EVALUATION OF A VARIABLE SPEED LIMIT SYSTEM FOR WET AND EXTREME WEATHER CONDITIONS

Phase 1 Report

SPR 743

Oregon Department of Transportation

EVALUATION OF A VARIABLE SPEED LIMIT SYSTEM FOR WET AND EXTREME WEATHER CONDITIONS

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Washington, DC 20590-0003

June 2012

Technical Report Documentation Page

1. Report No. FHWA-OR-RD-12-14	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of a Variable Speed Limit System for Wet and Extreme Weather Conditions: Phase 1 Report		5. Report Date June 2012 6. Performing Organization Code
7. Author(s) Ahmed Al-Kaisy, Levi Ewan and David Veneziano		8. Performing Organization Report No. SPR 743
9. Performing Organization Name and Address Western Transportation Institute Montana State University Bozeman, MT 59717-4250		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Oregon Department of Transportation Research Section 200 Hawthorne Ave. SE, Suite B-240 Salem, OR 97301-5192 and Federal Highway Administration 400 Seventh Street, SW Washington, DC 20590-0003		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Weather presents considerable challenges to the highway system, both in terms of safety and operations. From a safety standpoint, weather (i.e. precipitation in the form of rain, snow or ice) reduces pavement friction, thus increasing the potential for crashes when vehicles are traveling too fast for the conditions. Under these circumstances, the posted speed limit at a location may no longer be safe and appropriate. From an operations standpoint, inclement weather could have considerable impacts on the capacity of the highway system and the efficiency of using the system by motorists. Consequently, new approaches are necessary to influence motorists' behavior in regards to speed selection when inclement weather presents the potential for reduced pavement friction at a given location. Among these approaches is the use of Variable Speed Limit (VSL) systems. This document presents the results of initial work completed in the development of such a system. The work completed included a literature review related to different aspects and types of VSL systems, as well as a review of sensor systems capable of providing roadway grip/friction measurements. The work also developed a Concept of Operations and Requirements for the prospective VSL system, with detailed information provided in the Appendix. Sensor testing was completed on the Vaisala DSC 111 to determine its accuracy and applicability for inclusion in the prospective VSL. Finally, a policy and legal implications review that was completed by Oregon Department of Transportation staff including a summary of Oregon's recently enacted administrative rules on use of variable speed limits and statutes and rules adopted by other states is presented.

17. Key Words Variable speed limit, weather, grip number, policy and legal review		18. Distribution Statement Copies available from NTIS, and online at http://www.oregon.gov/ODOT/TD/TP_RES/	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages XXX	22. Price

Technical Report Form DOT F1700.7 (8-72) Reproduction of completed page authorized ♲ Printed on recycled paper

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

*SI is the symbol for the International System of Measurement

ACKNOWLEDGEMENTS

The authors wish to thank the Oregon Department of Transportation, the Federal Highway Administration, and the University Transportation Centers Program of the Office of Research, Development and Technology, Research & Innovative Technology Administration at the U.S. Department of Transportation for the funding of this research. They also wish to thank the project Technical Advisory Committee, including Galen McGill, Kathi McConnell, Jason Shaddix, Sgt. Steve Schaer, Nathaniel Price, June Ross, Joel McCarroll, Mike Barry, Dennis Mitchell, Luci Moore and Mike Stinson for their input and assistance in this work. Finally, they thank Michelle Akin of the Western Transportation Institute for her assistance in the sensor testing portion of this work.

DISCLAIMER

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1.0 INTRODUCTION

There is an integral relationship between highway speed and safety. The posted speed limit at a given location is usually set taking into account a number of considerations, including road surface characteristics (wet pavement conditions), free flow 85th percentile speeds, highway alignment and other factors. Based on this posted speed limit, vehicles can expect to safely traverse a given segment. When drivers travel above the posted speed limit, the potential for adverse safety consequences (i.e., higher crash occurrence) increases. This is particularly true at the location of horizontal curves where lower design speeds are usually used and the traction between the tire and pavement may become an issue when design speed is exceeded.

Weather presents considerable challenges to the highway system, both in terms of safety and operations. From a safety standpoint, weather (i.e., precipitation in the form of rain, snow or ice) reduces pavement friction, thus increasing the potential for crashes when vehicles are traveling too fast for the conditions. Under these circumstances, the posted speed limit at a location may no longer be safe and appropriate. From an operations standpoint, inclement weather could have considerable impacts on the capacity of the highway system and the efficiency of motorists using the system. Highway closures, reduced speeds, increased headways, and crash-related closures are all examples of inclement weather operational effects.

The aforementioned issue is of concern on the ramps of the U.S. 26/Oregon 217 interchange in Beaverton, Oregon (shown in Figure 1.1).Traffic data indicates that over 60,000 vehicles per day use the ramps at this interchange. Crash data has shown that one or more "loss of control" crashes per day have been observed during wet pavement conditions, with secondary crashes occurring on many occasions. Historically, once wet pavement conditions occur at this site, crashes classified as "loss of control" increase. While the site has traditional passive signage and flashing beacons in place, crashes continue to occur. Oregon Department of Transportation (ODOT) personnel have concluded that additional measures are necessary to address the problem.

Source: Google maps

Figure 1.1: U.S. 26/Oregon 217 interchange, Beaverton, Oregon

The current project involves the previously stated safety challenges which have led to safety concerns at the U.S. 26 / Oregon 217 interchange. On one hand, the interchange involves transition in highway alignment in the form of horizontal curves at the location of ramps that are used by high-speed mainline traffic taking any of the interchange ramps. While speed limits are posted on the mainline of the two crossing roadways, there is no posted speed limit on the ramps. Advisory speeds posted at the ramps closely correspond to safe design speed, but could be exceeded by many vehicles coming from the high-speed mainline. On the other hand, rainy conditions are commonplace during the fall and winter seasons which could lead to inadequate pavement-tire traction for those vehicles traveling at speeds too high for the conditions.

Traditional approaches to address this problem, such as the use of passive warning signs and flashing beacons, may lose effectiveness over time as drivers become acclimated to them. The end result is a higher crash occurrence at those locations during inclement weather, even when traditional warnings are provided to motorists. Consequently, new approaches are necessary to influence motorists' behavior in regards to speed selection when inclement weather presents the potential for reduced pavement friction at a given location. Among these approaches is the use of Variable Speed Limit (VSL) systems.

The following report presents a summary completed during the initial phase of this project. Chapter 1 has provided an introductory overview and background of the problem and the prospective approach to address it. Chapter 2 presents a literature review related to different aspects and types of VSL systems. Chapters 3 and 4 provide an overview of the Concept of Operations and Requirements for the prospective VSL system, with detailed information provided in the Appendix. Chapter 5 presents the results of tests performed of the Vaisala DSC 111 to determine its accuracy and applicability for inclusion in the prospective VSL. Finally, Chapter 6 presents conclusions and recommendations drawn from the work, including a potential approach to incorporating Vaisala DSC 111 data into a VSL system. Also included as an Appendix is a policy and legal implications review that was completed by Oregon Department of Transportation staff. It includes a summary of Oregon's recently enacted administrative rules on use of variable speed limits and statutes and rules adopted by other states.

It should be noted that, after much of the work in this report was accomplished, the Oregon Department of Transportation changed its plans and determined that the system described in this report will not be implemented at the US26/OR217 interchange location. At this point, completion of Phase 2 of this research is problematic. If another location is identified for a weather-related VSL system it is possible that Phase 2 of this research can be carried out.

2.0 LITERATURE REVIEW

VSL systems target a number of different speed and safety-related issues. These include congestion, incidents, weather and other issues. The following sections of this literature review provide a summary of the different VSL systems that have been deployed and reported/evaluated to date. The review begins with a discussion of weather-related VSL systems that are reported in the literature, and then examines other VSL systems deployed for general applications (e.g. congestion). This is followed by a discussion of other, more general weather warning systems that do not necessarily address speed limits but rather, provide warning to drivers. A discussion of VSL system issues is provided next. Finally, the document concludes with an overview of the existing different weather (pavement conditions) sensors that is of particular interest to the current project.

2.1 WEATHER RESPONSIVE VSL SYSTEMS

To date, only limited work has been conducted in the U.S. and internationally that is specific to the use of VSLs in addressing weather conditions. The information reviewed here illustrates that such systems have been deployed more recently in the U.S, while international examples have been deployed over a longer period of time. Consequently, the information provided in this section indicates that overall, weather-specific VSLs are still in their infancy, with only limited deployments and evaluations reported in the literature. These systems have been deployed to address rain, fog, wind and snow/ice conditions. The intent of these systems has varied, ranging from addressing traffic safety concerns stemming from specific weather conditions and other reasons related to safety and efficiency.

2.1.1 Arizona

The Arizona DOT undertook research in 1998 to develop a prototype algorithm and hardware/communication links for an experimental VSL system for use on Interstate 40. The system would incorporate fuzzy logic to identify appropriate speed limits for different environmental conditions (road surface state, wind speed and gust, crosswinds, visibility, and precipitation intensity (*Placer 1998*). However, the system had not reached deployment as of 2000, but was slated for follow-up development work. This follow-up work was performed in 2000-2001, and involved the upgrading of RWIS sites along I-40 to provide atmospheric, surface condition and traffic data (*Placer 2001*). Since the completion of that work however, there is no indication in that the VSL system was ever deployed in the field.

2.1.2 Australia

An Austroads report presented a number of different weather-based VSL systems, although specific details and evaluation results for these systems were somewhat limited (*Han et al 2009*). A New South Wales (NSW) VSL system, deployed around 2005 on highway F3 between Sydney and the New England Highway, addressed wet weather conditions. The system employed weather station data, two pairs of VSL signs, one VMS and six static support signs to adjust speed limits when weather conditions warranted. When wet conditions were detected, a 90 km/h regulatory speed limit was implemented (it was not specified if this speed limit could be lowered additionally as conditions deteriorated). While no formal safety or operational evaluation was completed, results of a resident survey indicated that the system was viewed positively.

Another NSW VSL system was fog-based and deployed in the Blue Mountains to address the occurrence of rapid onsets of fog. A fog detector was used in this system to notify traffic management personnel, who then initiated speed limit changes. No further information or evaluation results from this system were reported.

South Australia deployed a VSL system along the Adelaide-Crafers Highway in 2005 to address incidents and weather. The system deployed 45 VSL signs which were dynamically adjusted by traffic management personnel from a control center based on the location of an incident or existing weather conditions. The speed limits were set to 60, 80 or 100 km/h based on observations made via CCTV imagery. Safety improvements were observed during the first year of operation for the system, with a reduction in crash rates of between 20 and 40 percent reported.

2.1.3 Finland

Robinson discussed a Finnish deployment of an experimental VSL system in 1994 which employed weather information to determine a recommended speed limit (*Robinson 2000; Zarean et al. n.d.*). The system used 67 VSL signs and 13 VMS signs along a 15 mile (25 km) segment of rural roadway. The weather data taken into consideration by the system included wind velocity and direction, air temperature, relative humidity, rain intensity, cumulative precipitation, and road surface condition (dry, wet, salted, etc.). This information was used to establish the following speed limits:

- 74 mph (120 km/h) for good road conditions;
- 62 mph (100 km/h) for moderate conditions;
- 49 mph (80 km/h) for poor conditions.

These speeds were regulatory and enforced. An evaluation found that 95 percent of drivers that were interviewed endorsed the use of the weather VSL system.

Rama and Schirokoff discussed the results of an evaluation of a weather controlled VSL on injury crashes in Finland (*Rama and Schirokoff 2004*). Systems were deployed in eight locations along two lane roadway segments ranging between 8 km and 41 km in length. Data used in determining speed limits came from RWIS, CCTV, weather forecasts and maintenance operations made in the field. During good conditions, the posted speed limit was 100 km/h. A speed limit of 80 km/h was posted during moderate conditions, and speed limits of 60 km/h or 70 km/h were posted in adverse conditions. The systems were controlled either manually or automatically based on system data processing and classification, depending on the site. Results of the safety evaluation found that a 13 percent decrease in crashes during the winter and a 2 percent decrease during the summer occurred following deployment.

2.1.4 France

Robinson indicated that France deployed weather-based VSL signs in the Marseille area along 5 miles (8 km) of roadway (*Robinson 2000; Zarean et al. n.d.*). The system set a speed limit based on prevailing speeds and weather conditions. The information for this system provided by Robinson was limited, so it is not clear what weather data was employed, whether the speed limits were advisory or regulatory, and if any formal evaluation of the system's effectiveness was made. A further search specific to this system during the course of this project has yielded no further information.

2.1.5 Germany

Bertini et al. (*2006*) discussed the impacts of a VSL deployed on the German Autobahn near Munich. The system processed incident, speed and weather data through an algorithm which determined an appropriate speed limit based on three control strategies. These included incident detection, speed harmonization and weather presence. The sensors employed in providing the data to determine posted speed limits were not discussed by the authors, nor were the processing algorithms or logic employed in determining them. Results of a data analysis performed on speed data recorded by system loop detectors showed decreases in posted speed limits were observed primarily after observations in increasing flow accompanied by decreasing vehicle speeds (*Bertini et al. 2006*). Note however, that the findings reported by the authors did not include performance during a weather event.

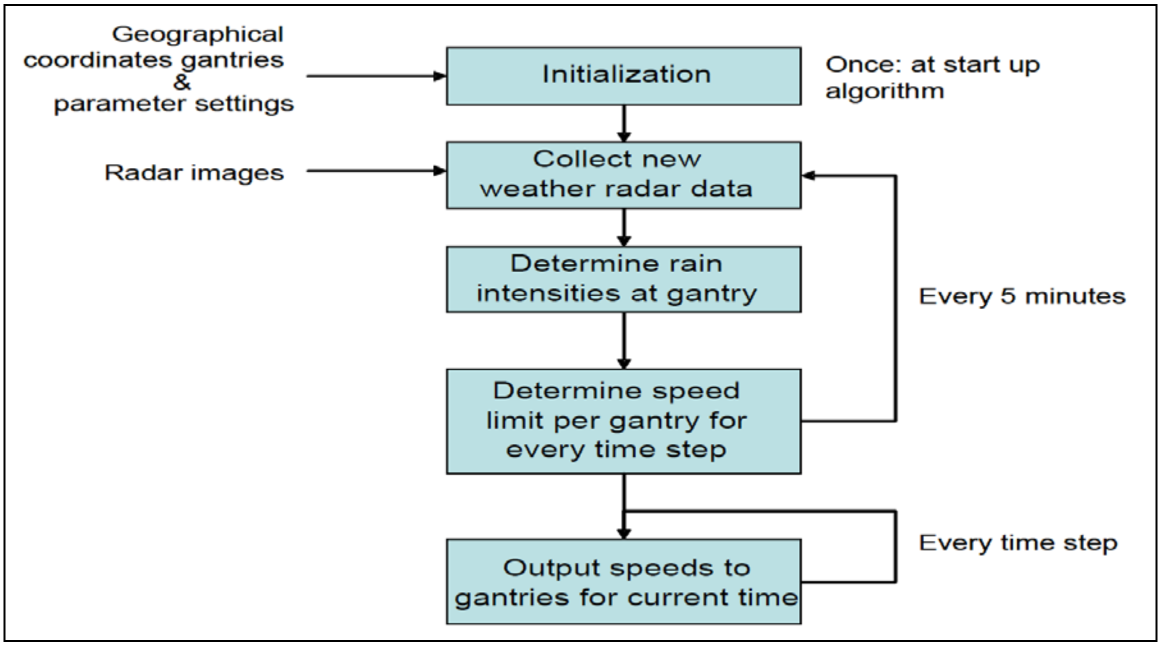
2.1.6 The Netherlands

Jonkers et al. (*2008*) identified appropriate speed limits for given rain intensities and developed an algorithm that employed weather radar data to lower speed limits based on weather conditions in the Netherlands. Based on a review of literature and a workshop with stakeholders, a series of speed limits associated with varying rain intensities for a 75 mile per hour roadway were identified. These are presented in Table 2.1. The researchers were advised that the VSL should not display a speed limit lower than 50 mph, as this was already well below the speed drivers would normally drive during heavy rain.

Table 2.1: Speed limits for given rain intensities

Water on road surface	Rain intensity	Speed limit
0.0 mm	0.0 mm/hr	75 mph (No restriction)
0.2 to 0.6 mm	0.0 to 2.5 mm/hr	75 mph (No restriction)
0.6 to 2.0 mm	2.5 to 6.0 mm/hr	60 mph
0.6 to 2.0 mm	6.0 to 30.0 mm/hr	50 mph

The algorithm developed by the researchers to set and adjust speed limits relied on weather radar data to classify rain intensities by sign location. A schematic of the algorithm is presented in Figure 2.1. As this figure indicates, the process is iterative and checks for condition changes at five-minute intervals. The developed algorithm and VSL system had not been deployed as of 2008 (and results from its deployment have not yet been published), so its impacts on addressing vehicle speeds and crashes during inclement weather remain unknown.



Source: Jonkers et al. (*2008*)

Figure 2.1: Speed limit adjustment algorithm

Robinson presented information from a fog-based VSL system in the Netherlands (*Robinson 2000; Zarean et al. n.d.*). The system was installed on an urban roadway in 1991 along a 7.4 mile (12 km) section to address vehicle speeds during fog. The system deployed signs every 0.4 to 0.5 miles (700 to 800 m), along with 20 visibility sensors. During normal visibility conditions, the posted speed limit was 62 mph (100 km/h). When visibility degraded, speeds were adjusted as follows:

- Visibility of 456 feet (140 m) – speed limit reduced to 49 mph (80 km/h);
- Visibility of 228 feet (70 m) – speed limit reduced to 37 mph (60 km/h);
- Incident detected (via CCTV) – speed limit reduced to 31 mph (60 km/h).

It was unknown whether the system posted advisory or regulatory speed limits or whether the posted speeds were enforced. However, following deployment, mean speeds were observed to fall by 5 to 6 mph (8 to 10 km/h) during fog conditions when the system was active.

2.1.7 New Jersey

New Jersey's VSL system adjusted speed limits for crashes, congestion, construction, ice, snow and fog in increments of 5 mph down to as low as 30 mph (*Robinson 2000*). The source of weather data was not specified however. The system originally consisted of 120 signs along 148 miles of roadway (more current figures are unavailable) and employed loop detectors to collect current speed and volume data. The signs have been viewed over time by officials as being effective in providing motorists with information on the need for speed reductions.

2.1.8 Sweden

Peterson (*2007*) presented a general overview of VSL trials and initial results throughout Sweden between 2003 and 2007. Of the different systems employed, some were weather-based, although the specific weather events addressed were not cited (likely snow). One weather-based VSL system used weather station data that was processed using a weather model to calculate surface friction and wind vectors. When specified criteria were met, traffic managers received notifications which alerted them to when the system should be manually activated or deactivated. Observations from these systems indicated that fewer motorists drove 10 km/h over the posted speed limit compared to before VSL deployment.

2.1.9 Utah

Perrin et al. (*2002*) tested a system installed along a fog-prone segment of Interstate 215 in Utah between 1995 and 2000 that determined current sight distance and corresponding safe speed. The system, which posted advisory speed messages to Variable Message Signs based on visibility, was found to reduce speed variability by twenty-two percent during inclement conditions. Speed variability was reduced up to thirty-five percent for moderate fog conditions, which were the primary focus of the system. The researchers noted that evaluation of crash trends was a necessary part of future research.

2.1.10 Washington State

Ulfarsson et al. (*2001*) discussed the deployment of a winter weather responsive VSL in Washington State. The Snoqualmie Pass project was deployed in 1997 on a nearly 40 mile stretch of road. This system takes measurements from six environmental sensor stations, capable of measuring air temperature, humidity, precipitation, wind speed and direction, pavement condition (dry, wet, ice, etc.) and pavement temperature. Each of the environmental sensor stations used an in-pavement type sensor to determine road surface conditions. Using the current weather conditions and computer logic to generate suggested speeds, centrally located traffic operations personnel made posted speed limit decisions. The operators could choose to agree with the computer's suggested speed limits and messages and post them on the 13 dynamic message signs. These signs were capable of displaying text messages and variable speed limits simultaneously. The speed limits could vary from 65 mph to 35 mph in 10 mph increments depending on the weather sensor data and traffic conditions. Figure 2.2 shows a sign from this project.

Source: Warren (*2000*)

Figure 2.2: Snoqualmie Pass VSL and Warning Sign

An in-depth study of the effects of the Snoqualmie Pass VSL system on driver behavior was conducted as part of the TravelAid project. The work did not examine post-deployment accident and speed trends; rather, their work developed modeling approaches that could be employed in the future to complete such evaluations. A negative binomial model was developed to examine accident frequencies as a function of geometric and weather–related variables. The final model indicated that roadway sections with grades exceeding 2 percent, maximum rainfall and the number of rainy days per year significantly increased accident frequency. Negative binomial models were also developed to examine different accident severities as a function of geometric, weather and human factors. Finally, standard multiple regression models were developed to estimate mean speeds and speed deviations for each lane of the roadway using data from loop detectors from one site in the study area. Vehicle mix and distribution of traffic across lanes were found to be significant determinants of mean speeds and speed deviations by these models. Interestingly, despite the extensive modeling efforts completed during this project, no publications have presented evaluations results for the post-deployment performance/impact of the overall system (*Ulfarsson et al. 2000*).

2.1.11 Wyoming

Buddemeyer et al. (*2010*) examined a VSL system deployed to address high wind, blowing snow and icy conditions on Interstate 80 in Wyoming and its impacts on vehicle speeds. Their results indicated that the VSL produced speed reductions of between 0.47 and 0.75 miles per hour for every mile per hour of reduction in the posted speed. Note that the system itself did not rely on detection equipment or algorithms to establish weather conditions of concern; rather, the Wyoming State Patrol determined when conditions warranted a lowering of the posted speed limit. Given the deployment is fairly recent (February, 2009), long term evaluation of crash rates and speed data on the corridor is still ongoing.

2.1.12 General Fog Systems

The most common weather responsive VSL use in the United States was for fog related reduced visibility conditions. Alabama, New Jersey, South Carolina, Tennessee, and Utah all have systems that detect low visibility conditions caused by fog and post varying speeds, either advisory or regulatory, accordingly (*Goodwin 2003*). Table 2.2 outlines the systems used in each state.

Table 2.2: Fog VSL Systems

State	Signage (No. Signs)	Road Type	Project Length	Speeds	Control
AL	Dynamic Message Signs (DMS) (5) VSL (24)	Interstate	6 miles	65mph to 35mph	Regulatory and Advisory
NJ	DMS (113) VSL (120+)	Freeway	148 miles	65mph to 30mph	Regulatory and Advisory
SC	DMS (8)	Interstate	7 miles	60mph to 25mph	Advisory
TN	Static w/beacon (6) DMS (10) VSL (10)	Interstate	19 miles	65mph to 35mph	Regulatory and Advisory
UT	DMS (2)	Interstate	2 miles	65mph to 25mph	Advisory

These variable speed limit applications have produced beneficial results. The Alabama Interstate 10 project “improved safety by reducing average speed and minimizing crash risk in low visibility conditions” (*Goodwin 2003*). The New Jersey turnpike project also decreased vehicle speeds and reduced the frequency and severity of weather-related crashes. The South Carolina Interstate 526 project had no fog related crashes occur for at least the first 11 years of operation and possibly longer. The Tennessee Interstate 75 project was said to have significantly improved safety and only one fog related crash was reported in the first 9 years of operation. The Utah Interstate 215 project found that displaying advisory speeds decreased speed variability by increasing speeds of the overly cautious drivers during light fog conditions. This is thought to increase safety and reduce the risk of crashes (*Goodwin 2003*). Figure 2.3 shows a fog warning VSL sign.

Source: Goodwin (*2003*)

Figure 2.3: Fog warning VSL Sign

2.2 OTHER VSL SYSTEMS

The concept of variable speed limit systems to address driving conditions dates back to the early 1960's, with reported applications in Michigan and New Jersey (*Robinson 2000*). These original systems relied on manual observation of existing conditions and the subsequent triggering of the VSL, while in more recent decades, automated sensor-based data and electronic processing has been employed to trigger the VSLs. The primary intent of these systems over the years has been to improve the safety and performance of highways during periods of congestion, incidents, construction, and, more recently, weather events. The adjusted speed limits presented to motorists by VSLs have been comprised of both advisory and regulatory[1]. The following sections provide a synthesis of past VSL applications, both domestic and international, which have been applied to address general operational and safety concerns. Note that this review does not include weather responsive VSLs, which will be discussed in a later section.

