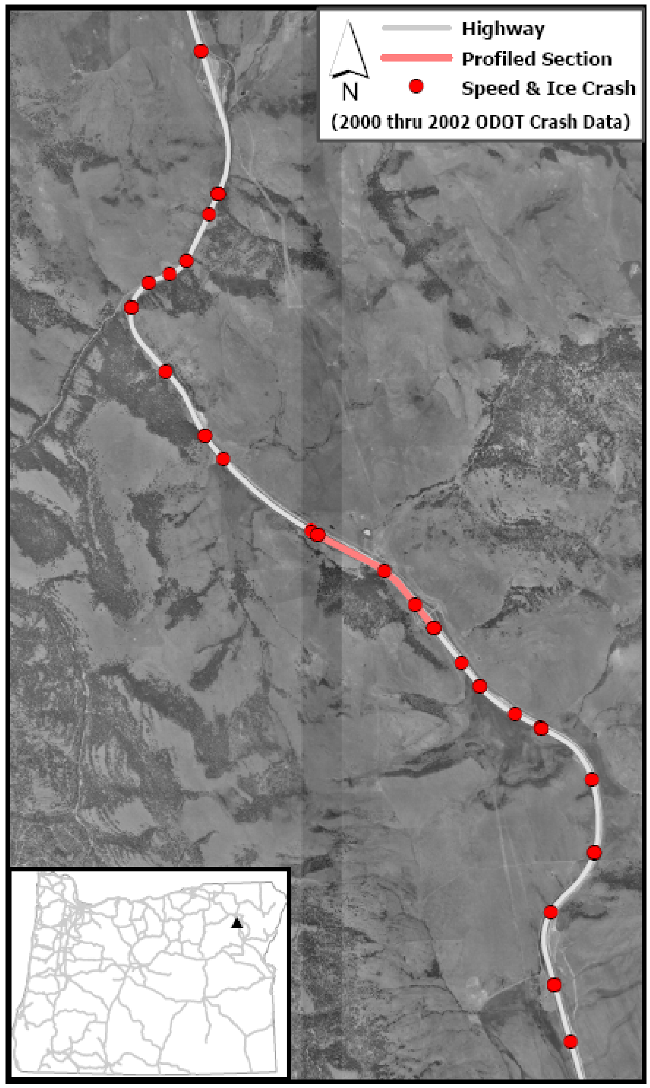


Zonal Rank 18

I-84, MP 273 - 274

Statewide Rank: 14
Speed & Ice Crashes: 17
MVMT: 9.64
Crash Rate: 1.76
Crash Rate Rank: 143
Zonal Exceedance: 206%

Number of Lanes: EB 2, WB 2
Pavement Width (ft): EB 38, WB 38
Maximum Central Curve Angle (degrees): est EB 20, est WB 20
Mean Annual Days with Snowfall > 0.1 inch: 20.5 – 30.4