2.2.1 Australia

Austroads, the association of Australian and New Zealand road transport and traffic authorities, compiled an extensive literature review regarding best practices of VSL systems in Australia and internationally (*Han et al. 2009*). The information provided in this report regarding systems deployed in the United States and Europe has been discussed in other sections of this literature review document. Of specific interest to this work, was the summarization of VSLs deployed in Australia (and New Zealand), including deployments in New South Wales, Victoria, Queensland, Western Australia, South Australia, Tasmania, Australia Capital Territory, and Northern Territory. The following subsections present further detail on these systems.

[1]Note: An advisory speed is a speed recommended to motorists by signage but not enforced. An example would be the advisory speed presented to motorists about to traverse an entrance or exit ramp on a controlled access facility. A regulatory speed limit is the posted legal speed limit which is enforceable.

2.2.1.1 New South Wales

Beginning in 1993 through 2007, over 400 VSL signs had been installed in New South Wales (NSW) for a variety of purposes. These included incident management, queue management, speed control during inclement weather, reversible lanes, school zones, and for tunnels and bridges.

A deployment of VSL for queue management was made on the M4 Motorway. The system employed an algorithm from an existing queue management system to reduce the posted speed limit from 100 or 90 km/h (depending on the specific location) to 70 km/hr, depending on traffic conditions. The system was controlled by a field device, requiring no input from traffic managers, and processed occupancy and incident detection data in order to determine and post the appropriate speed limit. No evaluation results from this system were reported.

A VSL system was deployed to adjust speed limits when a heavy vehicle inspection station was in operation along the New England Highway. The system was operated by inspectors at the inspection site. No further information or evaluation results from this system were reported.

One hundred schools participated in a trial of six types of different speed limit signs, including VSL systems. However, aside from the provision of images of the different sign types used in the trial, no further information or evaluation results were reported.

2.2.1.2 Victoria

Victoria has deployed different VSL systems since the 1980s, with some systems remaining active. The primary purpose of these systems was to address incident and congestion issues.

A VSL deployed on the West Ring Road in 2002 addressed traffic congestion and incidents. The system employed 68 changeable regulatory speed limit signs deployed in both directions of travel over a distance of 24 km. The system processed input data (unspecified data streams) to calculate recommended speed limits and check their feasibility and logic before posting. No further information or evaluation results from this system were reported.

Approximately 250 school zones had deployed either electronic or manual speed limit signage to improve safety. The speed limits were set either by the on-site system (electronic signs) or manually by a crossing supervisor (manual flip signs) based on the time of day. Similarly, 50 shopping center zone electronic signs have been deployed, with speed limits changed by the on-site system based on the time of day. No further information or evaluation results from these systems were reported.

2.2.1.3 Queensland

When the report was published in 2009, Queensland was making initial preparations for the deployment of VSL systems. These systems would address congestion, safety, weather (wind/rain), construction zone and school zone issues. At present, no information regarding these systems or their deployment status is available.

2.2.1.4 Western Australia

Western Australia has deployed a few trial VSL systems in school zones, but no further information or evaluation results from these systems were reported.

2.2.1.5 South Australia

South Australia deployed a VSL system along the Adelaide-Crafers Highway in 2005 to address incidents and weather. The system deployed 45 VSL signs which were dynamically adjusted by traffic management personnel from a control center based on the location of an incident or existing weather conditions. The speed limits were set to 60, 80 or 100 km/h based on observations made via CCTV imagery. Safety improvements were observed during the first year of operation for the system, with a reduction in crash rates of between 20 and 40 percent reported.

2.2.1.6 Other Australian Locations

Tasmania had not deployed any VSL systems at the time the report was written, but was planning a system for use on the Tasman Highway to address congestion at peak times. Other systems were under consideration to address congestion and weather issues, but had not yet moved to a planning level.

The Northern Territory had one VSL system deployed on an urban, multi-lane road in a high pedestrian traffic area. The system used two VSL signs with timers that lowered posted speed limits from 70 to 50 km/h during certain times of day when heavy pedestrian traffic could be expected. No further information or evaluation results from this system were reported.

Finally, New Zealand deployed a VSL system in 2001 on a steep roadway in the Ngauranga Gorge. The system employed data from a fixed speed camera to change speed limits based on a traffic flow algorithm and weather data input. The exact speed limit levels were not indicated, nor was further information or evaluation results from this system reported.

2.2.2 Colorado

In 1995, the Colorado Department of Transportation deployed a truck speed warning system along I-70 west of Denver to identify and provide vehicle-specific safe operating speeds for a long downgrade. The system, which provided advisory speeds, employed a weigh in motion sensor, a variable message sign, loop detectors and hardware/software to compute and post a safe speed based on a truck's weight, speed and axle configuration (*Robinson 2000*). Initial results indicated a decline in truck-related accidents on the downgrade, even after truck traffic had increased by 5 percent. A formal evaluation of the system found that on days when the sign was not on, more trucks traveled above 45 mph, with mean speeds 7.6 mph greater than when the sign was on (*Janson 1999*). Additionally, t-tests indicated that the differences in mean speeds of 33.5 mph when the sign was on versus 41.1 mph when off were statistically significant.

2.2.3 Delaware

Around 2003, the Delaware Department of Transportation installed 23 VSL signs on Interstate 495 (*Werner 2003*). The intent of the system was to help reduce air pollution (lower Volatile Organic Compound emissions through lowering vehicle speeds) and manage incidents. The speed limits were regulatory and enforced. Speed limits were changed manually using standard operating procedures that specified how far speed limits should be lowered under different conditions. To date, no formal evaluation of the system or its effectiveness has been published.

2.2.4 Maine

Advanced Traveler Information Systems (ATIS), including variable speed limits, were deployed and evaluated in Maine in 2007 (*Belz and Garder 2009*). The VSL system was intended to address vehicle speeds during inclement winter weather. It was activated manually by Maine Department of Transportation staff based on the direction of State Police personnel in the field. Posted speeds were advisory and not enforced. Speed data collected by radar during different storm events indicated that the system had little effect on reducing vehicle speeds.

2.2.5 Michigan

Michigan reported an early deployment of VSL, with a system activated in 1962 (later removed after 1967) along urban freeways in Detroit (*Robinson 2000*). The system was deployed to alert motorists when to decelerate when approaching congestion and when to accelerate when leaving it. The system posted advisory (not enforced) speed limits to 21 signs. Given the time period the system was deployed, the logic used to determine speeds was rudimentary; signs were manually switched from a control center based on speed limits chosen by an operator viewing CCTV images and examining plots of current vehicle speeds. While no formal evaluation of the system was published, Robinson noted that officials concluded that vehicle speeds did not significantly increase or decrease as the result of the VSL system.

Lyles et al. (*2004*) evaluated a field test of an interstate work zone VSL deployed in Michigan during the summer of 2002. The system tested was trailer based (wireless radio communications between trailers) and monitored traffic speed and flow at a given location via microwave sensors. The collected data was used to calculate different statistics (e.g. mean speeds) and displayed an appropriate speed limit based on pre-determined logic. A total of seven signs were used at four separate deployment sites in an 18 mile long work zone at spacings that were, in some cases, less than one mile apart. Speed limits were typically set to the estimated 85th percentile speed calculated at the next downstream trailer, unless different logic prevailed, and were enforced. The evaluation found that the VSL had relatively minor impacts on vehicle speeds in the work zone, owing in part to the operational constraints at the test site beyond the control of the researchers. The effects of the system on 85th percentile speed and speed variance were found to be undetectable. However, the percentages of vehicles exceeding specific speed thresholds (e.g., 60 mph) were observed to decrease following deployment.

2.2.6 Minnesota

The Minnesota Department of Transportation had undertaken a demonstration of VSL in urban work zones at the time of Robinson's presentation. The system employed regulatory speed limits that were manually activated at a predetermined level (45 mph) when construction workers were present (*Robinson 2000*). No evaluation results were published in relation to this deployment.

Kwon et al. (*2007*) evaluated a VSL system deployed to reduce traffic conflicts in a Minnesota interstate work zone in 2006. The system employed data from radar sensors that measured speed and volume to set speed limits of upstream traffic approaching the work zone to the same level as the current downstream flow. These speed limits were posted to advisory speed limit signs (orange for work zone) and reduced speeds from the normal 65 mph to as low as 45 mph. Field data indicated a 25 to 35 percent reduction in the average one-minute maximum speed difference along the work zone during the morning peak period (6:00 to 8:00 A.M.), with a seven percent increase in total throughput volume. Additionally, driver compliance rates between the upstream and downstream signs showed a 20 to 60 percent compliance level.

2.2.7 Missouri

The Missouri Department of Transportation deployed VSLs in the St. Louis area along Interstate 270 in 2008 (*Missouri Department of Transportation 2011*). The posted speed limits were originally regulatory and enforced, although they have since been converted to advisory and not enforced. The speed limits are set based on lane occupancy observations and current vehicle speeds. To date, no formal evaluation or results on this system have been published.

2.2.8 Nevada

The Nevada Department of Transportation deployed a VSL system along I-80 in a rural canyon which adjusted speed limits based on 85th percentile speeds, visibility and pavement conditions (*Robinson 2000*). The system used four VSL signs (two in each direction of travel), visibility detectors, loop detectors, RWIS and static advanced warning signs. Regulatory speed limits were determined using a logic tree based on observed 85th percentile speeds, visibility and pavement conditions, with adjustments made in 10 mph increments. The system was entirely field-based and required no human interaction. No evaluation results were published in relation to this deployment.

2.2.9 New Mexico

New Mexico deployed three VSL signs along I-40 in Albuquerque from 1989 through 1997 (removed because of construction) to serve as a U.S. test bed for VSL equipment and algorithms (*Robinson 2000*). The system, which was fully automated, posted regulatory speed limits that reflected traffic conditions. The algorithm used to determine the posted speed employed a smoothed average speed and added an environmental constant (ranging from 0 mph when raining to 7.5 mph when clear and light). Overall, the equipment and algorithm were successful in the field, with a slight reduction in crashes observed. However, the overall evaluation of the system was hampered by high average speeds (exceeding the maximum posted speed limit of 55 mph), sign visibility, and sun glare.

2.2.10 Oregon

The Oregon Department of Transportation (ODOT) developed a speed advisory system for trucks on an I-84 downgrade which was deployed in 2002. The system used a weigh in motion scale, automatic vehicle identification (AVI) readers, and a roadside VMS to provide a specific speed message for each truck (*Robinson 2000*). Advisory speeds were computed for each truck based on the weigh in motion weight, while the owner of each vehicle was identified by the AVI reader, with a personalized message posted to the VMS. The system remains active today (*ODOT n.d.*) although no formal evaluation has been conducted to date.

2.2.11 Utah

Riffkin et al. and McMurtry et al. evaluated the effectiveness of an interstate work zone VSL system deployed in Utah during the summer of 2007 (*Riffkin et al. 2008; McMurtry et al. 2009*). The system consisted of two trailer-mounted VSL signs (standard regulatory speed limit signs) that were manually set to two test conditions:

- Constant posted speed limit of 65 mph, 24 hours per day (reduced from normal speed limit of 75 mph);
- Varying posted speed limit of 55 mph during the day and 65 mph at night (no construction present).

A standard speed limit sign with a posted speed of 65 mph was deployed in the work zone prior to the two VSL conditions to collect baseline data for comparisons. The two VSL conditions were employed in alternating two week intervals. The VSL signs were placed in advance of the work zone and at a point approximately 2 miles into the work zone. Speeds were collected in advance of each of the VSL signs, as well as at points after the two signs. Evaluation results found that the mean speeds between the static (65 mph) and VSL signs were not significantly different from one another at the 95 percent confidence level. However, speed variance was generally reduced, particularly at the speed detector following the first VSL sign in both VSL conditions.

2.2.12 Virginia

Fudala and Fontaine (*2010*) examined the use of VSLs in high-volume, congested urban work zones in Virginia. A VSL was deployed along I-495 (the Capitol Beltway) between Springfield, Virginia and the Virginia-Maryland state line in July, 2008. The field-deployed VSL used a total of 12 signs, seven on the outer loop and five on the inner. The study highway was divided into three zones on the outer loop and two zones on the inner loop. Speeds were regulatory and the VSL was only operated when lanes were closed for construction work. The maximum allowable speed limit was 50 mph, while the minimum was 35 mph. Flashing beacons were employed to alert motorists when the VSL was active. Figure 2.4 shows one of the work zone VSL signs and the warning sign for the VSL zone.

Source: Fudela and Fontaine (*2010)*

Figure 2.4: Work zone warning sign and VSL sign

When activated, the VSL signs displayed the maximum allowable speed initially. Microwave sensors located with each VSL sign detected cumulative volumes and occupancy at each site. These inputs were used to assign a threshold value for each detector location based on existing conditions (normal, slowing or stopped traffic). The threshold values for all detectors were processed to calculate a segment level threshold value. Based on the results of this calculation, the lowest applicable speed limit was posted to all VSL signs in the zone. The metrics associated with the previously cited queue levels are presented in Table 2.3, while the various speed limits are presented in Table 2.4. The speed limits determined by the VSL system were presented to a traffic control center, where they were manually approved and posted to each zone. The researchers noted that the algorithm employed in the field deployment prevented speeds from increasing as a vehicle progressed through the VSL area (i.e. the driver would not encounter a low speed limit, followed by a higher one); rather, a low speed limit would be encountered until existing the work zone.

Table 2.3: Queue levels

Threshold Value	Parameters
1 (normal)	Occupancy < 8% or Volume < 1400 vehicles per hour (vph)
2 (slowing)	8% ≤ Occupancy ≤ 15% or 1400 vph ≤ Volume ≤ 1600 vph
3 (stopped)	Occupancy > 15% or Volume > 1600 vph

Source: Ali (*2008)*

Table 2.4: Zone and Segment Speed Limits

	Outer Loop			Inner Loop	
	Zone 1 (Activity Area)	Zone 2	Zone 3	Zone 1 (Activity Area)	Zone 2
No. of Possible Speed Limits	4	5	3	4	3
Segment Level =1	50	55	55	50	50
Segment Level =2	45	50	50	45	45
Segment Level =3	40	45	45	40	40
Segment Level =4	35	40	N/A	35	N/A
Segment Level =5	N/A	35	N/A	N/A	N/A

Source: Ali (*2008*)

Based on observations of the field-deployed system, a number of conclusions were drawn. First, the nature of work zones, where the changing of construction activities can vary, made it difficult to place the VSL signs at locations that were highly visible (and constant) to drivers. Second, a work zone VSL system should be operated continuously as opposed to periodically so that the signs do not blend into the background. Finally, VSL control algorithms should be capable of facilitating a response to forming congestion rather than addressing it afterward. Note that this work did not incorporate any field measurements of system effectiveness (i.e. comparison of mean speeds versus posted speed limits, etc.).

Nicholson et al. (*2006*) carried out follow-up work to that of Fudala and Fountaine, evaluating several aspects of the Capitol Beltway VSL system. These included speed comparisons (85th and 50th percentiles and mean), capacity, travel time, queues and delay. Speed data were collected between February 2009 and January 2010, with weekday morning (7 A.M. – 9 A.M.), midday (12 P.M. - 2 P.M.) and afternoon (4 P.M. - 6 P.M.) peaks analyzed.

The analysis results on 85th and 50th percentile and mean speeds indicated that only a limited number of statistically significant differences (cited as being 1 mph or greater) were observed between the baseline (VSL not active) and comparison (VSL active) data. While no direct method was used to determine travel times, examining average speeds at each detector location and accounting for the distance between locations showed that average travel times on the outer loop consistently decreased during the peak periods when the VSL was active, while travel times on the inner loop were inconsistent. Queue lengths and delay when the VSL was active appeared to be slightly reduced, although it was noted that no direct method to evaluate these was available; rather, observations of conditions were made on site.

2.2.13 Germany

Germany first installed VSLs in the 1970s in order to stabilize flow under heavy traffic conditions (*Robinson 2000*). The signs were deployed along rural autobahn segments of varying lengths (up to 18 miles (30 km)), with signs located every 0.9 to 1.2 miles (1.5 to 2 km). Speeds of 62, 49 or 37 mph (100, 80 or 60 km/h) were displayed based on prevailing traffic data and environmental data (fog, ice, wind, etc.), collected from unspecified sensors. This data was processed by the system algorithm, with the appropriate regulatory speed posted (speeds were enforced). Following deployment, crash rates at the different sites were observed to fall by 20 to 30 percent.

2.2.14 The Netherlands

Robinson (*2000*) presented results on a VSL system in the Netherlands that was installed in 1992 to create speed uniformity between lanes on a rural roadway. The system was deployed along a 12.4 mile (20 km) segment and employed loop detectors spaced 0.3 miles (500 m) apart to collect real time speed and volume data. The normal posted speed limit for the section was 74 mph (120 km/h), with variable speed limits posted at 55, 43 and 31 mph (90, 70 and 50 km/hr) based on a system algorithm that looked at one minute speed and volume averages across lanes. The system posted either advisory (speed posted without a red circle around it) or regulatory (posted with a red circle) depending on traffic conditions. Results of the system indicated that shockwaves and speeds were reduced as expected, and motorists that were interviewed said that they adjusted their speeds in accordance with the signs.

2.2.15 Sweden

A 2006 paper by Towliat et al. (*2006*) discussed the evaluation of a VSL system deployed at a rural intersection in Sweden.2 The system employed vehicle detectors on the minor (side road) approach that, when traffic was detected, lowered the posted speed on the main road from 90 km/h (the normal posted speed limit) to 70 km/h. The VSL was deployed to increase observance of the posted speed limit and address crash issues which were happening at the specific t-intersection. A before deployment speed study was completed in the fall of 2003, with a post deployment speed study completed in the spring of 2005 (system deployment occurred during 2004). Results indicate that when the VSL posted speed was 90 km/h, speeds following deployment fell by 7.3 km/h and generally matched the posted speed limit. Speeds fell by 16.6 km/h during the after period when the VSL posted a speed limit of 70 km/h, suggesting that drivers recognized the need to slow down at the site. While no formal before-after crash evaluation had been completed at the time the paper was written, it was expected that fatal and serious injuries from crashes would drop by approximately 50 percent following deployment. This expectation was based on a power model analysis. Finally, surveys of drivers following deployment indicated that it was easier and safer to turn onto the main road from the minor approach following VSL deployment. Figure 2.5 shows a VSL for side road entering vehicles.

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[2]A total of six such systems were deployed at rural intersections, however, only one was evaluated.

Source: Peterson (*2007*)

Figure 2.5: VSL for Vehicles Entering Main Road from Side Road

Peterson presented a general overview of VSL trials and initial results throughout Sweden (*Peterson 2007*). The systems were deployed and tested throughout the country between 2003 and 2007 in a number of different applications. These included VSL systems that addressed weather conditions (fog and winds), congestion, and intersection safety discussed in the paragraph above. The posted speeds were regulatory, although no information was provided regarding whether they were enforced.

Lind (*2006*) discussed the results of VSL systems deployed at intersections in Sweden, expanding on the discussions of Towliat et al. (*2006*). The systems that were deployed used sensors (vehicle or pedestrian) to detect vehicle or pedestrian presence on approaches, at bus stops or at pedestrian crossings depending on the specific site (six sites total). Based on detected vehicle or pedestrian presence, posted speed limits were temporarily reduced on the primary roadway at the site. Variable message signs were used to display the posted speed limits in colors identical to those of static signage.

In general, speeds were found to decrease at each site within a range of 1 km/h to 17 km/h. Observations of accepted gaps from vehicles turning from intersecting side roads increased by one to two seconds at two sites, but differences at other sites were negligible. Based on the observations made over the course of the trials at all sites, a few recommendations were developed. First, intersection VSLs should be deployed where primary road traffic volumes were at least 10,000 vehicles per day and side road volumes were 20 to 30 percent of this volume. If side road traffic is 10 percent or less of the primary road's volume, a dynamic message sign should be used instead of a VSL. Finally, if side road traffic is 40+ percent of primary road volume, a fixed speed limit should be considered.

2.2.16 United Kingdom

A VSL system was deployed in the London area to smooth traffic flows and demonstrate the control of traffic speeds for potential use on other multilane motorways (*Robinson 2000*). The system was deployed along a 14 mile (22.6 km) segment with signs placed every 0.6 mile (1 km). Volume data from loop detectors placed every 0.3 mile (500 m) were used to change speed limits according to real-time measurements. Speeds were reduced from 70 to 60 mph when volumes exceeded 1,650 vehicles per hour per lane and from 60 to 50 mph when volumes exceeded 2,050 vehicles per hour per lane. The posted speed limits were regulatory and enforced. Results following deployment indicated high compliance with the VSL signage, with a 10 to 15 percent reduction in crashes observed.

2.3 OTHER WEATHER RESPONSIVE SYSTEMS

The current use of weather responsive systems in traffic applications is limited in general. These deployments tend to be more recent (i.e., in the last decade). Most applications utilize a dynamic message sign or static message sign (with flashing beacons that can be activated) to warn drivers of adverse weather conditions. Some weather responsive systems of this nature deal with reduced visibility due to fog, high wind warnings, icy roads, and flash flood warnings. Less common weather responsive systems include a hurricane evacuation responsive system in North Carolina and an avalanche warning system in the steep Hoback Canyon near Jackson, Wyoming (*Goodwin 2003*).

2.3.1 Wet Pavement Warning

The Florida Department of Transportation deployed a motorist warning system on an Interstate 595 interchange ramp (two lanes) that had experienced a high rate of wet weather/pavement crashes (*FHWA 2011*). The system employed an in-pavement sensor (puck) to monitor pavement condition and a precipitation sensor mounted near the roadway to detect and verify rain events. Sensor data was processed by a remote processing unit in the field, with flashing beacons activated on speed limit signs (the posted speed limit was 35 mph) when moisture/rain was present. Note that this system was not a VSL; it only activated warning beacons, with the posted speed limit remaining constant.

The system was found to be effective in lowering vehicle speeds during wet conditions. Observations indicated that 85th percentile speeds during light rain fell from 49 to 45 mph, and from 49 to 39 mph during heavy rains. Aside from the reduced speed observations, no crashes were observed during a nine week analysis period, aside from four crashes during the week immediately following system deployment. At present, this system is no longer operational.

2.3.2 Fog Advisories

Many weather responsive systems have been deployed in an attempt to sense low visibility conditions caused by fog and warn drivers (*MacCarley 1999*). These systems tend to use dynamic message signs to warn drivers that foggy conditions exist, and many of these systems were found to display a fog warning with an advisory speed.

A fog detection system was installed on a two-lane road in rural Saudi Arabia in an attempt to warn drivers, and reduce fog related crashes. The system that was tested activated a sign that displayed the word “fog” and the advisory speed (40 km/hr) during foggy conditions. This system was tested and found to reduce mean vehicle speed by 6.5 km/hr. Speed variability was not reduced and the advisory speed posted was exceeded by the mean speed but driver behavior did show a reduction in speeds (*Al-Ghamdi 2007*).

Another fog warning system was implemented in California after fog was found to be the cause of many multi-vehicle accidents in California’s San Joaquin Valley (Caltrans District 10). The system included six meteorological stations with visibility sensors, nine changeable message signs, and 36 vehicle speed monitoring sites. When reduced visibility conditions were detected by the sensors, dynamic message signs were automatically engaged to display appropriate warning messages. This system is thought to be one of the most advanced of its kind in the world and independent evaluation of the system is ongoing. Many other states including Arkansas, Florida, Georgia, North Carolina, Oregon, Tennessee, and Virginia as well as other countries (England, Germany, Netherlands, and Spain) have implemented similar fog warning systems (*MacCarley 1999*).

2.3.3 High Wind Warning

Another type of weather responsive applications is high wind warning systems. In areas where very strong winds are possible wind speeds can be monitored and warning signs can be activated accordingly to prevent vehicle crashes, especially for high-profile vehicles such as large trucks. On U.S. Route 101 between Port Orford and Gold Beach, and on the Yaquina Bay Bridge in Oregon, anemometers constantly monitor wind speeds and activate flashing beacons on wind warning signs if winds become strong. These sites were found to have statistically significant differences in crash rates between windy and non-windy conditions. These systems were shown to be noticed by drivers and drivers felt confident in the usefulness of the sign’s information. When surveyed, more than eight out of every 10 drivers at these sites reportedly observed the high wind warning during a high wind event. It was also found that over 80 percent of respondents agreed that the system provides accurate information (*Kumar and Strong 2006*).

Similar high wind warning systems exist in California and Nevada. In California on Interstate 5 between Weed and Yreka, unexpected high winds can occur due to the site’s proximity to Mt. Shasta. Static high wind warning signs were changed to dynamic signs and automated with remote wind monitoring equipment (*Kumar and Strong 2006*).

In Nevada, on US Route 395 between Carson City and Reno, the Nevada DOT operated a high wind warning system. This system also used dynamic message signs to display high wind warning when strong winds are detected by a nearby environmental sensing station capable of monitoring wind speed and direction (*Goodwin 2003*). Figure 2.6 shows a Nevada high wind warning DMS.

Source: Goodwin (*2003*)

Figure 2.6: Nevada High Wind Warning DMS

2.3.4 Icy Roads

Some weather responsive systems attempt to warn drivers of icy road conditions. Sensors can detect when roads become icy and exhibit low friction behavior, a condition which potentially leads to increased crash rates. Using information from ice sensors, warning signs are used to alert drivers about upcoming icy conditions. One such system was implemented by Caltrans which used in-pavement weather sensors and an active warning sign at the Fredonyer Pass to warn drivers about icy road conditions. This system was tested and was found to significantly reduce average vehicle speed and reduce crashes (*Veneziano and Ye 2011*).

Other icy road condition warning systems exist in Oregon and Wyoming. The Butte Creek Ice Warning System in southwestern Oregon uses a road weather information system and two static signs equipped with beacons to warn drivers of icy road conditions. When certain threshold icy conditions are detected the beacons flash, warning drivers that icy conditions are present ahead. Crash and speed data have not been rigorously investigated to show the system effect on driver behavior, but a survey of users found general trends toward increased driver attentiveness and caution and a decrease in driver reported speeds (*Lindgren and St. Clair 2009*).

A system to warn drivers of icy conditions on an approach to a bridge was installed on US Route 30 in southwest Wyoming. This system also used in-pavement sensors and atmospheric sensors in conjunction with speed sensors to activate beacons on warning signs when icy conditions existed. This system was shown to lower average speed by 5 to 10 mph during beacon activation (*Easley 2005*).

2.3.5 Flash Flood Warning

Flash flood warning systems have been investigated because more people are killed in flash floods than any other weather-related phenomena each year and most are on roadways (*Boselly 2001*). Water running over the roadway does not have to be very deep to sweep a vehicle off the road. Systems that would inform motorists of flash flooding and/or actively close roads accordingly could be beneficial to users and DOTs. A feasibility study performed to investigate potential flash flood warning systems found that technologies to monitor water over the roadway exist but challenges arise especially when dealing with an automated road closure system (*Boselly 2001*).

The city of Dallas, Texas uses stilling wells to monitor potential flood conditions and automatically activate dynamic message signs when necessary at over 40 locations throughout the city. Similar to the feasibility study above, gates across the roadway to block traffic were considered but found to be too costly to implement and there was concern that the city would be held liable for signs that don't properly activate or operate during flood conditions. Since the system was installed in 2000 there have been no claims related to flooded roads filed against the city (*Goodwin 2003*).

2.4 VSL OPERATIONAL ISSUES

In addition to discussing different Australian VSL deployments, the Austroads report also summarizes the key operational issues of such systems (*Han et al. 2009*). This includes system components, operational principles, signage display and placement, and other issues. The following text presents a summary of this information.

With respect to system components, the report identified the following components which were typically present in the systems reviewed:

- Vehicle detectors for speed and flow information.
- Weather stations to identify inclement weather conditions.
- Control systems (centralized or on-site) that process data via algorithms, as well as contain user interfaces, logging systems and other systems as needed (e.g., incident detectors).
- Variable speed limit signs to post speeds dynamically.
- Communications systems to provide communications with other systems and a centralized location and to allow control center personnel to monitor and control the system.
- Other systems, such as Closed Circuit Television (CCTV) for monitoring of Variable Message Signs (VMS) for advanced driver notification.

The operational principles established where and how a VSL would operate, and included:

- Speed zone requirement, which establishes whether a speed reduction may be needed.
- Selection of speed limit, which establishes what speed limit should be posted for a specific condition.
- General rules for speed changes, which establish the specifics related to different aspects of the speed limit posting, such as frequency of changes, minimum posted speeds, etc.
- Failure mode, which establishes what needs to be done in the event of a VSL system failure.
- Communication and highlighting of speed changes to alert drivers that a different speed is posted (e.g. flashers, advanced notice via VMS, etc.).

The signage display and placement section of the report discussed VSL aspects such as sign size, placement and displays, and included:

- Sign type, including electronic (either full or partial, i.e., the numeric speed portion) or static, which employs features such as flashers to convey that the speed limit is in effect (e.g., school zones).
- Size, which in the United States follows MUTCD recommendations for similar static signage.
- Location, which follows Manual on Uniform Traffic Control Devices (MUTCD) recommendations for similar static signage.
- Appearance and display, which are outlined by the MUTCD:
- The MUTCD provides guidance for using newer, full-matrix and full-color, changeable message signs that imitate static signs. If an electronic sign is capable of displaying the proper color schemes and shapes the sign should use the same styles, colors, and sizes as its static equivalent (*FHWA 2009*).
- Mounting and protection, which indicated that shielding the sign from sunlight to enhance visibility may be necessary.
- Vandalism resistance, which discussed different types of protections that should be incorporated in signage (e.g., polycarbonate sheeting to protect against object impact).

Finally, other issues discussed included the integration of the VSL system with other ITS, such as VMS or ramp meters.

2.5 WEATHER SENSOR TECHNOLOGY

Sensors intended to measure roadway weather conditions can be of two general types, invasive and noninvasive. The invasive sensors, more commonly known as in-pavement sensors, are installed in the pavement level with the road surface and can use many different sensing technologies in determining roadway conditions. Noninvasive sensors are typically installed on the roadside or somewhere over the road surface and use non-contact means of monitoring weather surface conditions. The reader should note that the discussions included in this section largely rely on online information published by manufacturers of the various sensors presented.

2.5.1 In-Pavement Sensors

In-pavement sensors use the dielectric characteristics of the condition present on the surface of the sensors to determine if the road is dry, damp, wet, or icy and to detect the presence of de-icing chemicals (*Schedler 2009*). The conductivity of the liquid present on a sensor can be used to determine the freezing point temperature of that liquid; this type of sensor is known as a passive sensor. An active sensor is one that actively heats or cools itself to directly measure the freezing point of a liquid present on the sensor (*Jonsson 2010*). Some in-pavement sensors also utilize microwave radar to measure the depth of water present on the sensor (*Schedler 2009*). Training for Field Test Procedures for Environmental Sensor Stations (NCHRP Project 6-15) found that in-pavement type sensors are "extremely sensitive to solar radiation" and work best when proper shading techniques are implemented. Also the in-pavement sensors were found to require being "thoroughly dried (for example with a heat gun)" in order to sense a dry condition (*SRF Consulting Group 2006*) In the case of the Oregon project, the researchers are looking for sensors that can test for a variety of conditions including precipitation, freezing, and so forth. As a result, the focus of this review will not be solely on sensors capable only of freezing point temperature measurements. In the following paragraphs, some of the commercially available weather sensors identified during the literature review will be briefly described. Please note that most of the information provided was obtained from the manufacturers' websites.

A sensor known as the IRS31, manufactured by Lufft, is an in-pavement sensor which combines the passive freezing point principle with the microwave radar for liquid depth and the dielectric method for surface condition determination. Road surface temperature is measured from -40°C to 70°C with 0.1° resolution. The freezing temperature is determined from -20°C to 0°C with 0.1° resolution. The water film depth is measured from 0mm to 4mm with 0.01mm resolution. The road condition is characterized as dry, moist, wet, residual salt, freezing wet/black ice, critical, or undefined (*Lufft 2010*). Independent testing showed that the IRS31 sensor accurately measured road surface temperatures, but the sensor often displayed "undefined" surface conditions when the roadway was wet or moist and never displayed "residual salt" despite many roadway salt applications (*Jonsson 2010*). Figure 2.7 shows an IRS31.

Figure 2.7: Lufft IRS31

Vaisala produces a similar in-pavement sensor known as the FP2000. This sensor also measures surface temperature and pavement conditions by determining “if water or a chemical solution is on the pavement” (*Vaisala 2011*). Road surface temperature is measured from -51°C to 80°C and water film depth is measured from 0.3 cm to 1.27 cm; resolutions for these measurements are not published. The characterization of the road surface state is output as dry, damp, wet, chemical wet, watch (caution), and snow/ice warning (*Surface Systems, Inc. 2006*) The average time between failures claimed by the manufacturer is 40,000 hours (*Vaisala 2011*). Figure 2.8 shows a FP2000 sensor.

Figure 2.8: Vaisala FP2000

A final in-pavement sensor, the Road Condition Sensor 3565 is produced by Aanderaa Data Instruments. This instrument measures surface temperature, freezing point temperature, dry or wet surface status, and has an optional optical snow detector. Road surface temperature is measured from -43°C to 48°C with 0.1° resolution. The freezing temperature is determined from -22.5°C to 0°C. Road condition is determined as either wet or dry and the optional snow sensor characterizes the condition as either snow or no snow (*Aanderaa Data Instruments 2010*). Figure 2.9 shows the Road Condition Sensor 3565.

Figure 2.9: Aanderaa Road Condition Sensor 3565

2.5.2 Noninvasive Sensors

Non-invasive sensors are mounted apart from the road surface, either above the roadway or at the roadside, and use spectroscopic methods, thermal radiation, and infrared radar methods to determine surface weather conditions from a distance. Infrared radiation and thermal radiation are measured to determine the temperature of the road surface. Spectroscopic measures are used to determine roadway surface conditions (dry, damp, wet, ice, etc.) remotely. Friction metrics can be calculated from the temperature and surface conditions (*Jonsson 2010*).

One non-invasive sensor, the NIRS31, is manufactured by Lufft. A pyrometer that monitors thermal radiation is used to measure surface temperatures. Optical spectroscopy is used to determine road surface conditions and water film depth on the roadway. Friction is calculated based on the spectroscopic measurements taken. Road surface temperature is measured from -40°C to 70°C with 0.1° resolution. The water film depth is measured from 0 µm to 2000 µm with 0.01 µm resolution. Friction is calculated and given as a value between 0 and 1 with 0.01unit resolution. The road condition is characterized as dry, damp, wet, snow/ice, or critical wetness (*Lufft 2011*). Figure 2.10 shows an NIRS31.

Figure 2.10: Lufft NIRS31

Vaisala produces two non-intrusive weather sensors, the DST111 temperature sensor and the DSC111 road condition sensor. The DST111 measures infrared radiation to determine road surface temperatures. The DSC111 uses spectroscopic methods to determine roadway conditions and water film depths. Road surface temperature is measured from -40°C to 60°C with 0.1° resolution. The water film depth is measured from 0 mm to 2 mm with 0.01 mm resolution. The friction is calculated and given as a value between 0 and 1 with 0.01unit resolution. The road condition is output as dry, moist, wet, snow/frost, ice, or slush (*Vaisala 2010a, Vaisala 2010b*). The DSC111 was independently tested along with five other weather sensors, two non-invasive sensors, and three in-pavement sensors, and was found to be reliable and recommended for use above all others. The DSC111 was "very responsive toward changes in road surface state" and the friction metrics determined by the sensor were found to be reasonable when compared to a SAAB tire type friction tester for dry, wet and snowy conditions (*Jonsson 2010*). Figure 2.11

shows a DST111 with a DSC111. The reader should consult the following section for more information on these sensors in use.

Figure 2.11: Vaisala DST111 (left) and DSC111 (right)

Another noninvasive sensor that is manufactured by a Swedish company is known as the Sensice ice detector. This sensor uses infrared spectroscopy to determine the roadway conditions from three to 15 meters away. The sensor characterizes roadway conditions as dry, wet, clear ice, snow, sleet, or wet clear ice. The sensor takes no direct temperature measurements (*Sensice 2010*). Figure 2.12 shows the Sensice ice detector.

Figure 2.12: Sensice Ice Detector

High Sierra Electronics produces a non-invasive sensor known as IceSight model number 5433. This sensor utilizes laser and electro-optical technology to determine the surface condition from up to 50 feet away. Monitoring near infrared spectral differences allows the sensor to determine between different states of water on the road (water, snow and ice). The reported sensitivity of the sensor is plus or minus 4°F for surface temperature, plus or minus 1°F for ambient temperature, 0.01" of ice and water, and 0.05" for snow (*Gannett Fleming, Inc. 2007*). Figure 2.13 shows the High Sierra Electronics 5433 Sensor.

Figure 2.13: High Sierra Electronics 5433 Sensor

2.5.3 Weather Sensors in Use

As part of a larger NCHRP report in 2006 on testing and calibration methods for RWIS sensors, a survey of the use of pavement condition sensors was completed by nineteen (19) state DOTs (*SRF Consulting Group 2006*). It was found that 82% of the responding states used the FP2000 sensor from Surface Systems Inc. (SSI), now Vaisala, for roadway conditions (wet or dry). The three other sensors used were reportedly from Vaisala, Nu-Metrics (now Vaisala), and one unidentified manufacturer.

A similar survey was administered by the Pennsylvania DOT for an investigation into the future of RWIS (*Gannett Fleming, Inc. 2007*). This survey was completed by 26 state DOTs. Fifty percent of respondents reportedly use some Vaisala equipment, 36 percent used Quixote (now Vaisala) equipment, and 73 percent used SSI (now Vaisala) equipment. Eighty-eight percent of respondents indicated the sensors were being used to measure road surface condition (wet or dry).

Specific examples of non-invasive sensor use included the Vaisala DSC111 sensor being used in Yakima County, Washington; Aurora City, CO; North Dakota; Virginia; Alaska; British Columbia; Quebec; Ontario; Finland; Sweden; UK; and Germany (the specific use of these sensors was not indicated by the vendor, but it could be assumed to be surface state and friction) (*Vaisala 2006*). These reported users of the DSC sensor have been reported by Vaisala and have provided data that shows positive accuracy and reliability characteristics from the sensor's deployment. The reader is cautioned however that these optimistic reports are provided by the equipment vendor, not an unbiased third party evaluator.

A project conducted by the Aurora pooled fund (an international partnership of public agencies performing studies of RWIS) in Ontario and North Dakota was conducted to determine the accuracy and usefulness of the Vaisala DSC111 and DST111 (*Aurora 2010*). The project compared DSC111 data to an existing in-pavement sensor (Lufft IRS31) and friction data to a Traction Watcher One friction tester and a Halliday RT3 friction tester. Results indicated that the DSC111 sensor outputs for temperature and surface condition (wet, dry, etc.) were comparable to the in-pavement sensors. The friction testing results were vague, with concern over the DSC111's friction data at low friction ranges noted.

2.6 CONCLUSION

This chapter has summarized the literature pertaining to weather-responsive variable speed limit systems, both in the U.S. and internationally, as well as other, general VSL systems. Weather responsive VSL systems were used in a variety of applications (rain, fog, snow), and primarily deployed on high volume roads. No weather-responsive VSL systems to date have focused on interchange ramps. Different approaches employed to set posted speed limits for weather-responsive VSLs, including the use of set algorithms/data processing, as well as manual observations where an operator changed speed limits based on viewed conditions. In general, the weather-responsive systems deployed to date have shown to have different, positive impacts on reducing crashes and lowering speeds.

General VSL systems were found to be deployed by agencies to address a variety of safety and operational issues. These systems relied on a variety of data inputs to determine appropriate speed limits. This included loop detector data for speeds and lane occupancy/traffic volumes, closed circuit television for manual observation, and other inputs. The speed limits for each system were determined manually or automatically, based on data inputs and the sophistication of the system itself. These general VSL systems were typically shown to be effective when evaluations were made, although such evaluations were not made for all systems.

The literature review also examined other weather-responsive systems that were not necessarily VSLs, but did provide some form of motorist warning. These systems were deployed to address different safety and operational concerns, using weather data to activate different technologies, such as dynamic message signs, to provide information to motorists. While specific speed limits were not set or provided by these systems, they still were observed in general to be effective in lowering vehicle and/or reducing crashes.

The final portion of the literature review examined the different types of weather sensors available for determining pavement conditions (and in some cases, friction/grip). Two general types of sensors are available, invasive and noninvasive. Invasive sensors (in-pavement sensors) are installed in the pavement level with the road surface and can use different sensing technologies in determining conditions. Noninvasive sensors are installed on the roadside or somewhere over the road surface and use non-contact means of monitoring weather and surface conditions. During the course of the sensor review, it became apparent that Vaisala was the primary vendor in the sensor market, and the firm's DST111 and DSC111 system appeared to hold promise for use in a weather-responsive VSL system. These sensors, working in tandem, are capable of measuring roadway conditions (wet, snow, ice) and water film depth, as well as temperature. They are also capable of measuring friction as a calculated as a value between 0 and 1, with 0.01 unit resolution. Such a measure is expected to be useful in setting variable speed limits on curving interchange ramps, where different amounts of moisture/precipitation can have a dramatic effect on pavement condition and friction. While independent testing found the system to be “very responsive toward changes in road surface state” and friction metrics to be reasonable when compared to a SAAB tire type friction tester for dry, wet and snowy conditions, discussions with ODOT project personnel concluded that further testing of the sensor under different conditions was necessary before incorporating the sensors into any future VSL system. This testing is the focus of a later chapter of this report.

3.0 CONCEPT OF OPERATIONS

The Concept of Operations (Con Ops) for the variable speed limit (VSL) system at the US Highway 26 / OR Highway 217 Interchange in Beaverton, OR is in Appendix A. It includes the scope of the project, referenced documents, the system concept, stakeholder operation descriptions, the system overview, and operational scenarios. This chapter presents the highlights.

The primary goal of this project is to employ variable speed limits to address wet weather and pavement crashes at the US26/OR217 Interchange. The specific ramps included in the VSL system include the US26 eastbound to OR217 southbound ramp, the US26 westbound to OR217 southbound ramp, and the OR217 northbound to US26 westbound ramp. Figure 3.1 presents an overview of the project interchange and the respective ramps.

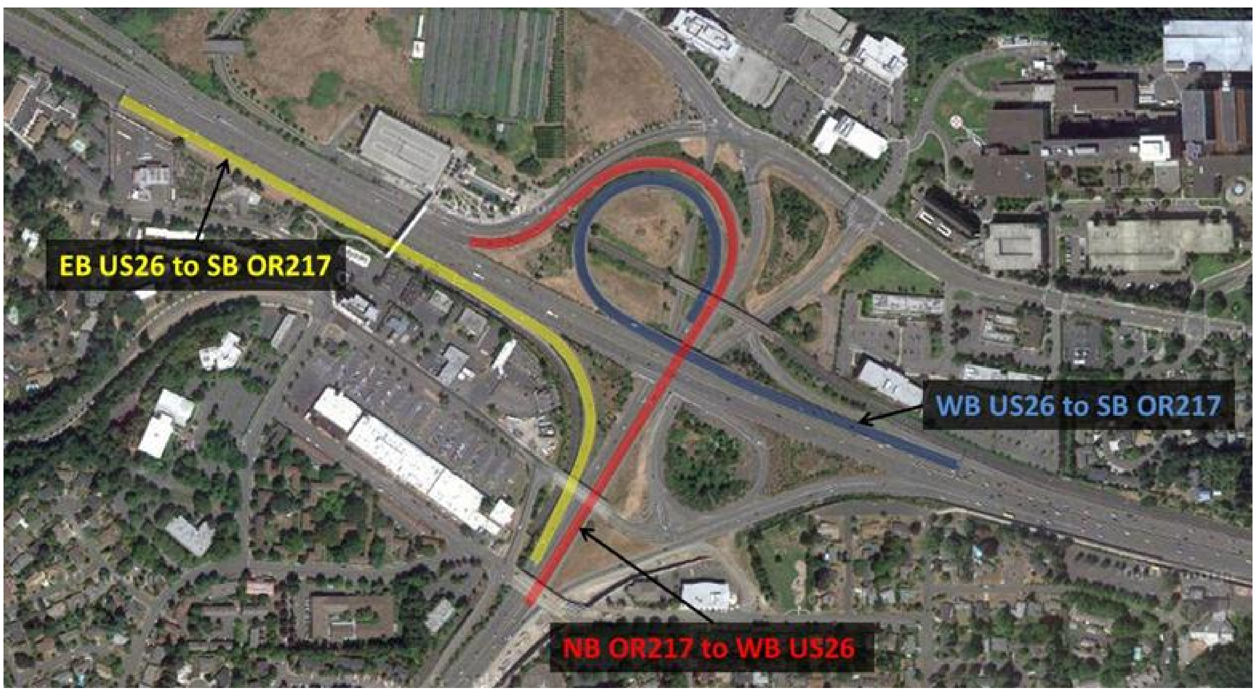

Figure 3.1: US26/OR217 site

3.1 PURPOSE FOR SYSTEM IMPLEMENTATION

Traffic data of the US26/OR217 interchange in Beaverton, Oregon indicates that over 60,000 vehicles per day collectively use the interchange ramps. Crash data provided by the City of Beaverton has shown that one or more "loss of control" crashes per day have been observed during wet pavement conditions, with secondary crashes occurring on many occasions. Historically, once wet pavement conditions occur at this site, crashes classified as "loss of control" increase. While the site has traditional passive signage and flashing beacons in place, crashes continue to occur. ODOT personnel have concluded that additional measures are necessary to address the problem.

This project seeks to reduce the occurrence of wet weather crashes on the interchange ramps of the US26/OR217 interchange through the use of a weather-responsive variable speed limit system. Such a system will post appropriate speed limits based on weather conditions, with the intent of lowering motorists' speeds accordingly. The system may also incorporate active warning signs in the form of dynamic message signs (DMS) to provide advanced warnings to motorists in advance of the ramps. As motorists lower their speeds for different weather conditions, they will be traveling at safer speeds for prevailing conditions, with a corresponding reduction in crash occurrence expected.

3.2 PROJECT OBJECTIVES

The specific project goals to reduce wet weather crashes include:

- Develop an advanced weather-responsive variable speed limit adjustment system to be deployed by ODOT at the previously cited ramps of the US 26/OR 217 interchange. This involves identifying and evaluating system components (ex. sensors, processors, etc.) to detect weather conditions and support the overall functions of the system
- Develop methodologies and algorithms for setting adjustable speed limits based on weather conditions. This will support the determination of appropriate speed limits based on current weather conditions.
- Assess the effectiveness of the system in reducing average vehicle speeds and the number of speed-related crashes and/or incidents at the study site under different types of weather conditions and posted speed limits. This will be achieved through examining speed and crash/incident experience before and after system deployment.
- Develop guidance to assist in future deployments of similar systems at other locations in Oregon. This will allow for transferability of such systems to sites with similar safety problems.

3.3 SYSTEM CONCEPT

The concept of the VSL system is to adjust the speed limit on the interchange ramps during inclement weather to influence driver behavior – primarily to reduce speeds based on the presence of wet pavement. Using pavement condition and weather sensors at the site, different road weather conditions can be detected and established. Based on the current road weather and pavement conditions at the site, speed limits can be adjusted accordingly using VSL signs. The operation of the system will involve this general sequence of events:

- Weather and pavement sensors (non-invasive) monitor precipitation occurrences, type, accumulations, pavement temperature, ambient temperature, and an estimation of grip level of the surface of the roadway.
- Road condition changes are identified based on the detected conditions processed by the system controller, using threshold values determined by the system algorithm developed prior to deployment.

- Upon identification of changes in current conditions, the system logic automatically changes the signage for the desired control strategy (e.g. change from advisory to regulatory posted speed limit of 25 mph).
- The system continuously monitors current conditions, compares those conditions to the established threshold values, determines control strategies/speed limits, and implements necessary changes in signage.

3.4 WEATHER SENSORS

Road weather sensors come in an array of types with many capabilities. Sensors that focus on the condition of the pavement on the roadway are of interest to the system described here and come in two major types: in-pavement and non-invasive. In-pavement sensors are puck shaped sensors that are set in the roadway and can measure pavement temperature, precipitation occurrences, precipitation type, and depth of precipitation. Non-invasive sensors use spectroscopy principles to measure road surface conditions from above the roadway. Non-invasive sensors can measure pavement temperature, precipitation occurrences, type, and depth and give an estimate of the level of grip of the pavement. Non-invasive sensors which provide information on both pavement condition and grip are to be used in the system presented here. Additionally, a road weather information system (RWIS) to be installed at the interchange site in conjunction with the VSL deployment will provide supplemental data from sensors such as precipitation occurrence detectors and ambient temperature sensors.