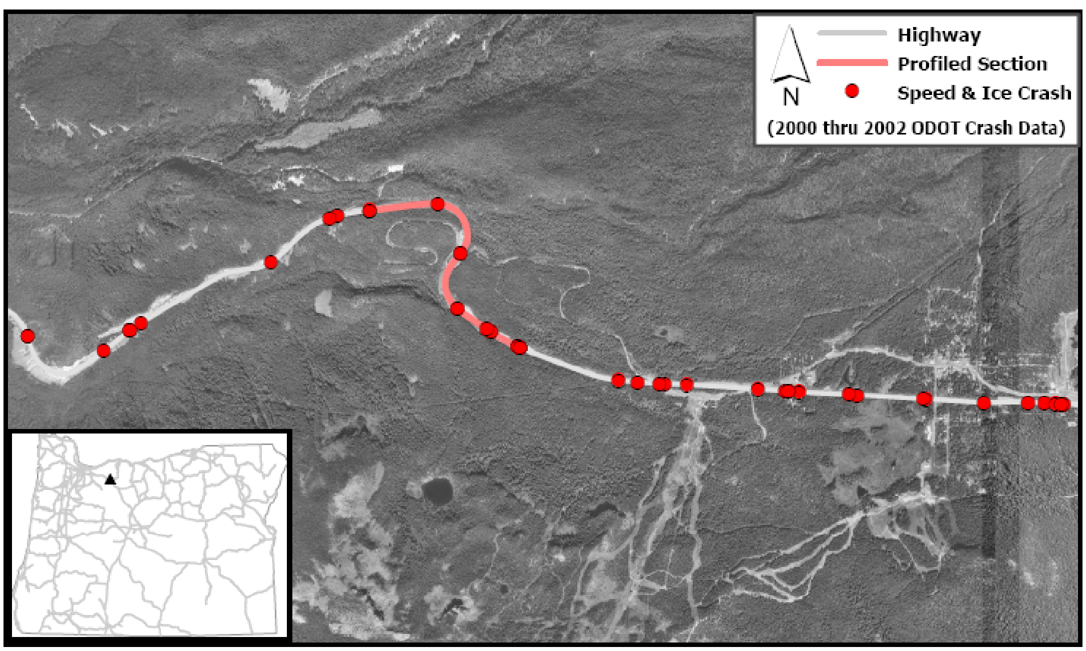


Zonal Rank 19

US 26, MP 51 - 52

Statewide Rank: 4
Speed & Ice Crashes: 20
MVMT: 8.43
Crash Rate: 2.37
Crash Rate Rank: 71
Zonal Exceedance: 201%

Number of Lanes: 4
Pavement Width (ft): 66
Maximum Central Curve Angle (degrees): 100
Mean Annual Days with Snowfall > 0.1 inch: >60.4

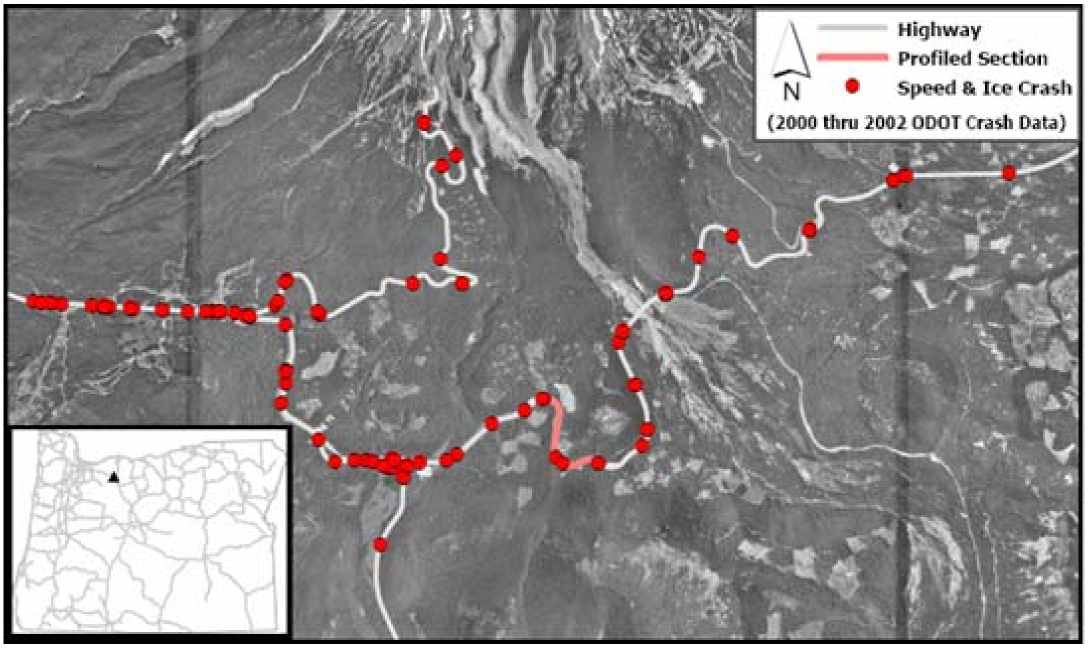


Zonal Rank 20

OR 35, MP 59 - 60

Statewide Rank: 13
Speed & Ice Crashes: 8
MVMT: 1.97
Crash Rate: 4.06
Crash Rate Rank: 21
Zonal Exceedance: 199%