Wet and extreme weather crashes likely occur on the interchange ramps due to a loss of grip between the wet pavement and vehicles travelling too fast for the conditions of the roadway. To monitor when the roadway exhibits potentially dangerous conditions, sensors will need to monitor precipitation occurrences, type, depth, and pavement temperatures. Grip levels can only be measured by non-invasive sensors and this is why such a pavement condition sensor has been selected as the primary sensor for the VSL system.

3.5 VARIABLE SPEED LIMIT SIGNS

The VSL signs will be installed at the beginning of the three ramps being investigated (US26 EB to OR217 SB, US26 WB to OR217 SB, and OR217 NB to US 26 WB). The signs will be placed on the roadside(s) where sufficient space is available. Regulatory VSL signs will be placed at the point of curvature (POC) of the ramps and the advisory sign with LED numbers will be placed 100 feet upstream of the POC. Figure 3.2: Electronic VSL Sign shows a typical ramp geometry with POC and a location 100 feet upstream of the POC identified as potential sign locations. The figure also shows the existing locations for the exit and advisory speed signs. The existing advisory speed signs will be removed upon the deployment of the proposed VSL system.

3.6 VSL SIGN TYPES

Two types of VSL sign are proposed for use as part of this project. One type is a full matrix type variable electronic sign. The other is a more traditional static background sign with a light emitting diode (LED) panel that changes only the numerical speed part of the sign.

3.6.1 Variable Electronic Sign

A full matrix variable electronic sign is capable of displaying an electronic version of static signage as well as dynamic flashing graphics (e.g. simulated flashing beacons above a static sign). For the purposes of this project, the sign will have the ability to display a regulatory speed limit sign with any numerical speed in the appropriate colors that conform to MUTCD guidance. When the sign is not activated, (i.e. when an advisory speed limit is in effect during dry conditions), the electronic sign will be blank (blacked out) and convey no information. Figure 3.2 shows an example of the electronic full matrix VSL signage.

Figure 3.2: Electronic VSL Sign

The regulatory electronic VSL signs will be placed on the right side of the road at the point of curvature of the ramps. This point of curvature is the start of the most restrictive curve encountered by the driver using the ramp.

3.6.2 Static Sign with Variable LED Numbers

A static background curve warning sign attached to a dynamic advisory speed sign with LEDs is proposed for the system to work in coordination with the full matrix regulatory VSL sign described previously. Such warning / advisory signs would be a traditional static warning sign similar to those already present on the ramps that displays the ramp geometry on the metal portion of the sign and the advisory speed limit on a changeable LED sign attached below the metal sign. The static portion of the sign would always display the ramp geometry since it has no electronic features, but the LED speed would only be displayed when applicable and would be blank when not activated. Figure 3.3 illustrates this sign, showing the static background with LED advisory VSL signage below it.

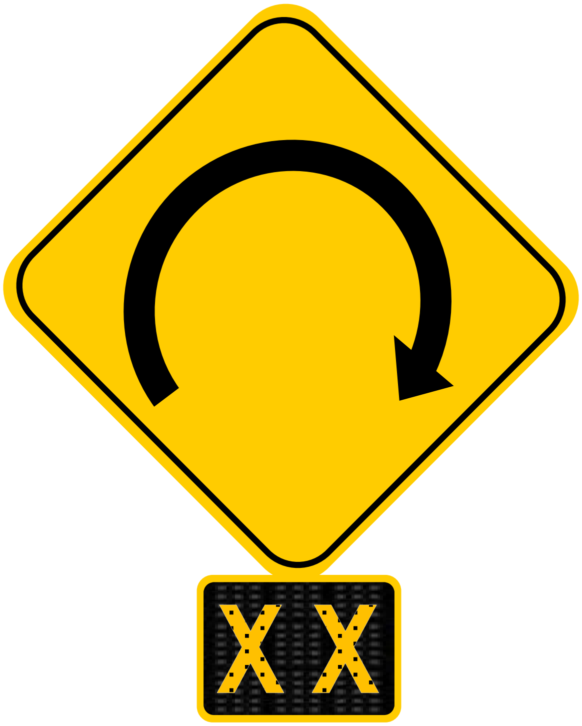

Figure 3.3: Static background advisory sign with LED VSL

The advisory speed signs will be placed at the roadside at 100 feet upstream from the regulatory VSL signs. This conforms to the MUTCD recommendations that advisory warning signs be up to 100 feet upstream of the point of curvature of a ramp and at least 100 feet from any other signs.

3.7 ADVANCED WARNING SIGNS

Advanced warning signs will be used sufficiently upstream of the ramps to notify drivers that they may encounter a reduced speed limit zone ahead. These signs would be Dynamic Message Signs (DMS) and only activated when the reduced speed limit zone is in effect on the ramps being investigated. The sign would display a message predetermined by ODOT to alert drivers on the ramps that they are approaching the reduced speed limit zone. The DMS should be equipped with flashing beacons, either within the border of the DMS or externally attached to the sign to capture driver attention. These beacons will flash only when reduced speed limits are in effect. Figure 3.4 shows an example of potential advanced warning sign and posted message.

Figure 3.4 Advanced warning sign

3.8 SYSTEM OVERVIEW

The VSL system is controlled by software that will use an algorithm to determine recommended speeds. The algorithm determines appropriate speed limits during different pavement and weather conditions. The possible weather conditions are: dry pavement with no rain, light to moderate precipitation with minor reductions in pavement grip, and heavy precipitation with significant reductions in pavement grip. The VSL speed control software employed in the system will comply with the applicable standards and procedures for changing speed limits on Oregon freeways. The system will:

- not change speed limits more than once every 5 minutes,
- not display a speed limit below 20 mph,
- only display speed limits in 5 mph increments, and
- will automatically assess weather conditions every 60 seconds.

A separate system requirements document will detail specific functional requirements.

3.9 COMMUNICATIONS SYSTEM

Existing infrastructure will be used as part of the main communication system between the TMOC and sensors, processors, controllers and signs in the field. The existing infrastructure at the site is a network of fiber optic cable and copper wire.

3.10 SYSTEM CONTROL

The existing TMOC in Portland, OR will operate and oversee the VSL system. Changes in road weather conditions will be detected automatically and appropriate speeds will be posted without the need for direct operator involvement. The operator will be informed of changing road weather conditions by alarms triggered when posted speed limit changes are warranted. Incidents will be monitored by the operator using radio communication, telephone calls, and from CCTV cameras at or near the site. The operator may expect to first receive an alarm of lowered speed limit, observe automatic speed limit change being posted (via system outputs, not CCTV), and verify the weather conditions using the existing on site camera, and any other cameras that may be added at the project site.

3.11 OPERATIONAL SCENARIOS

The possible operational scenarios for the VSL system include:

- Dry Pavement Operations
- Wet or Extreme Pavement Operations (three conditions)
- Failure Operations (single component and entire system failure)

3.12 CONCLUSION

This chapter has provided a general overview of the Concept of Operations developed for the prospective VSL system. Additional details related to this concept are provided in Appendix A of this report. The concept of the VSL system is to adjust the speed limit on the interchange ramps during inclement weather to influence driver behavior – primarily to reduce speeds based on the presence of wet pavement. Using pavement condition and weather sensors at the site, different road weather conditions can be detected and established. Based on the current road weather and pavement conditions at the site, speed limits can be adjusted accordingly using VSL signs.

4.0 REQUIREMENTS

This section presents a brief overview of the System Requirements Specifications (SRS) for a wet weather variable speed limit system to be employed at the US Highway 26 / OR Highway 217 Interchange in Beaverton, Oregon. The complete specifications can be found in Appendix B. Requirements are used to define what the system should do, how well it is to perform, and under what conditions or constraints. In defining the requirements for the website, the researchers recognized that it is a challenge to specify requirements for a system specific to an interchange that has not been developed before. As a result, this document is considered to be a work in progress, with requirements added and modified as changes occur.

4.1 OVERVIEW OF REQUIREMENTS

System Name: Variable Speed Limit System for Wet and Extreme Weather

System Acronym: VSL or VSL system

System Owner Information: ODOT ITS Unit Manager (Galen McGill)

The requirements are broken out into several categories including Security, System Performance, Software, Hardware, Materials, Training, and Service Processes, each of which are described later. The Software requirements and specifications are further broken down by Work Process (Functions) and Unit Tasks (Unit Processes).

The intended audience for the Requirements document is ODOT business management and staff, Transportation Application Development (TAD), Management, system architects, system, data, and business analysts, developers, testers, and those responsible for implementing and maintaining the software.

After the introduction, the major topics covered in the Requirements include:

- Project History to provide context for understanding the VSL system and its requirements.
- System Overview that describes the system purpose, objectives, and key issues related to system objectives, scope, and overall feasibility.
- System Requirements with system context relevant to business tasks and system security related to physical and operational requirements (access, data protection, and recovery).
- System Performance requirements including but not limited to network response time, maintainability, portability, and adaptability to different environments.
- Assumptions and Dependencies that could affect requirements, including but not limited to characteristics of the operating environment and interface design convention.
- Software Requirements for the construction and implementation of the system.
- Data Requirements for the operation of the VSL system.
- Hardware Requirements for support infrastructure configurations.

- Service Requirements for email, database, data backup, and data restoration/disaster recovery services.
- Trained Personnel Requirements to establish the skills and knowledge necessary to operate the system.
- Materials Requirements for physical forms and similar materials needed for the system.
- Process Requirements for work processes, including manual and automated unit tasks applied by the user when using the system.
- Facilities Requirements for developing, testing, and operating the system, including a building, room, furniture, etc.
- Incomplete Requirements for any requirements that are believed to exist, but have not been covered in any other section of the document. Incomplete Requirements must be resolved or defined as targeted for future releases of the system before the document is finalized.

4.2 CONCLUSION

This section presented a brief overview of the System Requirements Specifications for a wet weather variable speed limit system to be employed at the US Highway 26 / OR Highway 217 Interchange in Beaverton, Oregon. The complete specifications can be found in Appendix B. Requirements are used to define what the system should do, how well it is to perform, and under what conditions or constraints. The requirements are broken out into several categories including Security, System Performance, Software, Hardware, Materials, Training, and Service Processes, each of which are described in detail in the Appendix.

5.0 SENSOR TESTING

This chapter covers the testing of the Vaisala DSC111 (Remote Road Surface State Sensor) for its use in the prospective VSL system planned for the US Highway 26 / OR Highway 217 Interchange. The DSC111 and DST111 (Remote Road Surface Temperature Sensor) are typically used in tandem to ensure the best possible measurements. The DST111 measures road surface temperature, air temperature, relative humidity, and dew point. These DST111 measurements can then be used in conjunction with the DSC111 measurements to fully understand road conditions. The DSC111 measures the surface state (dry, moist, wet, frosty, snowy, icy, or slushy) and the depth of water, ice, and equivalent water content depth of snow present. These measurements are then used by the DSC111 to predict the level of grip a vehicle would have on the road surface, which ranges from 0 to 1. The grip number reported by the DSC-111 is a relative measure of expected friction between the road surface and a vehicle's tires. Low numbers (below 0.2) can be thought of as driving on a surface similar to an ice skating rink, while higher numbers (above 0.8) can be thought of as driving on dry pavement. The sensors are typically mounted on a pole at a measuring distance up to 15 meters away from the road surface. Figure 5.1 shows the Vaisala DST111 and the DSC111.

Figure 5.1: Vaisala DST111 (left) and DSC111 (right) (*Vaisala 2010*)

The ability of the sensors to determine the state of the road surface, the amount of precipitation present and the predicted grip level of the road is the primary motivation for their use in the VSL system. These measurements would be used by the VSL system to set an appropriate speed limit for vehicles based on the predicted grip level. However, before the data from these sensors can be incorporated into the proposed VSL system, a good understanding of their accuracy in measuring grip level under different surface conditions was deemed important. The accuracy of the Vaisala sensors was assessed by a suite of laboratory tests simulating various conditions, and is discussed throughout the remainder of this chapter.

5.1 METHODS

The sensor testing was performed at the Montana State University (MSU) Subzero Science and Engineering Research Facility, located on the MSU campus in Bozeman, Montana. This research facility has a number of large, walk-in environmental chambers (cold labs) that can be programmed to precise temperatures for testing. This allowed for sensor tests to occur under a number of different temperature conditions in a fully controlled environment.

5.1.1 Vaisala Sensors

As part of the overall project, the Vaisala DST111 and DSC111 sensors were recommended by the research, approved and acquired by ODOT, and were provided to WTI for testing. The sensors were secured atop a tripod set up in the cold lab and connected via an RS-232 communications cable to a laptop placed outside the lab. Figure 5.2 shows the sensors setup in the cold lab. The free data terminal program PuTTY[3] was used to send commands to and receive data from the sensors. This program allows the user to type commands in a PuTTY command window on the laptop and send them to the sensors. The sensors are also able to send responses and data to the laptop which are then displayed in the same PuTTY command window.

[3] PuTTY is not an acronym, but rather, the name given to the program by its creator.

Figure 5.2: Sensors setup in cold lab

The sensors were positioned so that the distance to the pavement samples was approximately 3 meters and the installation angle was approximately 37 degrees. This was done to comply with the limits for installation values published by the vendor in the sensors user's guides, to fit within the cold lab, and to ensure the DSC111's measurement ellipse was appropriately sized based on the dimensions of the pavement samples. Specifically, the measuring distance of the sensors must be between 2 and 15 meters from the pavement, with an installation angle between 30 and 85 degrees according to the manual. The measurement ellipse is the area on the sample that is measured by the DSC111, and this ellipse becomes larger as the measurement distance increases. The DSC111 Aiming Tool Kit was used to position the pavement samples on the floor to ensure they were being accurately measured.

5.1.2 Pavement Samples

One asphalt sample (9 inches wide, 20 inches long, and 1 inch thick) and one concrete sample (12 inches wide, 16 inches long, and 2 inches thick) were used to simulate roadway surfaces for testing. These samples were chosen from available materials with appropriate dimensions for testing. A silicon barrier was added near the outside edge of each sample to allow water to pond on the surface of the samples. Figure 5.3 shows the two samples.

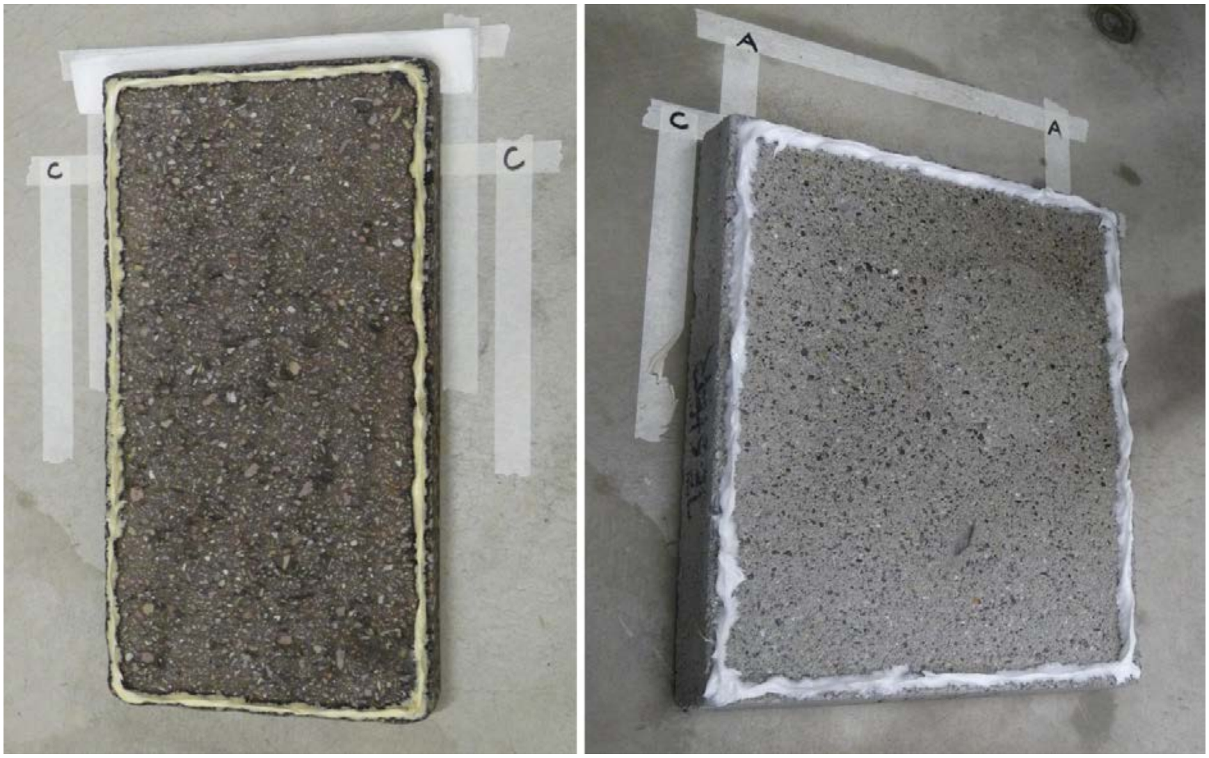

Figure 5.3: Asphalt (left) and concrete (right) pavement samples

5.1.3 Static Friction Tester

The coefficient of static friction (CSF) was measured for comparison to the DSC111 grip number. The CSF is a physical measurement defined as the ratio of the side force needed to overcome static friction and move the tester horizontally (the force measured by the spring scale as it is pulled horizontally to move the tester across the asphalt/concrete) to the normal force (force that exists due to gravity and mass of CSF tester; the weight of the CSF tester) (*Al-Qadi et al. 2002*). If the side force required to move the tester horizontally is equal to the weight of the tester the CSF equals 1.0. The CSF was measured using a steel tester weighing 9.23 pounds, with a 4-inch square of smooth neoprene rubber bottom (durometer rating of 30A). A spring scale was used to measure the side force needed to overcome static friction. Figure 5.4 shows the CSF tester on the concrete sample. The CSF was measured at six different locations on each pavement sample.

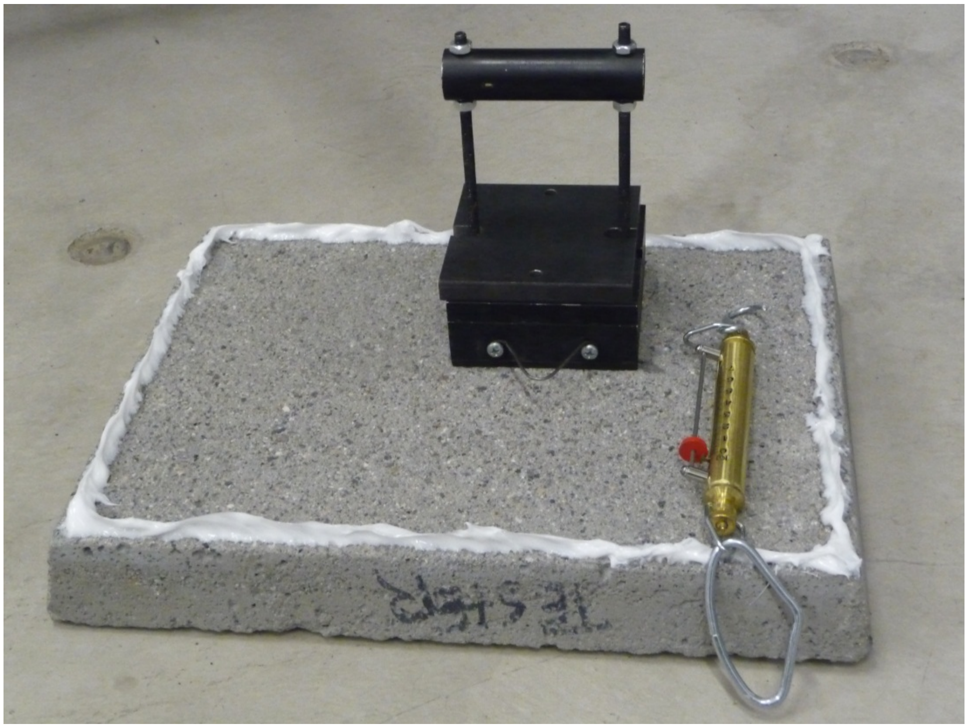

Figure 5.4: CSF tester on concrete sample

5.1.4 Testing Procedure

The laboratory testing simulated a variety of conditions from dry, moist, wet, loose snow, compacted snow, to ice with various depths, as feasible. A summary of the conditions created in the laboratory and their associated temperatures are shown in Table 5.1. The depths were chosen based on the reported capabilities of the DSC111. As suggested in the DSC111 manual, the sensor was calibrated for the dry condition for each sample before changing conditions. For each condition and corresponding pavement sample, the DSC111 output was monitored until the readings stabilized, at which time 12 data points were recorded and compared to the 6 CSF measurements collected from the same sample. Six CSF measurements are the most that can be taken on a sample without overlapping the measurement areas. This is especially important for snowy conditions when the CSF measurement process alters the surface by compacting the snow.

Table 5.1: Laboratory test conditions

Surface State	Depth (mm)	Temperature (°F)
Dry	N/A	45
Dry	N/A	15
Moist	trace	45
Wet	< 1.1 1.1 to 1.9 > 1.9	45
Loose Snow	~2 ~5	15
Compacted Snow	~5 (after compaction)	15
Ice	~1.5	15

The moist condition exists when the surface is visibly damp but no standing water is present. Water was applied with a trigger type squirt bottle set to spray a mist of water (not a stream of water). Figure 5.5 shows the spray bottle being used to apply water to the concrete sample. Wet samples with increasing water depth were created by spraying multiple lifts of water and allowing the DSC111 readings to stabilize between lifts. Water depth was measured using a steel washer of known thickness (1.1 mm) and a nickel of known thickness (1.9 mm). The washer and nickel were then placed on the sample in the water to ensure the correct depth ranges were being tested. Figure 5.6 shows the washer and nickel as used to determine the water depth range being tested.

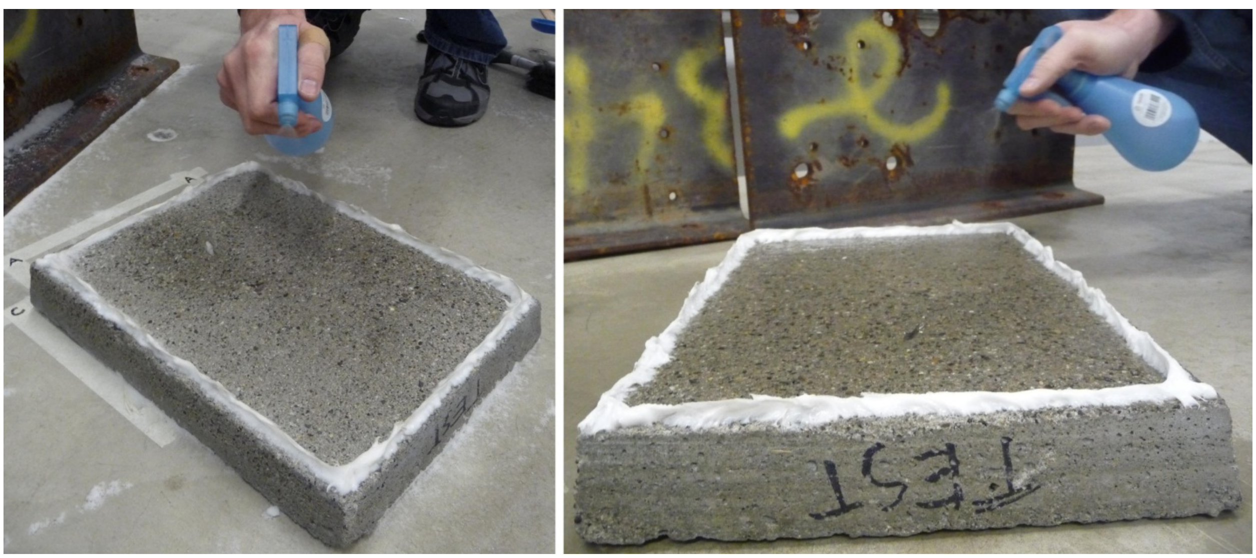

Figure 5.5: Water application

Figure 5.6: Water depth range determination

Snow created by the Subzero Science and Engineering Research Facility was used to simulate loose and compacted snow conditions. The snow was applied to the samples using a No. 14 sieve (as shown in Figure 5.7). As with water, the desired depth of snow was created slowly with multiple lifts, allowing the DSC111 readings to stabilize between lifts. The compacted snow condition was created by applying loose snow with the sieve then carefully placing foam board (used to keep snow from sticking to wood) and a section of plywood onto the sample. The tester then stood on the plywood to gently and uniformly compact the snow. Snow depth was measured by inserting a transparent ruler through the snow. For the compacted snow condition, the depth of snow before and after compaction was measured. Snow density was measured for both the loose and compacted snow conditions using a small cylindrical dish with known volume and a weight scale. Ice was created using the same technique as the water application but each lift of water was allowed to freeze on the sample. The ice thickness was measured using a digital caliper.

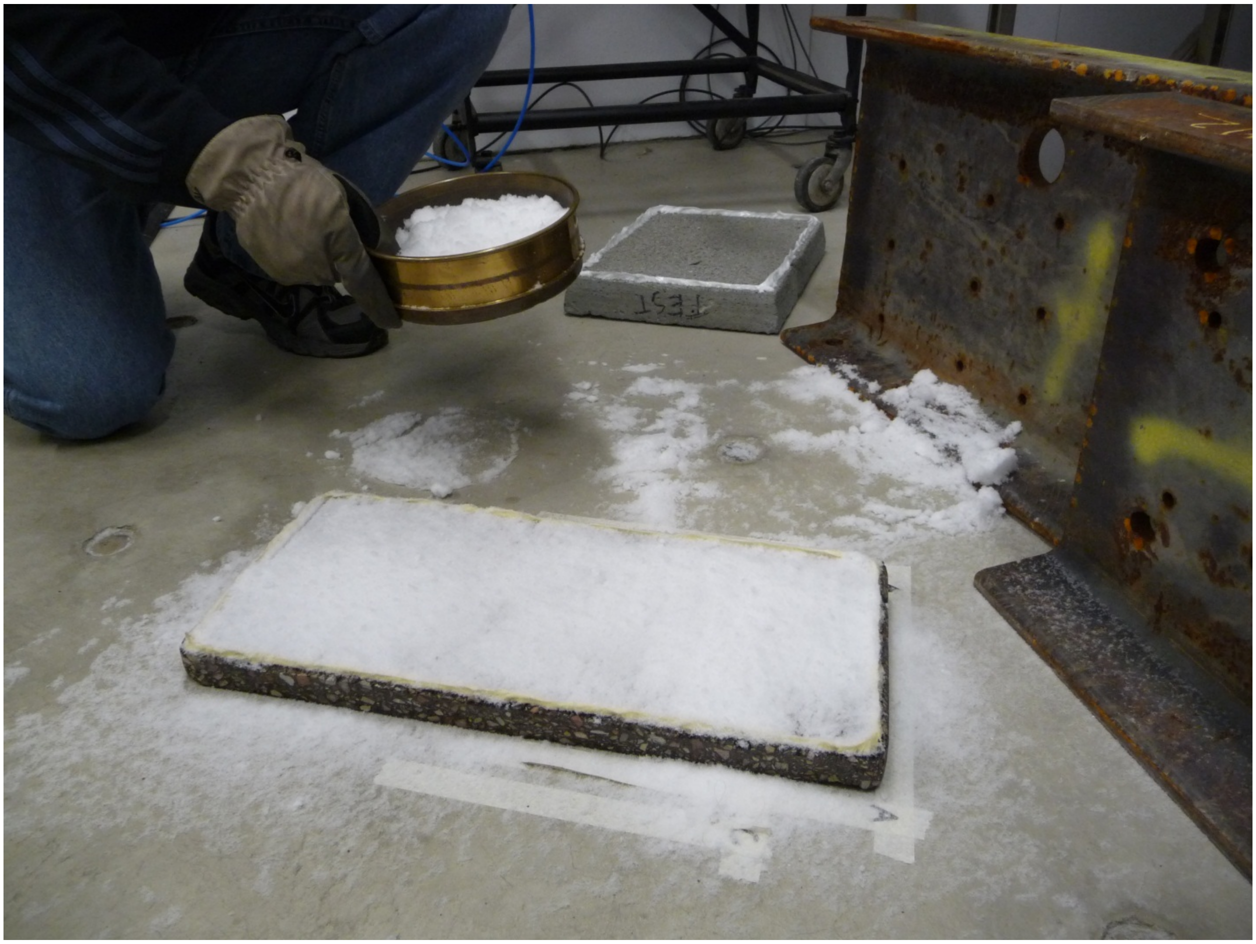

Figure 5.7: Snow application

5.2 RESULTS AND ANALYSIS

The surface state, precipitation depth, and friction measurements reported by the Vaisala sensors were compared to physically measured values from the CSF tester. The air temperatures reported by the sensor were in agreement with the temperatures recorded by a thermocouple installed in the cold lab for all test conditions. The pavement temperatures reported by the sensor were also similar to those collected with a hand-held infrared thermometer for all testing conditions.

5.2.1 Surface Conditions

The DSC111 identified all five surface conditions correctly for both asphalt and concrete samples, as shown in Table 5.2. Furthermore, for the ice condition, the DSC111 initially reported water, then slush and finally ice as the water froze on the sample.

Table 5.2: Comparison of DSC111 reported surface state to actual conditions

Sample	Actual Surface Condition	Depths(mm)	Temperature (°F)	DSC111 State
Both	Dry	N/A	45	Dry
Both	Dry	N/A	15	Dry
Both	Moist	trace	45	Moist
Both	Wet	< 1.1 1.1 to 1.9 > 1.9	45	Wet Wet Wet
Both	Loose Snow	~2 ~5	15	Snowy Snowy
Both	Compacted Snow	~5 (after compaction)	15	Snowy
Both	Ice	~1.5	15	Icy

5.2.2 Precipitation Depth

Precipitation depth measurements were also collected for comparison to the sensor measurements. The depths being tested for water and ice were small (~2 mm and less) and many physical depth measurements were taken and averaged to obtain a single depth measurement for comparison. The asphalt and concrete samples were level but can vary in thickness (surface elevation) by a couple millimeters, as would be expected for any road surface. These surface irregularities cause water depths to be variable across the sample surface. For example somewhere on the sample the water was 0.4 mm deep and elsewhere on the sample the water was 1.0 mm deep. A contour gauge was used to visually assess the surface variations in profile view. Figure 5.8 shows a typical asphalt surface profile, which is generally very smooth with only a few pits shown by the small peaks on the contour gauge. Figure 5.9 shows a typical concrete surface profile, which is considerably rougher than the asphalt sample as shown by the many small peaks and valleys in contour gauge.

Figure 5.8: Typical asphalt sample surface profile

Figure 5.9: Typical concrete sample surface profile

The physical precipitation depth measurements were compared to the sensor measurements for all conditions. The DSC111 reports water and ice depths, but reports snow in water content (wc) depth. The depth and density measurements of the snow were used to calculate equivalent water content depth, which could be directly compared to the DSC111 readings. The comparison between actual depth and DSC111 reported depth is shown in Table 5.3.

Table 5.3: Laboratory test conditions

Sample	Actual Surface Condition	Measured Depth (mm)	DSC111 State	DSC111 Depth
Asphalt	Dry	0.0	Dry	0.00
Asphalt	Dry	0.0	Dry	0.00
Asphalt	Moist	0.0	Moist	0.01
Asphalt	Wet	< 1.1	Wet	0.44
Asphalt	Wet	1.1 to 1.9	Wet	1.52
Asphalt	Wet	> 1.9	Wet	2.95
Asphalt	Loose Snow	2 (snow), 0.37 (wc)	Snowy	N/A (snow), 1.01 (wc)
Asphalt	Loose Snow	5 (snow), 0.93 (wc)	Snowy	N/A (snow),1.26 (wc)
Asphalt	Compacted Snow	5 (snow, compacted) 2.16 (wc)	Snowy	N/A (snow) 1.21 (wc)
Asphalt	Ice	1.4	Icy	1.54
Concrete	Dry	0.0	Dry	0.00
Concrete	Dry	0.0	Dry	0.00
Concrete	Moist	0.0	Moist	0.02
Concrete	Wet	< 1.1	Wet	1.05
Concrete	Wet	1.1 to 1.9	Wet	2.82
Concrete	Wet	> 1.9	Wet	4.87
Concrete	Loose Snow	2 (snow), 0.37 (wc)	Snowy	N/A (snow),0.78 (wc)
Concrete	Loose Snow	5 (snow), 0.93 (wc)	Snowy	N/A (snow),0.82 (wc)
Concrete	Compacted Snow	6 (snow, compacted)3.17 (wc)	Snowy	N/A (snow),0.79 (wc)
Concrete	Ice	1.5	Icy	1.40

For the smooth asphalt sample the DSC111 accurately reported the water and ice depths. For the rougher concrete sample the DSC111 accurately described the ice depth, but the water depth readings do not agree with the physical measurements. Specifically, sensor readings were generally higher than the physical measurements. This is mostly due to the inability of the physical water depth measurement to accurately quantify the presence of water contained in the low areas of the rough concrete surface. That is, if the concrete sample was as smooth as the asphalt sample, the comparison between the physical measurements and the DSC111 reported depths would likely be more similar (as was seen with the smoother asphalt sample).

The snow depths reported by the DSC111 do not appear to reasonably correlate to the physical measurements. The sensor readings varied in a relatively small range and were not highly sensitive to the actual snow water content measurements especially for compacted snow. However, the DSC111 accurately detected the presence of snow and this is critical for the proposed VSL system being investigated. In such a case, detecting the presence of snow may be more important than knowing its depth in the context of a VSL system, as once roadway becomes more snow-covered, grip is compromised regardless of depth, and slower speed limits would be posted.

5.2.3 Friction

The grip number reported by the DSC111 was compared to the CSF measurements taken for each condition. The DSC111 grip number is intended to represent the friction of the road surface as experienced by a vehicle traveling on the road, i.e., a vehicle in a state of motion. The CSF is a physical friction measurement based on the principle that "the friction coefficient is a measure of the resistive forces of movement between two opposing object surfaces" (*Al-Qadi et al. 2002*). The CSF tester measures the horizontal force needed to overcome the resistive horizontal component of the normal force to initiate movement. While these two friction metrics may not be expressing the exact same characteristic, they do both attempt to describe the grip between the tire and pavement and were therefore compared with the understanding that the absolute scales used for the CSF measurements and the DSC-111 grip numbers are not necessarily equivalent. The DSC111 has an absolute range of 0 to 1, with 0 being very slick and 1 being high friction. The CSF by definition does have a lower limit of 0 but does not have an upper limit of 1, and often when a rubber surface is involved the CSF is larger than 1. However, it is reasonable to believe that the two measures should be highly correlated, as both are indicators of the surface friction, and thus skid resistance properties. Considering these factors, and the sensor's potential use for road weather conditions, sensible changes in friction measurements from one pavement state to another are likely more meaningful than the specific values of the static friction or the grip number.

For the following analysis, the six CSF measurements are averaged for comparison to the average of the twelve DSC111 grip numbers per test condition. The variability for both CSF and DSC111 grip numbers was small. The asphalt sample's CSF measurements ranged from 1.17 for dry pavement to 0.45 for compacted snowy pavement. The DSC111 grip ranged from 0.82 for dry pavement to 0.11 for snowy and icy pavements. Figure 5.10 shows the CSF measurements and the sensor grip number readings for all surface conditions tested for asphalt. All raw CSF numbers are higher than DSC111 grip readings, with significant drops in both CSF and grip numbers observed for snowy and icy pavement. It is interesting to see the grip number readings decreasing with the water depth on the surface, while the CSF measurements remained relatively constant and very close to the dry conditions.

Figure 5.11 shows the same data for the concrete sample. Again all CSF values are higher than DSC111 grip numbers, but both show significant decreases for snowy and icy pavements. Other trends shown in this figure are similar to those exhibited in Figure 5.10 for the asphalt pavement. One minor exception is the more significant decline in the CSF measurement for wet conditions in comparison to those for dry conditions.

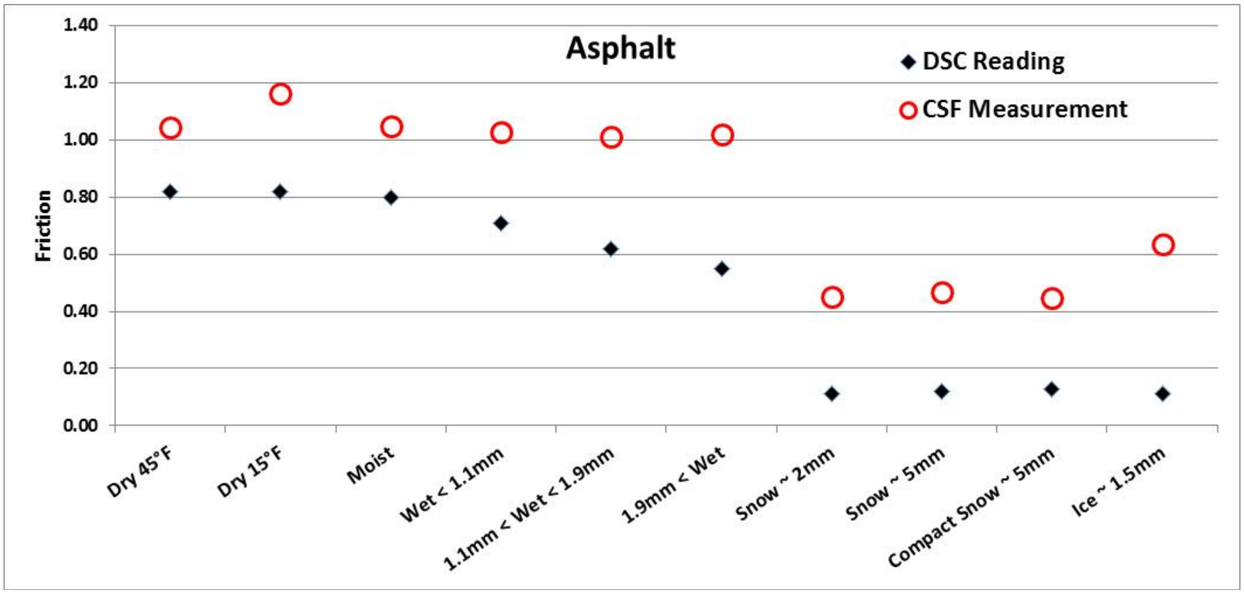

Figure 5.10: Raw CSF and grip measurements on asphalt

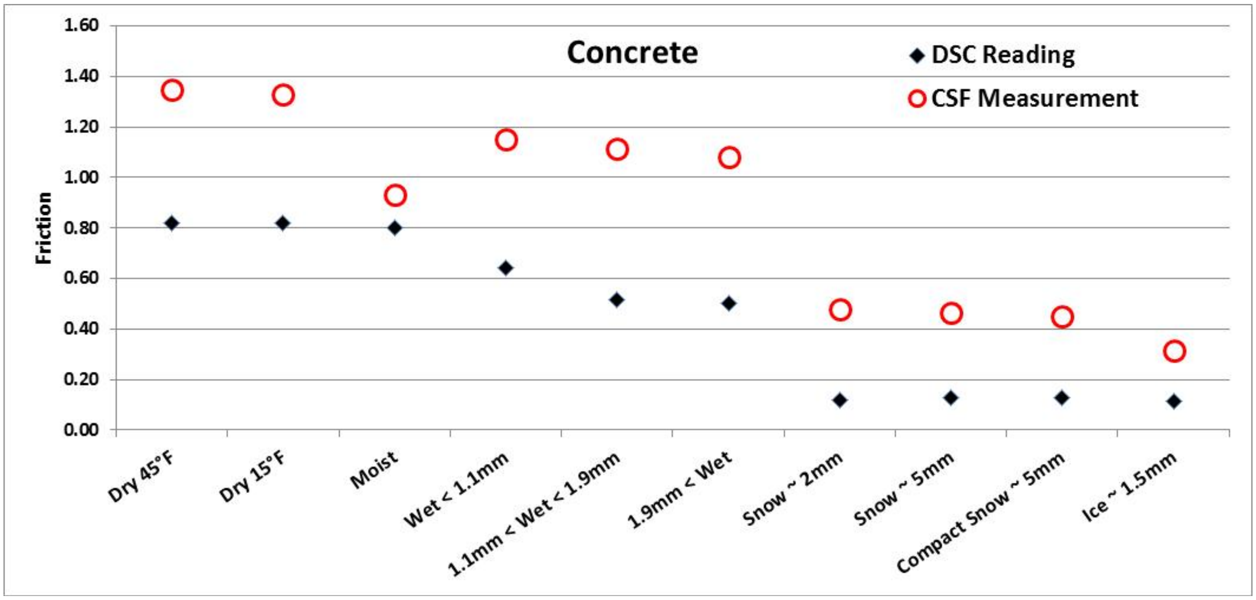

Figure 5.11: Raw CSF and grip measurements on concrete

To better compare CSF values to grip numbers the CSF numbers are adjusted down by percent difference in the CSF and grip number for the dry condition at the relevant temperature. This effectively sets the CSF for the dry condition equal to the grip number for the dry condition and all other CSF values are also reduced by this percentage. Figure 5.12 and Figure 5.13 show the adjusted CSF values compared to the raw grip number for asphalt and concrete, respectively.

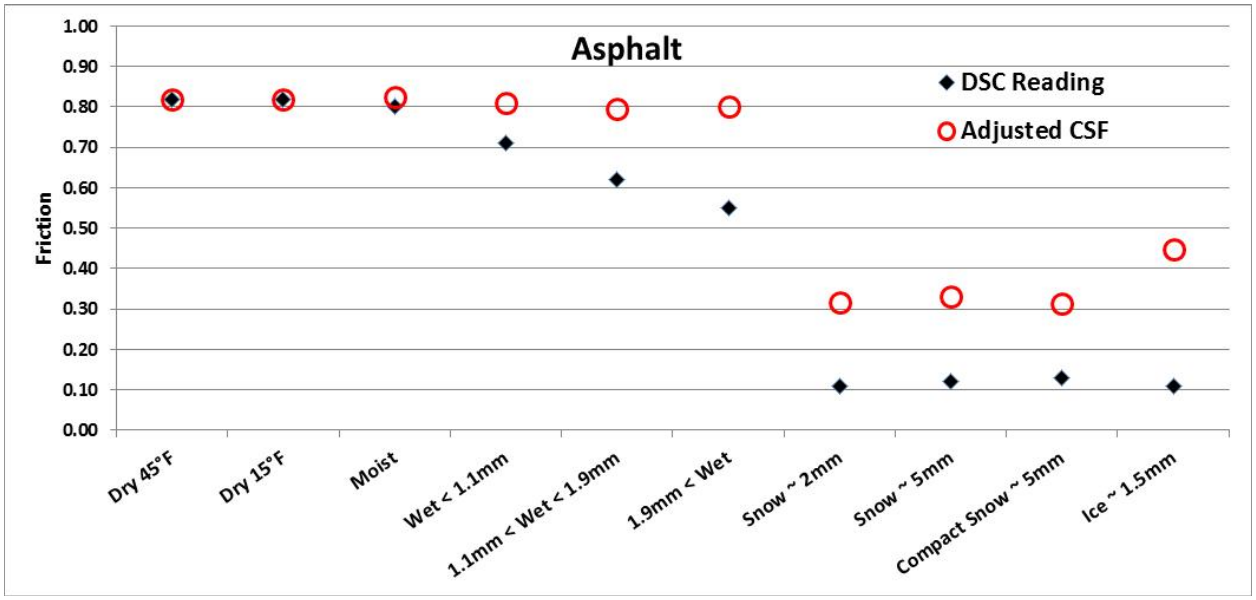

Figure 5.12: Adjusted CSF and raw grip measurements on asphalt

The adjusted CSF measurements are similar for dry and wet conditions, whereas the DSC111 predicts reduced friction with increasing water depth. This may be because the CSF tester displaces almost all of the water from the smooth asphalt surface and the resulting CSF measurement is being performed with very little water remaining between the rubber and asphalt. The adjusted CSF for icy and snowy pavement is somewhat different than the grip number for icy pavement but both are considerably lower than dry measurements. This difference may or may not be important when making road weather based decisions. It is more likely that knowing that a friction is below 0.4 is more meaningful than knowing if the friction is 0.1 vs. 0.3, as in either case friction would be quite poor for vehicles.

For concrete, the adjusted CSF values correlate somewhat well with wet concrete grip numbers. The moist concrete CSF is significantly different than the moist grip number. Snowy and icy adjusted CSF values were slightly higher than DSC readings. Again the difference in very low friction values may not be as important as simply knowing the friction is below some threshold that presents an unsafe roadway surface.

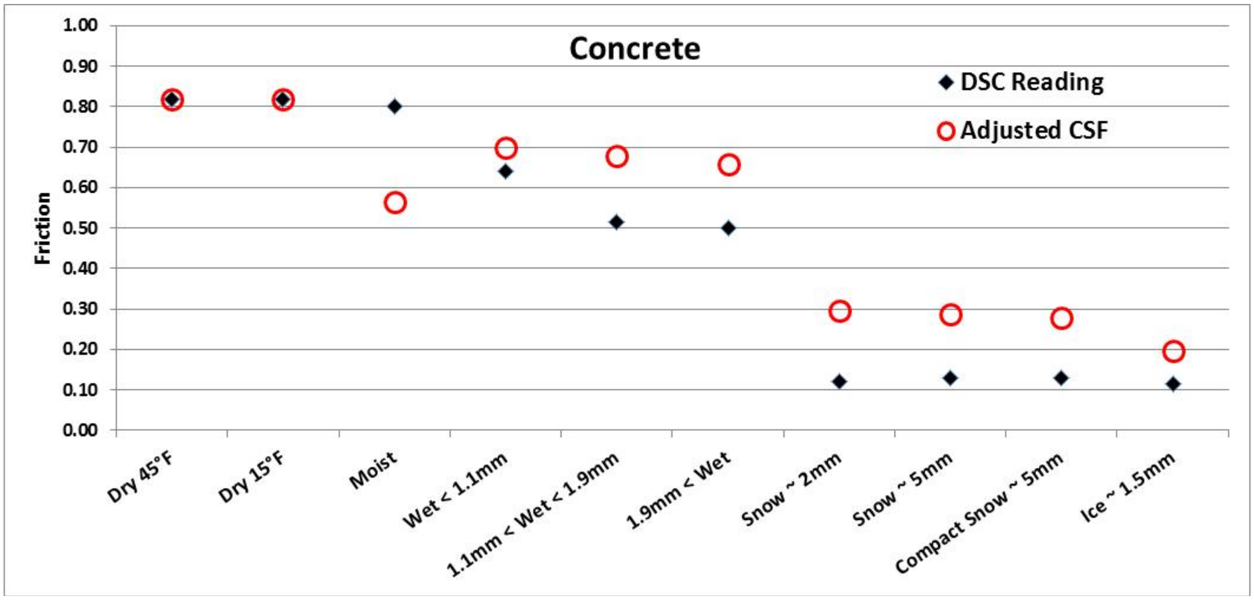

Figure 5.13: Adjusted CSF and raw grip measurements on concrete

Published values were available from past research for asphalt pavements tested under similar conditions as those tested during this investigation. Two studies, one sponsored by the Swedish National Road Administration (*Wallman 1997*) and one published in the Journal of Cold Regions Engineering (*Bergstrom 2003*), were found to have used other friction measurement devices (Saab Friction Tester and a Portable Friction Tester that both utilize a slipping wheel) on many similar pavement conditions. One study performed for the Swedish Transport Authority (*Jonsson 2010*) was found to show field testing results of the DSC111. Figure 5.14 shows the adjusted CSF values, grip readings, and published friction values for asphalt pavements from the three studies cited.