Number of Lanes: 3
Pavement Width (ft): 44
Maximum Central Curve Angle (degrees): 107
Mean Annual Days with Snowfall > 0.1 inch: >60.4



5.3 SUMMARY

This chapter has presented a brief review of additional countermeasures that are available to treat ice-related crashes. They included ant-icing, ice warning, pavement heating, and priority maintenance strategies. The top 20 sections identified by the zonal ranking method were then briefly discussed, with recommendations or suggestions on preliminary speed/ice crash countermeasures. The ranking method identified sites where cost-effective countermeasures could be considered, but a more detailed analysis would be required to select the most cost-effective measures.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to improve the procedures used to select speed-related safety countermeasures and contribute toward safer roads with lower cost solutions. The study began with a detailed literature review to examine past research that focused on establishing and documenting the relationship between speed and crash occurrence. This included research that examined the impact of speed on vehicle operating characteristics, as well as studies that included very detailed post-crash investigations, in an attempt to pinpoint the key causal factors. The review included studies that examined the impacts of speed reduction techniques, including geometric modifications to roadways, traffic control devices, operations and ITS, and enforcement. The review also included a brief review of network screening techniques for safety improvements.

The study then focused on an analysis of the number of crashes of different types that occurred on the Oregon highway system during the years 2000–2002. Crash data analysis illustrated the distribution of speed-related crashes by different surface conditions, lighting conditions, weather conditions, crash severity, and collision type. An overrepresentation analysis confirmed that speed-related crashes were overrepresented under icy conditions.

Based on the conclusion that speed/ice conditions were a substantial concern for highway safety in Oregon, the research developed several methods for ranking speed/ice crashes, including statewide frequency, statewide rate, statewide rate quality control and a unique zonal rate quality control procedure using nine climate zones. For each method, the "top 20" one-mile sections were identified. A comparison of the methods showed that the rate method produced the list that had the least in common with other methods and that the frequency method, although simple, did identify sites that were flagged by the more complex methods. Although the Wilcoxon test did not reveal any statistical difference between the zonal RQC and statewide RQC, the zonal RQC method identified as the preferred method because of its theoretical appeal.

The study undertook a brief review of additional countermeasures that are available to treat ice-related crashes. They included anti-icing, ice warning, pavement heating, and priority maintenance strategies. The top 20 sites identified by the zonal RQC method were then briefly reviewed for possible countermeasures or suggestions to address speed/ice crashes. It appears that the ranking method did identify sites where cost-effective countermeasures could be considered, but a more detailed engineering analysis would be required.

6.1 RECOMMENDATIONS

The results of this analysis are promising. The more detailed zonal rate quality control method appears to have identified some sites that are notably different than similar sections based on weather and crash experience. In a few cases, sites were identified that would have escaped being flagged by a statewide ranking of sites. The method appears to have been better at identifying sites that are abnormal. In any network screening, disaggregation of data and more appropriate groupings of similar facilities will likely produce better results. These techniques could be expanded to road class, terrain type, intersection volumes, and a number of safety categorizations. ODOT should consider enhancing its current Safety Priority Index System to include a more refined crash selection than total crashes. This research reveals that there is significant benefit to disaggregation of crash analysis and network screening in particular.

6.2 SUGGESTIONS FOR FURTHER RESEARCH

While this research effort focused on identifying sites related to speed/ice conditions, the methodology could be applied to any number or combinations of crash variables. As is the case in much analysis, additional data increases the analysis burden but also refines the results. By aggregating roadways to similar climate conditions, it is believed that more "outliers" or locations that are significantly different from the average of their peer facilities were more readily identified.

An additional ranking method could be pursued based on the potential for improvement. The next ranking method that should be pursued and compared using these methodologies is the potential for improvement method. Here predictive models of safety performance can be constructed to estimate the most likely crash frequencies. These models could be used to estimate the expected number of crashes at a location using empirical-Bayes methodologies (or similar techniques to account for crash data trends), and an estimate of the excess crashes at a section could be made. Sites with the most excess crashes would be candidates for improvements.

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