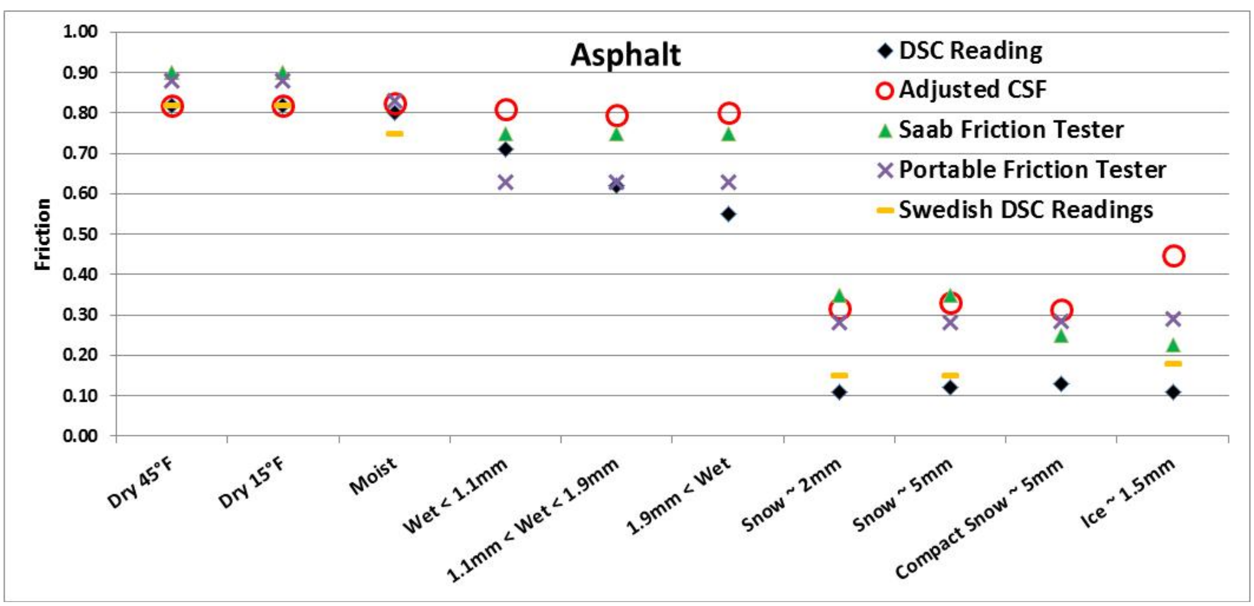

Figure 5.14: Adjusted CSF, raw grip measurements, and published values on asphalt

These published values are generally in agreement with the adjusted CSF and grip numbers for dry, moist, wet, snowy and icy asphalt pavements.

5.3 CONCLUSIONS AND RECOMMENDATIONS

After testing the DSC111 under different pavement conditions for both asphalt and concrete surfaces the overall performance of the sensor seems to match well with simulated road weather conditions. The sensor accurately classified the surface state of the samples as dry, moist, wet, snowy or icy for all conditions on both asphalt and concrete samples. The depths of water and ice on the samples reported by the DSC111 were reasonable and agreed with physical depth measurements, especially considering the limitations of accurately measuring small depths on samples with small variations in thickness. The snow depths reported by the DSC111 were less representative of the actual measured amounts of snow present, but the sensor's ability to recognize that snow is present may be sufficient for the intended VSL application. Pavement grip numbers reported by the DSC111 did show logical reductions in magnitude for changing surface states. When compared to CSF measurements, the grip readings appeared reasonable for most conditions, especially considering the limitations of the static friction tester. When adjusted CSF and grip readings were checked against published values for similar conditions, all measurements fell within expected ranges. Moist concrete was the only condition that yielded a much lower CSF than grip number. Reasons for this discrepancy were not obvious and which value is most representative of actual driving conditions is unknown. The fact that all three wet CSF measurements for concrete are considerably higher than the moist CSF for concrete is curious and may be justification for concluding that the moist CSF was due to unknown factor(s) in the experiment and not representative of actual driving conditions. Retesting was not considered because of the fact that all six independent CSF measurements consistently yielded very similar low numbers, which led the researchers to conclude that re-testing would not yield considerably different results.

5.4 SENSOR USE IN VSL SYSTEMS

Sensor testing results suggest that the performance of the DSC111 is promising for its application in the prospective US Highway 26 / OR Highway 217 VSL system, as well as for other weather-based VSL system deployments. The sensor was found to consistently and accurately determine the road surface condition. An algorithm that uses the DSC111 measurements to determine recommended speed limits could rely on the reported surface state (as the primary input) and potentially the grip number of the roadway (as a secondary input) to make posted speed limit decisions.

Overall, the DSC111 could be used as the primary sensor for gathering road weather conditions for a weather-responsive VSL system because of the following reasons:

- The sensor proved to consistently and accurately identify the road surface condition as either dry, moist, wet, frosty, snowy, icy or slushy, which is a critical input for any weather-based VSL algorithm.
- The sensor-measured grip level, an indicator of the frictional forces between the tire and pavement, exhibited logical sensitivities (variation) to various surface conditions during

the lab experiments. Should the need exist, this could be used as another input to the VSL algorithm, and

- The sensor detects changing road weather conditions quickly, allowing for rapid response, should the need to lower the speed limit arise.

6.0 CONCLUSIONS

There is an integral relationship between highway speed and safety. The posted speed limit at a given location is usually set taking into account a number of considerations, including road surface characteristics (wet pavement conditions), free flow 85th percentile speeds, highway alignment and other factors. Based on this posted speed limit, vehicles can expect to safely traverse a given segment. When drivers travel above the posted speed limit, the potential for adverse safety consequences (i.e., higher crash occurrence) increases. This is particularly true at the location of horizontal curves where lower design speeds are usually used and the traction between the tire and pavement may become an issue when design speed is exceeded.

Weather presents considerable challenges to the highway system, both in terms of safety and operations. From a safety standpoint, weather (i.e., precipitation in the form of rain, snow or ice) reduces pavement friction, thus increasing the potential for crashes when vehicles are traveling too fast for the conditions. Under these circumstances, the posted speed limit at a location may no longer be safe and appropriate. From an operations standpoint, inclement weather could have considerable impacts on the capacity of the highway system and the efficiency of motorists using the system. Highway closures, reduced speeds, increased headways, and crash-related closures are all examples of inclement weather operational effects.

The aforementioned issue is of concern on the ramps of the U.S. 26/Oregon 217 interchange in Beaverton, Oregon. Traffic data indicates that over 60,000 vehicles per day use the ramps at this interchange. Crash data has shown that one or more "loss of control" crashes per day have been observed during wet pavement conditions, with secondary crashes occurring on many occasions. Historically, once wet pavement conditions occur at this site, crashes classified as "loss of control" increase. While the site has traditional passive signage and flashing beacons in place, crashes continue to occur. Oregon Department of Transportation (ODOT) personnel have concluded that additional measures are necessary to address the problem. One approach pursed is the development of a weather-responsive Variable Speed Limit (VSL) system discussed in this report. The work completed to date and presented in this document covers a literature review, development of a Concept of Operations and System Requirements, sensor testing of the Vaisala DSC 111, which would provide friction/grip data for the prospective VSL, and a policy and legal implications review that includes a summary of Oregon's recently enacted administrative rules on use of variable speed limits and statutes and rules adopted by other states. The following sections summarize the results and findings of this work.

6.1 LITERATURE REVIEW

Literature pertaining to weather-responsive variable speed limit systems, both in the U.S. and internationally, as well as other, general VSL systems was summarized in order to understand the current state-of-the-art. Weather responsive VSL systems were used in a variety of applications (rain, fog, snow), and primarily deployed on high volume roads. No weather-responsive VSL systems to date have focused on interchange ramps. Different approaches employed to set posted speed limits for weather-responsive VSLs, including the use of set algorithms/data processing, as well as manual observations where an operator changed speed limits based on viewed conditions. In general, the weather-responsive systems deployed to date have shown to have different, positive impacts on reducing crashes and lowering speeds.

General VSL systems were found to be deployed by agencies to address a variety of safety and operational issues. These systems relied on a variety of data inputs to determine appropriate speed limits. This included loop detector data for speeds and lane occupancy/traffic volumes, closed circuit television for manual observation, and other inputs. The speed limits for each system were determined manually or automatically, based on data inputs and the sophistication of the system itself. These general VSL systems were typically shown to be effective when evaluations were made, although such evaluations were not made for all systems.

The literature review also examined other weather-responsive systems that were not necessarily VSLs, but did provide some form of motorist warning. These systems were deployed to address different safety and operational concerns, using weather data to activate different technologies, such as dynamic message signs, to provide information to motorists. While specific speed limits were not set or provided by these systems, they still were observed in general to be effective in lowering vehicle and/or reducing crashes.

The final portion of the literature review examined the different types of weather sensors available for determining pavement conditions (and in some cases, friction/grip). Two general types of sensors are available, invasive and noninvasive. Invasive sensors (in-pavement sensors) are installed in the pavement level with the road surface and can use different sensing technologies in determining conditions. Noninvasive sensors are installed on the roadside or somewhere over the road surface and use non-contact means of monitoring weather and surface conditions. During the course of the sensor review, it became apparent that Vaisala was the primary vendor in the sensor market, and the firm's DST111 and DSC111 system appeared to hold promise for use in a weather-responsive VSL system. These sensors, working in tandem, are capable of measuring roadway conditions (wet, snow, ice) and water film depth, as well as temperature. They are also capable of measuring friction as a value between 0 and 1, with 0.01 unit resolution. Such a measure is expected to be useful in setting variable speed limits on curving interchange ramps, where different amounts of moisture/precipitation can have a dramatic effect on pavement condition and friction. While independent testing found the system to be "very responsive toward changes in road surface state" and friction metrics to be reasonable when compared to a SAAB tire type friction tester for dry, wet and snowy conditions, discussions with ODOT project personnel concluded that further testing of the sensor under different conditions was necessary before incorporating the sensors into any future VSL system. This testing is the focus of Chapter 5.0 of this report.

6.2 CONCEPT OF OPERATIONS AND SYSTEM REQUIREMENTS

The primary goal of this project is to employ variable speed limits to address wet weather and pavement crashes at the US26/OR217 Interchange. In light of this, the concept of the VSL system is to adjust the speed limit on the interchange ramps during inclement weather to influence driver behavior – primarily to reduce speeds based on the presence of wet pavement. Using pavement condition and weather sensors at the site, different road weather conditions can be detected and established. Based on the current road weather and pavement conditions at the site, speed limits can be adjusted accordingly using VSL signs. The operation of the system will involve this general sequence of events:

- Weather and pavement sensors (non-invasive) monitor precipitation occurrences, type, accumulations, pavement temperature, ambient temperature, and an estimation of grip level of the surface of the roadway.
- Road condition changes are identified based on the detected conditions processed by the system controller, using threshold values determined by the system algorithm developed prior to deployment.
- Upon identification of changes in current conditions, the system logic automatically changes the signage for the desired control strategy (e.g. change from advisory to regulatory posted speed limit of 25 mph).
- The system continuously monitors current conditions, compares those conditions to the established threshold values, determines control strategies/speed limits, and implements necessary changes in signage.

The fully developed concept for the VSL system can be found in Appendix A of this report.

The System Requirements Specifications for the prospective wet weather variable speed limit system to be employed at the US Highway 26 / OR Highway 217 Interchange in Beaverton, Oregon can be found in Appendix B. Requirements are used to define what the system should do, how well it is to perform, and under what conditions or constraints. The requirements presented in the Appendix are broken out into several categories including Security, System Performance, Software, Hardware, Materials, Training, and Service Processes.

6.3 SENSOR TESTING

An important portion of this work was the testing of a sensor system with the potential to provide grip/friction data for use by the VSL system. The selected sensor system that was selected for testing by this project was the Vaisala DSC111 and DST111 (Remote Road Surface Temperature Sensor). The DST111 measures road surface temperature, air temperature, relative humidity, and dew point. These DST111 measurements can then be used in conjunction with the DSC111 measurements to fully understand road conditions. The DSC111 measures the surface state (dry, moist, wet, frosty, snowy, icy, or slushy) and the depth of water, ice, and equivalent water content depth of snow present. These measurements are then used by the DSC111 to predict the level of grip a vehicle would have on the road surface, which ranges from 0 to 1 (0.8 is typical for a dry road).

The ability of the sensors to determine the state of the road surface, the amount of precipitation present and the predicted grip level of the road is the primary motivation for their use in the VSL system. These measurements would be used by the VSL system to set an appropriate speed limit for vehicles based on the predicted grip level. However, before the data from these sensors can be incorporated into the proposed VSL system, a good understanding of their accuracy in measuring grip level under different surface conditions was deemed important. The accuracy of the Vaisala sensors was assessed by a suite of laboratory tests simulating various conditions.

Laboratory testing simulated a variety of conditions from dry, moist, wet, loose snow, compacted snow, to ice with various depths, as feasible at temperatures of 45 and 15 degrees Fahrenheit.

After testing the DSC111 under different pavement conditions for both asphalt and concrete surfaces the overall performance of the sensor seems to match well with simulated road weather conditions. The sensor accurately classified the surface state of the samples as dry, moist, wet, snowy or icy for all conditions on both asphalt and concrete samples. The depths of water and ice on the samples reported by the DSC111 were reasonable and agreed with physical depth measurements, especially considering the limitations of accurately measuring small depths on samples with small variations in thickness. The snow depths reported by the DSC111 were less representative of the actual measured amounts of snow present, but the sensor's ability to recognize that snow is present may be sufficient for the intended VSL application. Pavement grip numbers reported by the DSC111 did show logical reductions in magnitude for changing surface states. When compared to CSF measurements, the grip readings appeared reasonable for most conditions, especially considering the limitations of the static friction tester. When adjusted CSF and grip readings were checked against published values for similar conditions, all measurements fell within expected ranges, moist concrete was the only condition that yielded a much lower CSF than grip number. Reasons for this discrepancy were not obvious and which value is most representative of actual driving conditions is unknown. The fact that all three wet CSF measurements for concrete are considerably higher than the moist CSF for concrete is curious and may be justification for concluding that the moist CSF was due to some anomaly in the experiment and not representative of actual driving conditions.

Overall, the DSC111 reported grip numbers below those of the CSF, which would be acceptable for a VSL system, as these lower measurements represent a margin of safety in setting speed limits. In other words, the fact that the DSC111 is reporting lower grip numbers indicates that the potential for a higher grip number to be reported during low grip conditions is less likely. Consequently, while it is possible this could lead to a lower speed limit than necessary being posted, this is a more acceptable outcome than a higher speed limit being set which could lead to a safety issue.

6.4 SENSOR USE IN VSL SYSTEMS

Sensor testing results suggest that the performance of the DSC111 is promising for its application in the prospective US Highway 26 / OR Highway 217 VSL system, as well as for other weather-based VSL system deployments. The sensor was found to consistently and accurately determine the road surface condition. An algorithm that uses the DSC111 measurements to determine recommended speed limits could rely on the reported surface state (as the primary input) and potentially the grip number of the roadway (as a secondary input) to make posted speed limit decisions.

Overall, the DSC111 could be used as the primary sensor for gathering road weather conditions for a weather-responsive VSL system because of the following reasons:

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- The sensor-measured grip level, an indicator of the frictional forces between the tire and pavement, exhibited logical sensitivities (variation) to various surface conditions during the lab experiments. Should the need exist, this could be used as another input to the VSL algorithm, and
- The sensor detects changing road weather conditions quickly, allowing for rapid response, should the need to lower the speed limit arise.

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APPENDIX A:
CONCEPT OF OPERATIONS

A-1.0 PURPOSE OF DOCUMENT

This document describes the Concept of Operations (Con Ops) for the variable speed limit (VSL) system at the US Highway 26 / OR Highway 217 Interchange in Beaverton, OR. It includes the scope of the project, referenced documents, the system concept, stakeholder operation descriptions, the system overview, and operational scenarios.

A-2.0 SCOPE OF PROJECT

The primary goal of this project is to employ variable speed limits to address wet weather and pavement crashes at the US26/OR217 Interchange. The specific ramps included in the VSL system include the US26 eastbound to OR217 southbound ramp, the US26 westbound to OR217 southbound ramp, and the OR217 northbound to US26 westbound ramp. Figure 1 presents an overview of the project interchange and the respective ramps. This section describes the purpose for system implementation and the specific project objectives.

Figure 1: Project Area

A-2.1 PURPOSE FOR SYSTEM IMPLEMENTATION

Traffic data of the US26/OR217 interchange in Beaverton, Oregon indicates that over 60,000 vehicles per day collectively use the interchange ramps. Crash data provided by the Oregon Department of Transportation (ODOT) has shown that one or more "loss of control" crashes per day have been observed during wet pavement conditions, with secondary crashes occurring on many occasions. Historically, once wet pavement conditions occur at this site, crashes classified as "loss of control" increase. While the site has traditional passive signage and flashing beacons in place, crashes continue to occur. ODOT personnel have concluded that additional measures are necessary to address the problem.

This project seeks to reduce the occurrence of wet weather crashes on the interchange ramps of the US26/OR217 interchange through the use of a weather-responsive variable speed limit system. Such a system will post appropriate speed limits based on weather conditions, with the intent of lowering motorists' speeds accordingly. The system may also incorporate active warning signs in the form of dynamic message signs (DMS) to provide advanced warnings to motorists in advance of the ramps. As motorists lower their speeds for different weather conditions, they will be traveling at safer speeds for prevailing conditions, with a corresponding reduction in crash occurrence expected.

A-2.2 PROJECT OBJECTIVES

The specific project goals to reduce wet weather crashes include:

- Develop an advanced weather-responsive variable speed limit adjustment system to be deployed by ODOT at the previously cited ramps of the US 26/OR 217 interchange. This involves identifying and evaluating system components (ex. sensors, processors, etc.) to detect weather conditions and support the overall functions of the system
- Develop methodologies and algorithms for setting adjustable speed limits based on weather conditions. This will support the determination of appropriate speed limits based on current weather conditions.
- Assess the effectiveness of the system in reducing average vehicle speeds and the number of speed-related crashes and/or incidents at the study site under different types of weather conditions and posted speed limits. This will be achieved through examining speed and crash/incident experience before and after system deployment.
- Develop guidance to assist in future deployments of similar systems at other locations in Oregon. This will allow for transferability of such systems to sites with similar safety problems.

A-3.0 REFERENCED DOCUMENTS

This concept of operations was developed with the guidance of and input from these documents:

- *Manual on Uniform Traffic Control Devices for Streets and Highways*, MUTCD 2009 Edition.

- *Manual on Uniform Traffic Control Devices for Streets and Highways, Oregon Supplement to the 2009 Edition*, MUTCD-ODOT Adopted December 2011.
- *Systems Engineering Guidebook for ITS* guidelines issued by FHWA (U.S. Department of Transportation Federal Highway Administration), 2007.
- *Traffic Sign and Design Manual*, ODOT, 2003.
- *I-5/I-405 Active Traffic Incident Management: Concept of Operations*, DKS Associates, 2010.
- *Research Project Work Plan for Evaluation of a Variable Speed Limit for Wet and Extreme Weather Conditions*, WTI, 2011.

A-4.0 SYSTEM CONCEPT

The concept of the VSL system is to adjust the speed limit on the interchange ramps during inclement weather to influence driver behavior – primarily to reduce speeds based on the presence of wet pavement. Using pavement condition and weather sensors at the site, different road weather conditions can be detected and established. Based on the current road weather and pavement conditions at the site, speed limits can be adjusted accordingly using VSL signs. The operation of the system will involve this general sequence of events:

- Weather and pavement sensors (non-invasive) monitor precipitation occurrences, type, accumulations, pavement temperature, ambient temperature, and an estimation of grip level of the surface of the roadway.
- Road condition changes are identified based on the detected conditions processed by the system controller, using threshold values determined by the system algorithm developed prior to deployment.
- Upon identification of changes in current conditions, the system logic automatically changes the signage for the desired control strategy (e.g. change from advisory to regulatory posted speed limit of 25 mph).
- The system continuously monitors current conditions, compares those conditions to the established threshold values, determines control strategies/speed limits, and implements necessary changes in signage.

The following subsections describe the components of the weather responsive VSL system.

A-4.1 WEATHER SENSORS

Road weather sensors come in an array of types with many capabilities. Sensors that focus on the condition of the pavement on the roadway are of interest to the system described here and come in two major types: in-pavement and non-invasive. In-pavement sensors are puck shaped sensors that are set in the roadway and can measure pavement temperature, precipitation occurrences, precipitation type, and depth of precipitation. Non-invasive sensors use spectroscopy principles to measure road surface conditions from above the roadway. Non-invasive sensors can measure pavement temperature, precipitation occurrences, type, and depth and give an estimate of the level of grip of the pavement. Non-invasive sensors which provide information on both

VSL deployment will provide supplemental data from sensors such as precipitation occurrence detectors and ambient temperature sensors.

Wet and extreme weather crashes likely occur on the interchange ramps due to a loss of grip between the wet pavement and vehicles traveling too fast for the conditions of the roadway. To monitor when the roadway exhibits potentially dangerous conditions, sensors will need to monitor precipitation occurrences, type, depth, and pavement temperatures. Grip levels can only be measured by non-invasive sensors and this is why such a pavement condition sensor has been selected as the primary sensor for the VSL system.

A-4.2 VARIABLE SPEED LIMIT SIGNS

The VSL signs will be installed at the beginning of the three ramps being investigated (US26 EB to OR217 SB, US26 WB to OR217 SB, and OR217 NB to US 26 WB). The signs will be placed on the roadside(s) where sufficient space is available. Regulatory VSL signs will be placed at the point of curvature (POC) of the ramps and the advisory sign with LED numbers will be placed 100 feet upstream of the POC. Figure 2 shows a typical ramp geometry with POC and a location 100 feet upstream of the POC identified as potential sign locations. The figure also shows the existing locations for the exit and advisory speed signs. The existing advisory speed signs will be removed upon the deployment of the proposed VSL system.

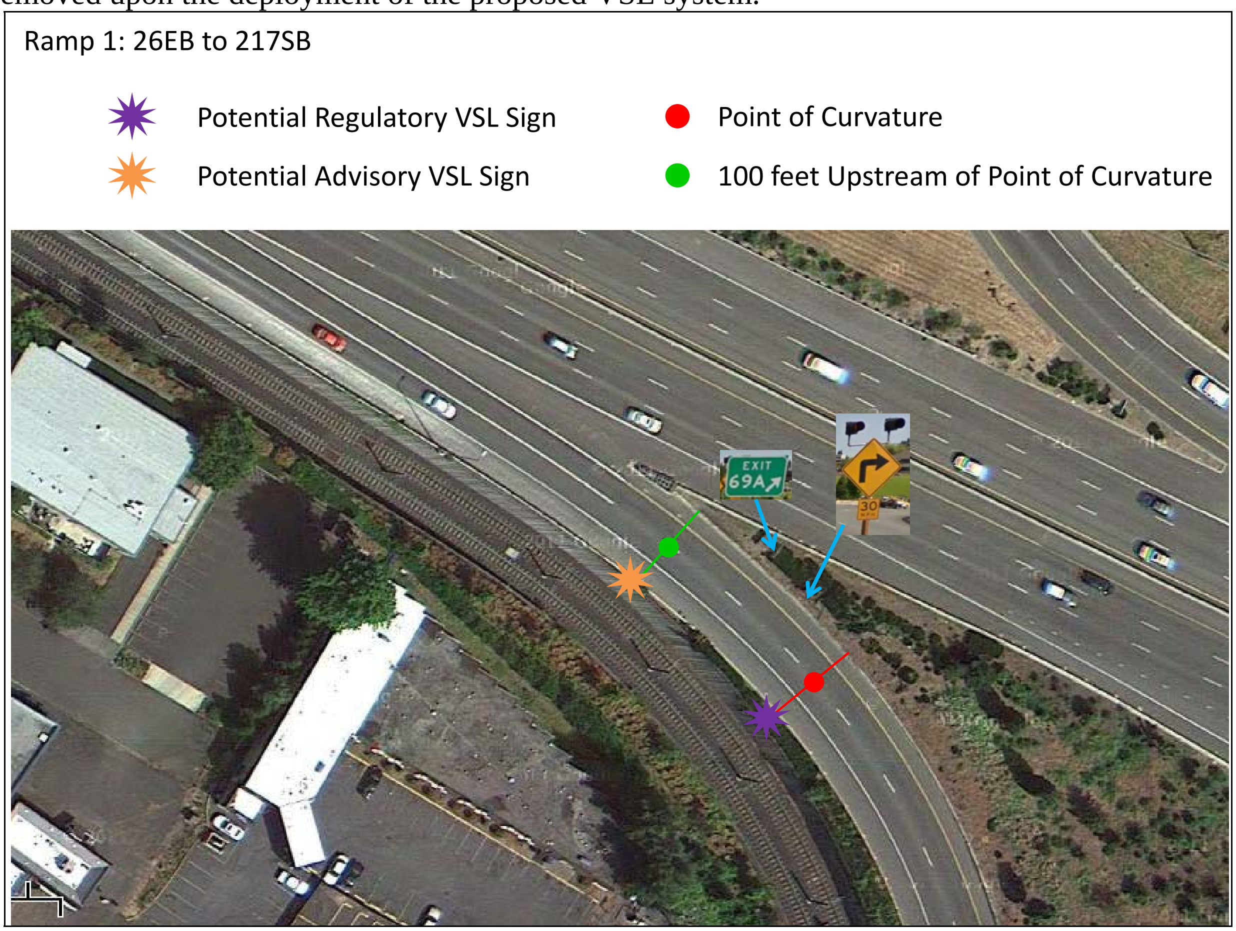

Figure 2: Potential Sign Placement

A-4.3 VSL SIGN TYPES

Two types of VSL sign are proposed for use as part of this project. One type is a full matrix type variable electronic sign. The other is a more traditional static background sign with a light emitting diode (LED) panel that changes only the numerical speed part of the sign.

A-4.4 Variable Electronic Sign

A full matrix variable electronic sign is capable of displaying an electronic version of static signage as well as dynamic flashing graphics (ex. simulated flashing beacons above a static sign). For the purposes of this project, the sign will have the ability to display a regulatory speed limit sign with any numerical speed in the appropriate colors that conform to MUTCD guidance. When the sign is not activated, (i.e. when an advisory speed limit is in effect during dry conditions), the electronic sign will be blank (blacked out) and convey no information. Figure 3 shows an example of the electronic full matrix VSL signage.

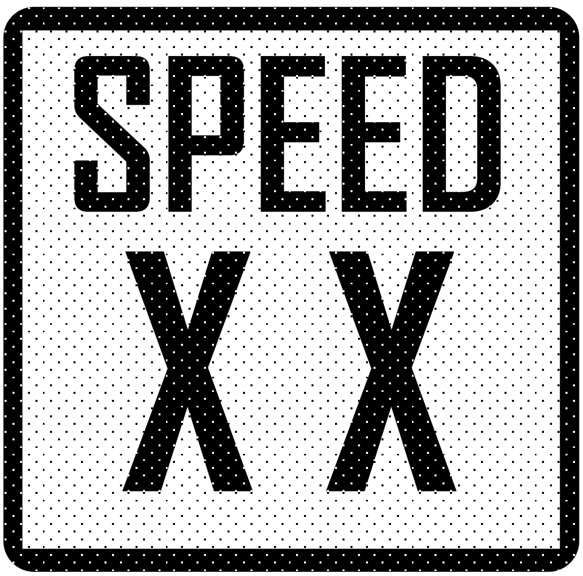

Figure 3: Electronic VSL Sign Example

The regulatory electronic VSL signs will be placed on the right side of the road at the point of curvature of the ramps. This point of curvature is the start of the most restrictive curve encountered by the driver using the ramp.

A-4.5 Static Sign with Variable LED Numbers

A static background curve warning sign attached to a dynamic advisory speed sign with LEDs is proposed for the system to work in coordination with the full matrix regulatory VSL sign described previously. Such warning / advisory signs would be a traditional static warning sign similar to those already present on the ramps that displays the ramp geometry on the metal portion of the sign and the advisory speed limit on a changeable LED sign attached below the metal sign. The static portion of the sign would always display the ramp geometry since it has no electronic features, but the LED speed would only be displayed when applicable and would be blank when not activated. Figure 4 illustrates this sign, showing the static background with LED advisory VSL signage below it.

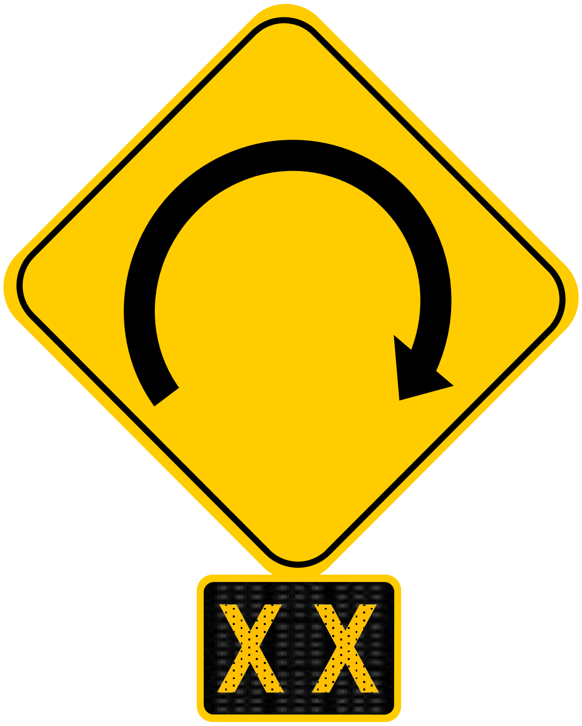

Figure 4: Static Background Advisory with LED VSL Sign Example

The advisory speed signs will be placed at the roadside at 100 feet upstream from the regulatory VSL signs. This conforms to the MUTCD recommendations that advisory warning signs be up to 100 feet upstream of the point of curvature of a ramp and at least 100 feet from any other signs.

A-4.6 ADVANCED WARNING SIGNS

Advanced warning signs will be used sufficiently upstream of the ramps to notify drivers that they may encounter a reduced speed limit zone ahead. These signs would be Dynamic Message Signs (DMS) and only activated when the reduced speed limit zone is in effect on the ramps being investigated. The sign would display a message predetermined by ODOT to alert drivers on the ramps that they are approaching the reduced speed limit zone. The DMS should be equipped with flashing beacons, either within the border of the DMS or externally attached to the sign to capture driver attention. These beacons will flash only when reduced speed limits are in effect. Figure 5 shows an example of potential advanced warning sign and posted message.

Figure 5: Advanced Warning Sign Examples

A-5.0 STAKEHOLDER OPERATIONAL DESCRIPTIONS

Stakeholder groups have different needs, expectations and benefits from a VSL system. This section describes how the system will operate from the perspective of the three primary stakeholder groups it affects: drivers, ODOT, and law enforcement.

A-5.1 DRIVERS

Drivers are the primary users of the VSL system. The different advisory and regulatory speed limits posted by the system are intended to provide drivers with an indication of the speed they should be operating their vehicle. When the pavement is dry, drivers will navigate the VSL ramps much in the same way they do currently, with an advisory speed limit of 30 mph posted. When the pavement becomes sufficiently wet or icy the drivers will observe a regulatory speed limit posted that is lower than normal. In such a case, it is anticipated that a driver will slow down accordingly in order to navigate the ramps. With lower speeds during wet pavement conditions, it is reasonable to expect that there will be a reduction in wet weather and loss of friction/grip crashes on then ramps.

A-5.2 ODOT

ODOT is responsible for operating and maintaining the system, which will be overseen by the Traffic Management Operations Center (TMOC) in Portland, OR. Traffic operators will monitor the operation of the system, but will not be required to actively change electronic signage as this will be done by a central processing unit (CPU) remotely. Traffic operators will only need to manually override the system if they feel it is warranted. Such a case would be when a system failure of some sort (loss of power, component failure, etc.) occurs. In such a case, an operator will have to manually override the system, and ODOT personnel may also need to deploy temporary static signage on the ramp if needed (depending on the exact issue).

A-5.3 LAW ENFORCEMENT

The interchange and its ramps are located within the Beaverton, Oregon city limits and are therefore patrolled mainly by the Beaverton Police Department. While the speed issues on the ramp could potentially be addressed through on-site enforcement, the benefits of pulling vehicles over to issue citations on or near interchange ramps are exceeded by the risks involved, particularly during wet conditions. At present, officers are tasked with responding to crashes on the ramps, exposing them to traffic and increasing the potential for a secondary crash. The deployment of the system can be expected to reduce crashes on the ramps thus reducing officer responses to such incidents and the associated secondary crashes.

A-6.0 SYSTEM OVERVIEW

The VSL system is controlled by software that will use an algorithm to determine recommended speeds. The algorithm determines appropriate speed limits during different pavement and weather conditions. The possible weather conditions are: dry pavement with no rain, light to moderate precipitation with minor reductions in pavement grip, and heavy precipitation with significant reductions in pavement grip. The VSL speed control software employed in the system will comply with the applicable standards and procedures for changing speed limits on Oregon freeways. The system will:

- not change speed limits more than once every 5 minutes,
- not display a speed limit below 20 mph,
- only display speed limits in 5 mph increments, and
- will automatically assess weather conditions every 60 seconds.

A separate system requirements document will detail specific functional requirements.

A-6.1 LOGICAL ARCHITECTURE

The VSL system is comprised of three separate systems, one for each ramp. Each individual ramp VSL system will address its ramp-specific pavement and weather conditions and display the appropriate speed limit. Pavement and weather conditions will be monitored at each ramp and speed limits will be assigned according to weather conditions. One centralized controller will be employed by the system, while individual condition detection sensors will be used on each ramp. The multiple sensors may allow for the system to perform quality control checks on other individual sensors to ensure that a sensor is not malfunctioning or outputting poor quality data.

A-6.2 LOGIC FOR CHANGING SPEEDS

Surface condition is primarily determined from the weather sensor data. This data will be assessed at 60 second intervals and appropriate changes in the type (advisory versus regulatory) and speed posted by the signage will be determined. The system will need to perform consistency checks over a 5 to 10 minute period to confirm weather / pavement conditions. The major weather condition categories will be:

- 1: dry pavement, no precipitation, high grip level
- 2: moist / wet pavement, light precipitation, moderate to high grip level
- 3: wet pavement, moderate to high precipitation, moderate grip level
- 4: ice/snow/slush/frost pavement, any precipitation, low grip level

Table 1 shows potential weather measurements that correspond to the categories 1 through 4.

Table 1: Weather Condition Classification

Surface State	Description	Condition Category
Dry	No precipitation	1
Moist / Wet	Precipitation < 1.00 mm	2
Wet	Precipitation > 1.00 mm	3
Ice / Snow / Slush / Frost	Any precipitation, freezing temperature	4

Figure 6 shows the general logic used to determine appropriate control signage strategies at a given ramp. The weather sensor will communicate measurements to the processor which will use the system logic and surface condition categories to determine the appropriate signage to be posted. The processor will communicate the desired signage to the VSL signs. The signs will display the necessary information for the conditions. The system will reassess the surface condition every 60 seconds and change the signage accordingly, but no more often than once every 5 minutes.

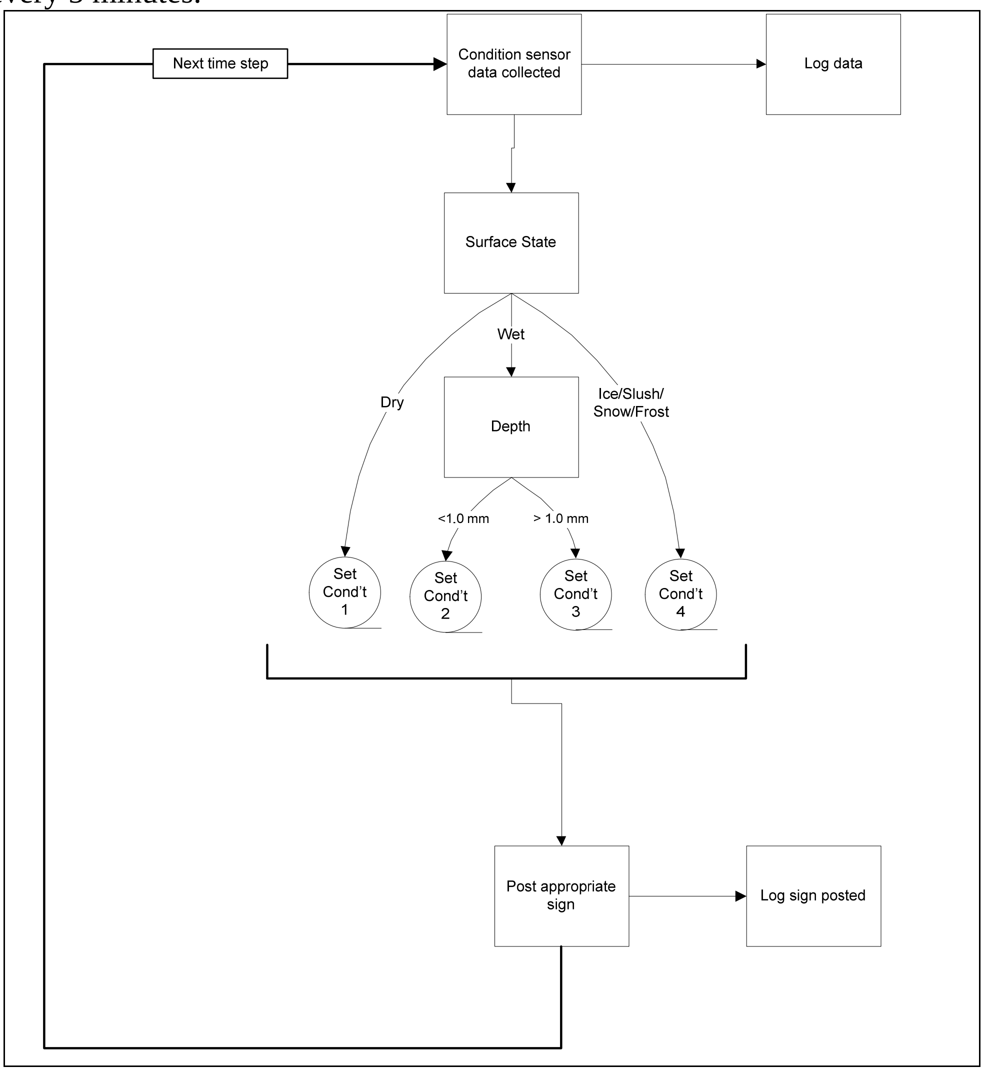

Figure 6: System Logic Schematic

The three ramps all currently have a posted advisory speed of 30 mph. Reduction in posted speed limits will be in 5 mph increments but will never be posted lower than 20 mph. Table 2 shows the potential signs and speeds posted from the logic determined weather condition category.

Table 2: Condition, Sign, Speed

Condition	Advisory VSL	Regulatory VSL	Speed Posted
1	ON	OFF	30
2	ON	OFF	30
3	OFF	ON	25
4	OFF	ON	20

A-6.3 COMMUNICATIONS SYSTEM

Existing infrastructure will be used as part of the main communication system between the TMOC and sensors, processors, controllers and signs in the field. The existing infrastructure at the site is a network of fiber optic cable and copper wire.

A-6.4 Communication Medium

The different pavement condition and weather sensors will send information to a central field hub location. This hub will gather and combine the sensor measurements and send that information to the TMOC using existing communication lines for archiving and reference purposes. Based on ODOT’s preference, existing copper wire, fiber optic cable, or wireless communication devices at or near the project site can be used as the communication mediums for the system. Alternatively, ODOT could also install new communication capabilities if so desired or deemed advantageous.

A-6.5 Communication Protocol

Existing communications mediums at the site are capable of supporting several types of communications protocols (including Ethernet) provided that the proper components are procured.[4] Communications protocol options for the VSL and sensor systems include Ethernet, RS232 and RS422. Ultimately, the protocol(s) selected by ODOT will determine the communication components required for the system. ODOT’s experience in developing and deploying VSL systems in other applications is expected to guide the communications protocol decisions for the system discussed here.

A-6.6 Communication Components

Ethernet communication is recommended, but this is at the discretion of ODOT. If the signs and sensors selected for the system are not Ethernet capable, other types of communication can be used and converted to Ethernet. To communicate between components of the system, the use of Ethernet serial to Ethernet converts, wireless transceivers with antennas, Ethernet edge switches, and Ethernet middle switches may be needed.

[4] Note that components for the ORION system are no longer manufactured, which could complicate adding the VSL and sensor systems to the existing communications system for that medium.

A-6.7 Device Communication Requirements

The various VSL sign, sensor and other system components should meet the following communication requirements:

Ethernet – Devices using Ethernet communications shall meet one or more of the following standards for communications port configurations and signal transfer:

- IEE802.3 (10Base-T Ethernet)
- IEE802.3u (100 Mbps- Fast Ethernet)
- IEE802.3z (1000 Mbps – Gigabit Ethernet)

RS232 – Any component of the system using RS232 communications shall meet EIA/TIA-232-F standards for communications port configurations and signal transfer.

RS422 – Any component of the system using RS422 communications shall meet EIA/TIA-422-B standards for communications port configurations and signal transfer.

A-6.8 SYSTEM CONTROL

The existing TMOC in Portland, OR will operate and oversee the VSL system. Changes in road weather conditions will be detected automatically and appropriate speeds will be posted without the need for direct operator involvement. The operator will be informed of changing road weather conditions by alarms triggered when posted speed limit changes are warranted. Incidents will be monitored by the operator using radio communication, telephone calls, and from CCTV cameras at or near the site. The operator may expect to first receive an alarm of lowered speed limit, observe automatic speed limit change being posted (via system outputs, not CCTV), and verify the weather conditions using the existing on site camera, and any other cameras that may be added at the project site.

A-6.9 Test Mode Operation

The VSL system will have the option to operate in a test mode. This test mode will operate the same way as normal operation, except it will not post the speeds determined from the algorithm. During the test mode, operators can observe the system as it operates and see the sign changes that are suggested by the processor, but the sign changes will not be shown in the field. This mode will allow operators to ensure the system is functioning properly before allowing the automatic speed changes to be implemented and presented to drivers.

A-6.10 Normal Operation

Normal operation of the VSL system will be employed once TMOC operators are satisfied that the system is operating correctly in the test mode. The system will analyze the weather measurements from the sensors, check the data against the system algorithm and threshold conditions, and automatically post the appropriate sign changes. An alarm will be triggered to inform TMOC operators of speed limit changes and confirm weather conditions, if desired.

A-6.11 Manual Operation

If desired, a TMOC operator can override the normal operation of the system and engage a manual operation mode. Using manual operation mode, the operator can choose to post any speed limit signage they feel appropriate for the conditions. Note, however, that such an operation should not be undertaken except in the case of a severe event or emergency. In such a case, local police or ODOT personnel in the field may also be consulted for input prior to performing any manual operation of the system. For example, an incident on the ramp (stall or crash) may necessitate a change in the posted speed limit that would not be triggered by weather conditions. Automatic signage changes from the VSL system processor will be suspended until the operator resumes normal operation mode. The VSL system will continue to monitor conditions and log suggested signage conditions. An alarm may also be used to inform operators in the event that the VSL system suggests a lower speed than manual operation currently has set.

A-7.0 OPERATIONAL SCENARIOS

The possible operational scenarios for the VSL system include:

- Dry Pavement Operations
  - Condition 1
- Wet or Extreme Pavement Operations
  - Condition 2
  - Condition 3
  - Condition 4
- Failure Operations
  - Single Component Failure
  - Entire System Failure

A-7.1 OPERATIONAL SCENARIO: CONDITION 1

When the site experiences dry conditions and sensors measure no precipitation and high[5] grip levels, operations will be classified as condition 1. Under condition 1, the variable advisory speed sign will display 30 mph and the regulatory VSL will be blank. The DMS will be blank as there is no reduction in speed limit for the driver to anticipate. Figure 7 shows the signage displayed during condition 1 operations.

[5] In the cases discussed here, “high” grip values refer to excellent friction at the higher end of the spectrum is present (towards 1.0) Conversely, “low” grip values refer to poor friction at the lower end of the spectrum is present (towards 0.0).

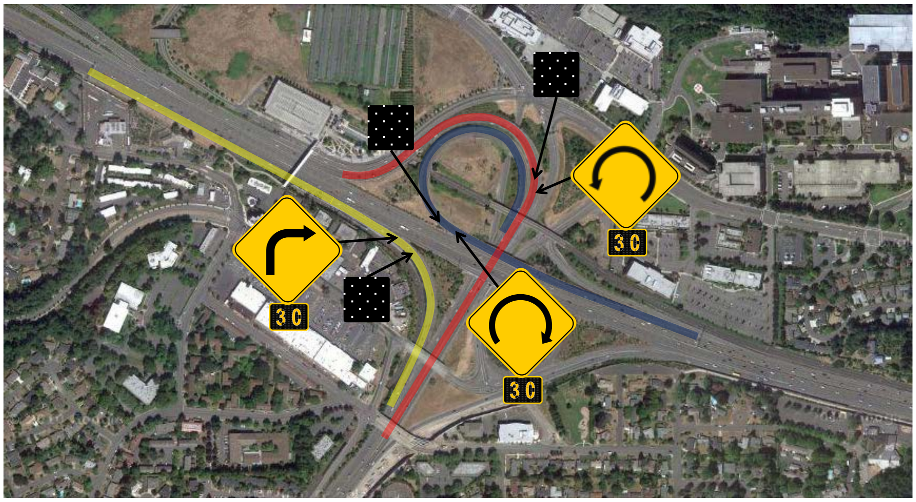

Figure 7: Condition 1 Operations

A-7.2 OPERATIONAL SCENARIO: CONDITION 2

When the site experiences light precipitation and sensors measure light precipitation with moderately high grip levels (i.e. good grip values in the presence of pavement moisture), operations will be classified as condition 2. Under condition 2, the variable advisory speed sign will display 30 mph and the regulatory VSL sign will be blank. The DMS will be blank as there is no reduction in speed limit for the driver to anticipate. Figure 8 shows the signage displayed during condition 2 operations.

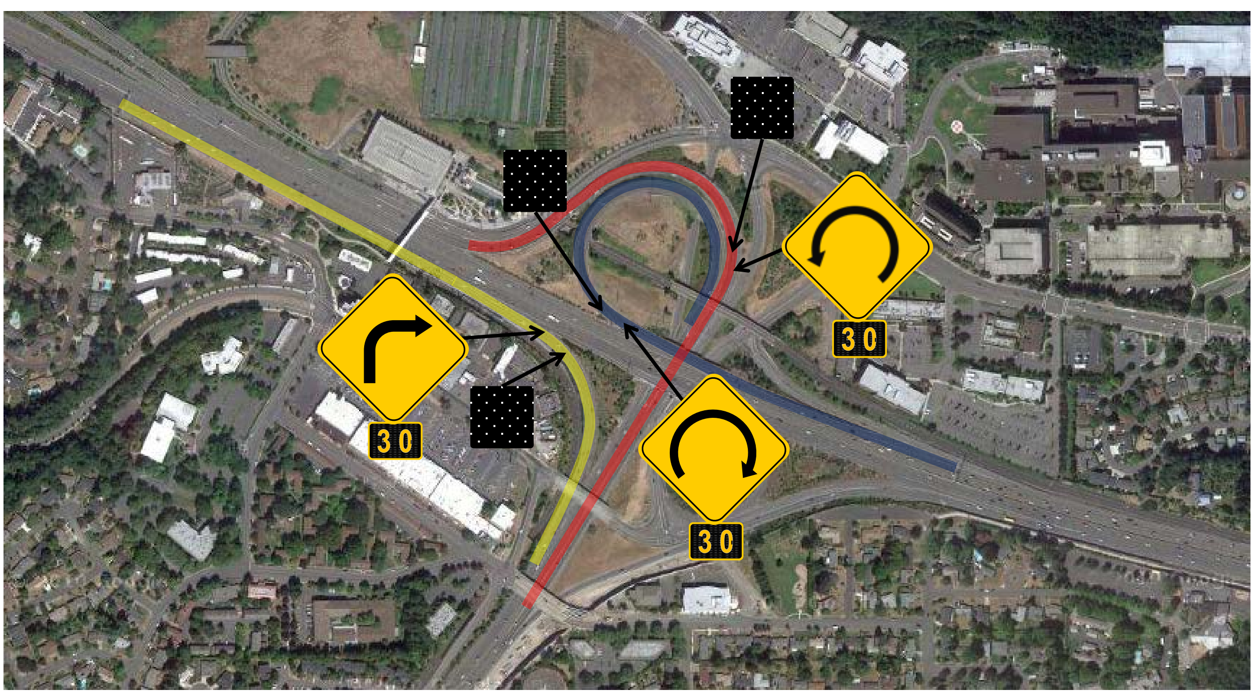

Figure 8: Condition 2 Operations

A-7.3 OPERATIONAL SCENARIO: CONDITION 3

When the site experiences precipitation and sensors measure some precipitation with mid-range[6] grip levels, operations will be classified as condition 3. Under condition 3, the regulatory VSL sign will display 25 mph. The variable advisory speed sign will be blank. The DMS will display a reduced speed limit ahead notification for drivers using the ramps. Figure 9 shows the signage displayed during condition 3 operations.

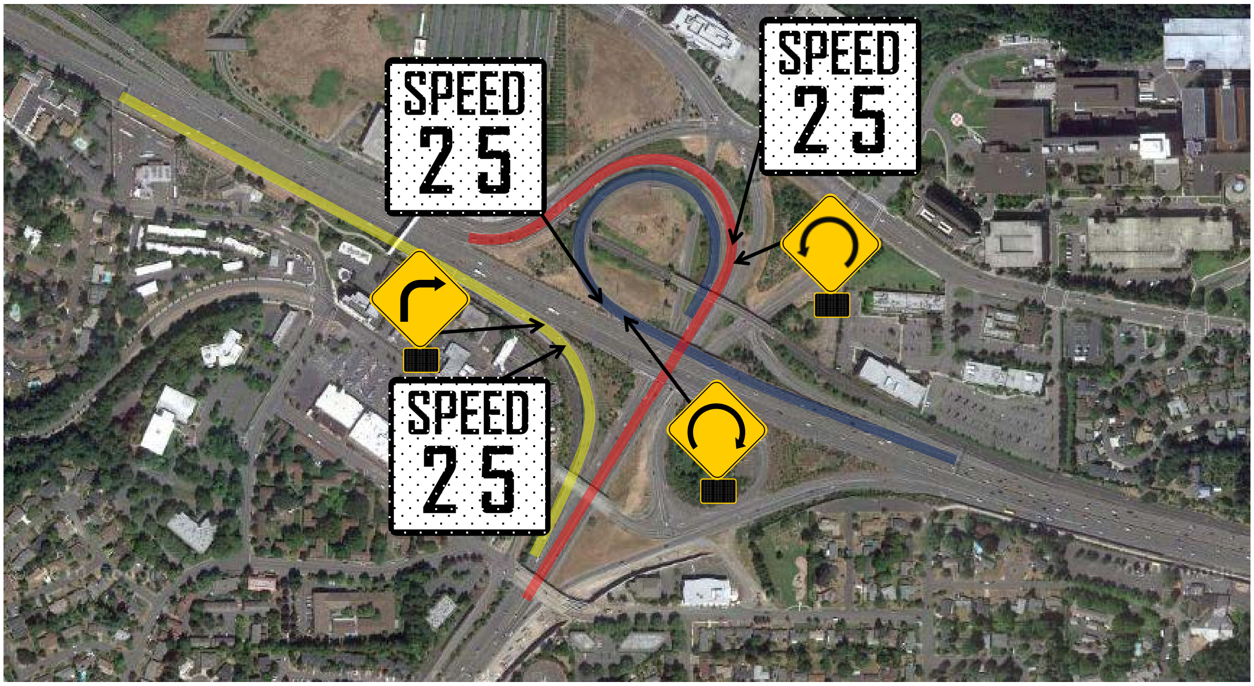

Figure 9: Condition 3 Operations

A-7.4 OPERATIONAL SCENARIO: CONDITION 4

When the site experiences icy, snowy, slushy, or frosty conditions and sensors measure ice, snow, slush, or frost precipitation with any grip level, operations will be classified as condition 4. Under condition 4, the regulatory VSL sign will display 20 mph. The variable advisory speed sign will be blank. The DMS will display a reduced speed limit ahead notification for drivers using the ramps. Figure 10 shows the signage displayed during condition 4 operations.

[6] Such a mid-range value would fall into the area of 0.40-0.60 grip level measurements.

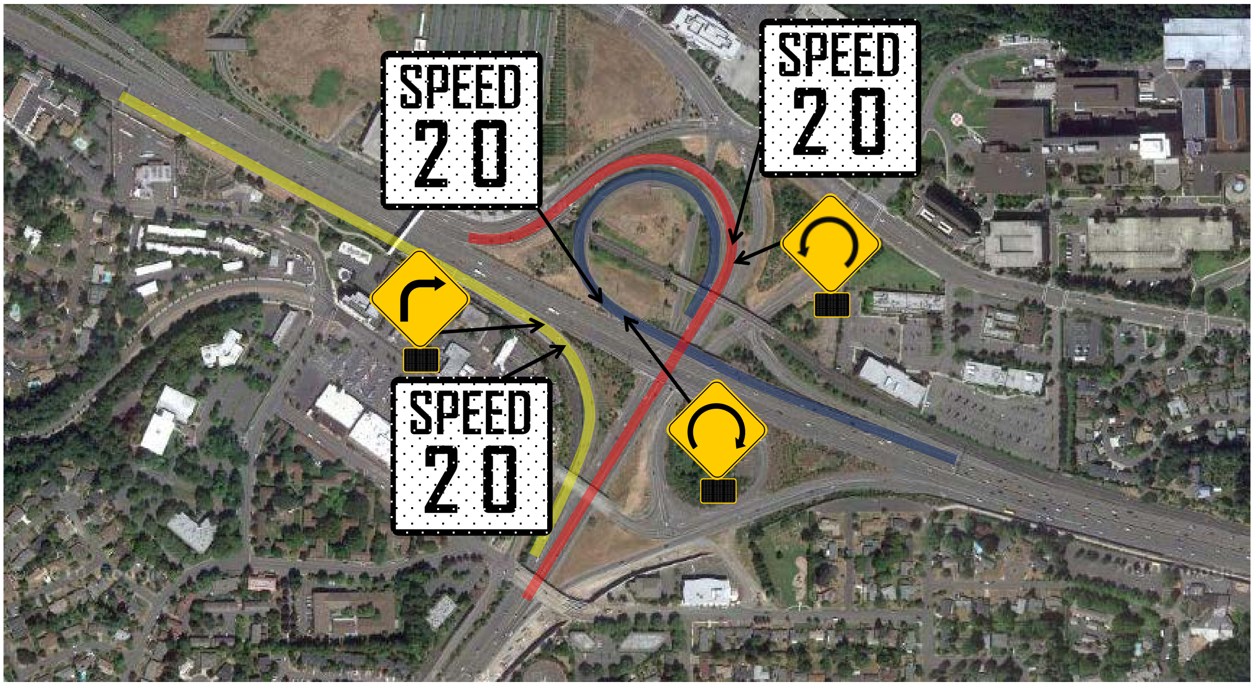

Figure 10: Condition 4 Operations

A-7.5 OPERATIONAL SCENARIO: DETECTION FAILURE

When the system experiences a single sensor/detector/component failure, other than the VSL sign, TMOC operators will be informed that a failure has occurred and can choose to manually operate the VSL sign or have the system automatically operate the VSL sign using the weather conditions from one of the other ramp's sensors.

A-7.6 OPERATIONAL SCENARIO: VSL SIGN OR ENTIRE SYSTEM FAILURE

If the entire VSL system fails in some manner, operators will be notified and drivers will only observe the static advisory geometry sign, as all LED boards will be blank. This may happen in the event of a power outage at the site. Both the regulatory and advisory VSL signs will be blank, but the ramp geometry advisory static metal sign will be observed by drivers on the ramps. The DMS will also be blank. Such a case would require ODOT personnel to travel to the site to set up temporary static metal signage displaying an advisory or regulatory speed limit. Figure 11 shows the signage displayed in the event of an entire system failure.

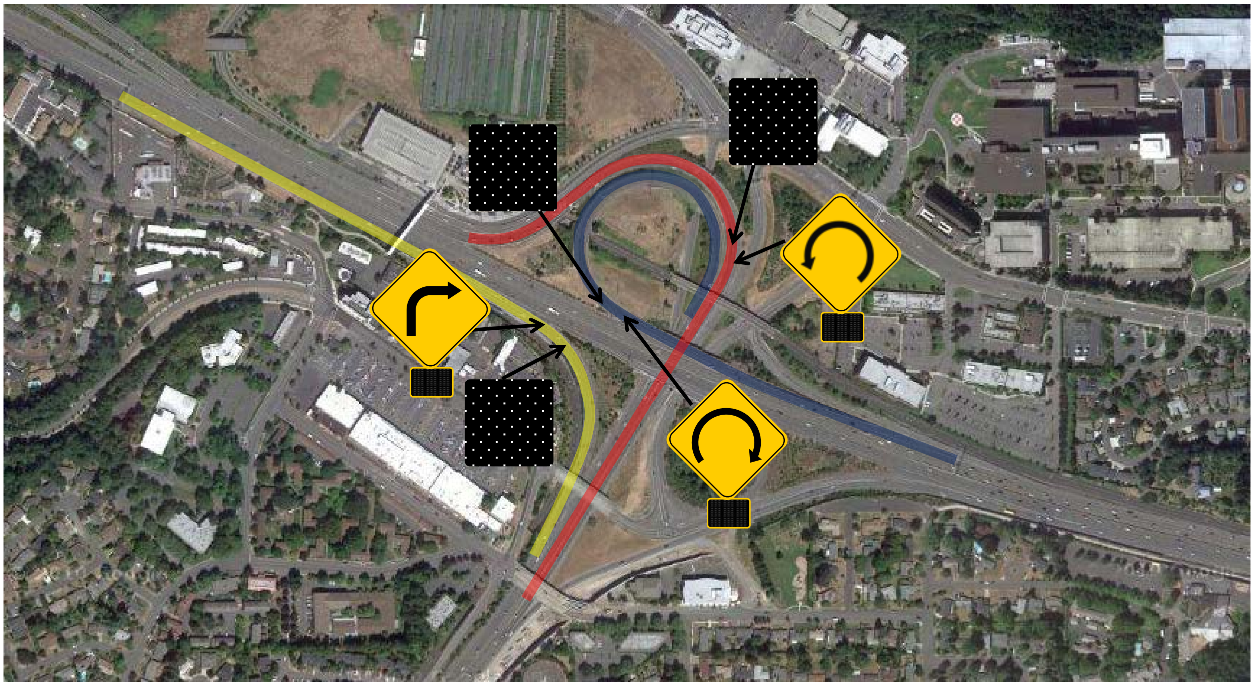

Figure 11: Entire System Failure Operations

APPENDIX B: REQUIREMENTS

B-1.0 INTRODUCTION

This section presents a brief overview of the System Requirements Specifications (SRS) for a wet weather variable speed limit system to be employed at the US Highway 26 / OR Highway 217 Interchange in Beaverton, Oregon. It is intended to help the reader understand how the document is organized and how to read and interpret it.

System Name: Variable Speed Limit System for Wet and Extreme Weather
System Acronym: VSL or VSL system
System Owner Information: ODOT ITS Unit Manager (Galen McGill)

B-1.1 DOCUMENT OVERVIEW

This document contains the requirements and specifications to be used in the functional design of the Variable Speed Limit (VSL) system for wet and extreme weather. These requirements are broken out into several categories including Security, System Performance, Software, Hardware, Materials, Training, and Service Processes, each of which are described later. The Software requirements and specifications are further broken down by Work Process (Functions) and Unit Tasks (Unit Processes).

The intended audience for this document is ODOT business management and staff, Transportation Application Development (TAD), Management, system architects, system, data, and business analysts, developers, testers, and those responsible for implementing and maintaining the software.

After the introduction, the major topics covered in this document include:

- Project History to provide context for understanding the VSL system and its requirements.
- System Overview that describes the system purpose, objectives, and key issues related to system objectives, scope, and overall feasibility.
- System Requirements with system context relevant to business tasks and system security related to physical and operational requirements (access, data protection, and recovery).
- System Performance requirements including but not limited to network response time, maintainability, portability, and adaptability to different environments.
- Assumptions and Dependencies that could affect requirements, including but not limited to characteristics of the operating environment and interface design convention.
- Software Requirements for the construction and implementation of the system.
- Data Requirements for the operation of the VSL system.
- Hardware Requirements for support infrastructure configurations.
- Service Requirements for email, database, data backup, and data restoration/disaster recovery services.

- Trained Personnel Requirements to establish the skills and knowledge necessary to operate the system.
- Materials Requirements for physical forms and similar materials needed for the system.
- Process Requirements for work processes, including manual and automated unit tasks applied by the user when using the system.
- Facilities Requirements for developing, testing, and operating the system, including a building, room, furniture, etc.
- Incomplete Requirements for any requirements that are believed to exist, but have not been covered in any other section of the document. Incomplete Requirements must be resolved or defined as targeted for future releases of the system before the document is finalized.

B-1.2 DOCUMENT CONVENTIONS

The following conventions are used throughout the document:

- The software and manual portions of the VSL system are partitioned based on general Work Processes. Each Work Process consists of one or more Unit Tasks. The requirements that apply to a given Unit Task are listed within that Unit Tasks' description.
- As indicated by the Requirements Document compiled for the Active Traffic Incident Management System (also referred to as the Staley's Junction project) the master P261s Systems Requirements Specification for TOCS includes preliminary information on work processes and unit tasks for Traffic Management and Device Management. For consistency, selected Unit Tasks from those areas have been extracted from the TOCS P261s document for use in this document, similar to those outlined in the Staley's Junction project document.
- Once finalized and approved, all Work Processes, Unit Tasks and Requirements presented in this document shall be "blended" back into and/or added to the master P261s Systems Requirements Specification for TOCS, so a record of all processes related to the high-level Transportation Operations "umbrella" can be found in one place.
- High-level requirements are designated by "H" followed by a unique number and are in bold type. Detailed requirements in this document are designated by a "D", and are followed by a unique number. Detailed requirements are listed under their associated high-level requirement.
- All requirement numbers are assigned sequentially, as they are discussed.
    - Unit Tasks that were "borrowed" from the TOCS Systems Requirement Specification document may include TOCS requirements.
    - New requirements discovered for the VSL system are numbered sequentially starting at 101.
    - There is no intended or implied hierarchy between high-level requirement numbers and detail requirement numbers. If a High Level requirement and a Detail Level requirement share the same first digit, etc., it is coincidental.
    - Requirement numbers do not imply any level of importance. For example, requirement H100 is not assumed any more or less critical than requirement H200.

- High-level requirements are general statements and serve as the parent of one or more detailed requirements. High-level requirements generally do not contain enough information to be developed or proven through testing. Since detailed requirements (D) are always shown under their high-level requirement, a high-level requirement may actually appear in multiple work processes and/or unit tasks, as a high-level requirement may have some subsidiary detailed requirements that belong to one unit task, and some subsidiary detailed requirements that belong to another unit task.
- Detailed requirement statements are clear, concise, testable and provable and will always belong to one and only one Unit Task. If the detailed requirement is shown at the Work Process level because it applies to the work process as a whole, it will not then also show in any Unit Task.
- Requirements may apply to software, hardware, facilities, manual work processes, training, and any other component of the system.
- Every requirement statement has its own priority of H (high), M (medium) or L (low). Detailed requirements should not be assumed to have the same priority as their associated high-level requirement.
    - Detailed requirements with a priority of H (high) are considered mandatory. The system will not be operational unless all high-priority detailed requirements are delivered.
- Selected sections within this document may lack detailed content and do not apply to the VSL system. Such sections are included for reference within the ODOT TAD system development methodology and to show that a given topic has not been overlooked.

B-1.3 REFERENCES

This document is based primarily on the functions of the system that were specified in the Concept of Operations document for Evaluation of a Variable Speed Limit System for Wet and Extreme Weather Conditions, developed in December, 2011. An additional reference consulted and used as a template for this document is Active Traffic Incident Management System P261S System Requirement Specifications, Version 0.07, dated October 24, 2011. This latter document was developed for the Staley's Junction project, a VSL system which shares many aspects with the present project.

A general reference on setting speed zones, as well as the laws, rules and standards that apply, is the "ODOT Speed Zone Manual", most recently published by the ODOT Traffic-Roadway Section in June, 2011. A copy of this manual is available on the Internet at: http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/Speed_Zone_Manual.pdf

B-1.4 DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

This document has been developed under the assumption that the reader has an understanding of general terms used in traffic engineering and management, roadway classifications, ODOT organizational structure and terms, Traffic Operations Center operations, etc. Consequently, the glossary presented here does not include such common terms. Rather, it presents acronyms and specialized term definitions needed to understand the requirements presented throughout the document.

Term	Definition
Alarm	Notification of a traffic or system issue requiring intervention presented to Operators by TOCS
Alarm Conditions	A traffic or system issue requiring personnel intervention. Example: a crash
Alert	A notification of some change to the system. Ex. technical support staff notification of a device or system failure.
ATMS	Advanced Traffic Management System
Con-Ops	Concept of Operations Document
Central location	Traffic Operations Center
Communication	Central to field device or system component interactions
Devices	Weather and pavement condition detection sensors
Device Manager	System component that manages devices
GUI	Graphical User Interface – a screen used within a computer application (system) to display information to a user, and/or to allow the user to input information that is to be stored and/or used by the system.
ITS	Intelligent Transportation Systems – the business area within ODOT that is the "Systems Owner" of the VSL.
Monitor	Regularly check system function
MTL	Minimum Time Lapse
NTCIP	National Transportation Communications for ITS Protocol
ODOT	Oregon Department of Transportation
Poll	A periodic data sample taken by a sensor
RWIS	Road Weather Information System - a network of meteorological and pavement sensors located along the highway system that provide accurate real-time road weather information and critical observations.
Sensor failure	Sensor sending no or improbable data, or that fails to communicate with the Device Manager
Sign failure	Sign sending no or improbable data, or that fails to communicate with the Device Manager
Speed Limit	The maximum rate at which a vehicle can legally travel on a given segment of road (in the case of the VSL system, a ramp).
TAD	Transportation Application Development – a unit within ODOT Information Systems. This organization provides computer application development and support for a significant portion of ODOT.

Term	Definition
The System	The VSL system for the US Highway 26 / OR Highway 217 Interchange as defined by the Concept of Operation, the P261S System Requirements Specification, and this document.
TMOC	Traffic Management Operations Center – the name by which the TOC in Portland is known. This organization will be the day-to-day operators of the VSL system.
TOC	Transportation Operations Center – a call center that receives reports of problems on the Oregon State Highway system from the general public, law enforcement, and ODOT employees. Operators in the TOC enter information into TOCS and dispatch crews as necessary to clear the problem.
TOCS	Transportation Operations Center System – a software application used by TOC staff as well as selected regional and district staff to enter information on events that may impact the traveling public. It is also used to dispatch crews to problem areas, and record damage and repairs done to ODOT property.
TTIP	TripCheck Traveler Information Portal
UMTL	Upward Minimum Time Lapse
VSL	Variable Speed Limit – a speed limit that may change on a given section of road depending on conditions.
VSLS	Variable Speed Limit Sign - a sign that has the capability to display different speed limits based on instructions provided to it by an operator and/or an automated system.

B-2.0 PROJECT HISTORY

Project Name: Evaluation of a Variable Speed Limit System for Wet and Extreme Weather
Project Start Date: June 14, 2011
Project Implementation Date: June 14, 2011
System Version or Release #: 1.0

The primary goal of this project is to employ variable speed limits to address wet weather and pavement crashes at the US26/OR217 Interchange. The specific ramps included in the VSL system include the US26 eastbound to OR217 southbound ramp, the US26 westbound to OR217 southbound ramp, and the OR217 northbound to US26 westbound ramp. Figure 1 presents an overview of the project interchange and the respective ramps. This section describes the purpose for system implementation and the specific project objectives.

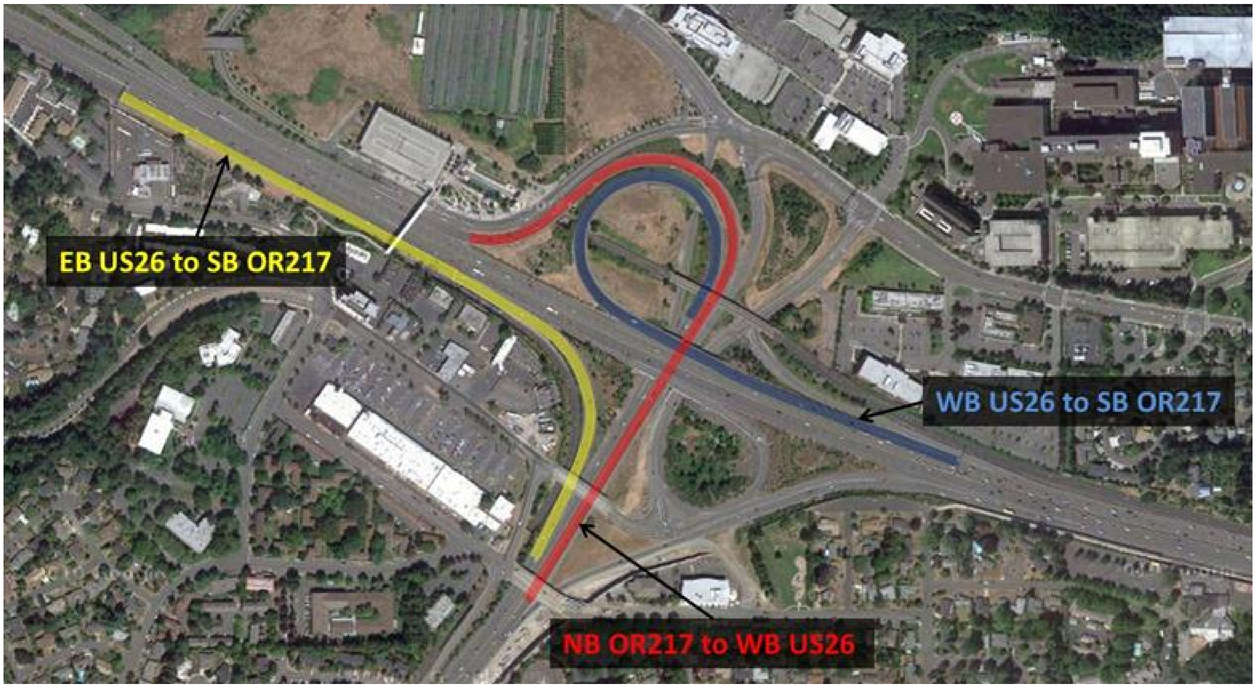

Figure 12: Project Area

Two types of VSL sign are proposed for use as part of this project. One type is a full matrix type variable electronic sign that will post a regulatory speed limit when the system determines wet/deteriorated conditions are present on the ramps. The other is a more traditional static background sign with a light emitting diode (LED) panel that changes only the numerical speed part of the sign which will be active when normal, dry conditions are detected on the ramps. The full matrix variable electronic sign will display an electronic version of a static regulatory speed limit sign with any numerical speed in the appropriate colors that conform to MUTCD guidance. When the sign is not activated (i.e. when an advisory speed limit is in effect during dry conditions) the electronic sign will be blank (blacked out) and convey no information. The static background advisory sign will be a traditional static advisory sign similar to those already present on the ramps that displays the ramp geometry on the metal portion of the sign and the advisory speed on a changeable LED sign attached below the metal sign. The static portion of the sign would always display the ramp geometry since it has no electronic features, but the LED speed would only be displayed when applicable and would be blank when not activated.

B-3.0 SYSTEM OVERVIEW

The system overview section presents the purpose for the system, objectives of the system, and some key issues dealing with the system.

B-3.1 SYSTEM PURPOSE

The ramp traffic data of the US26/OR217 interchange in Beaverton, Oregon indicates that over 60,000 vehicles per day use the ramps. Crash data has shown that one or more "loss of control" crashes per day have been observed during wet pavement conditions, with secondary crashes occurring on many occasions. Historically, once wet pavement conditions occur at this site, crashes classified as "loss of control" increase. While the site has traditional passive signage and flashing beacons in place, crashes continue to occur. Oregon Department of Transportation personnel have concluded that additional measures are necessary to address the problem.

This project seeks to reduce the occurrence of wet weather crashes on the interchange ramps of the US26/OR217 interchange in Beaverton, Oregon through the use of a weather-responsive variable speed limit system. Such a system will post appropriate speed limits based on weather conditions, with the intent of lowering motorists' speeds accordingly. The system may also incorporate active warning signs to provide advanced warnings to motorists in advance of the ramps. As motorists lower their speeds for different weather conditions, they will be traveling at safer speeds and crash occurrence is expected to drop.

B-3.2 OBJECTIVES OF THE SYSTEM

The specific project goals to reduce wet weather crashes include:

- Develop an advanced weather-responsive speed limit adjustment system to be deployed by ODOT at ramps of the US 26/OR 217 interchange. This involves identifying and evaluating system components (ex. sensors, processors, etc.) to detect weather conditions and support the overall functions of the system
- Develop methodologies and algorithms for setting adjustable speed limits based on weather conditions. This will support the determination of appropriate speed limits based on current weather conditions.
- Assess the effectiveness of the system in reducing average vehicle speeds and the number of speed-related crashes and/or incidents at the study site. This will be achieved through examining speed and crash/incident experience before and after system deployment.
- Develop guidance to assist in future deployments of similar systems at other locations. This will allow for transferability of such systems to sites with similar safety problems

B-3.3 KEY ISSUES

- For reasons dealing with sensor technology, the system may need to incorporate non-NTCIP compliant sensors for data collection that are not necessarily compatible with existing ODOT equipment or systems.

B-4.0 SYSTEM REQUIREMENTS

B-4.1 SYSTEM CONTEXT

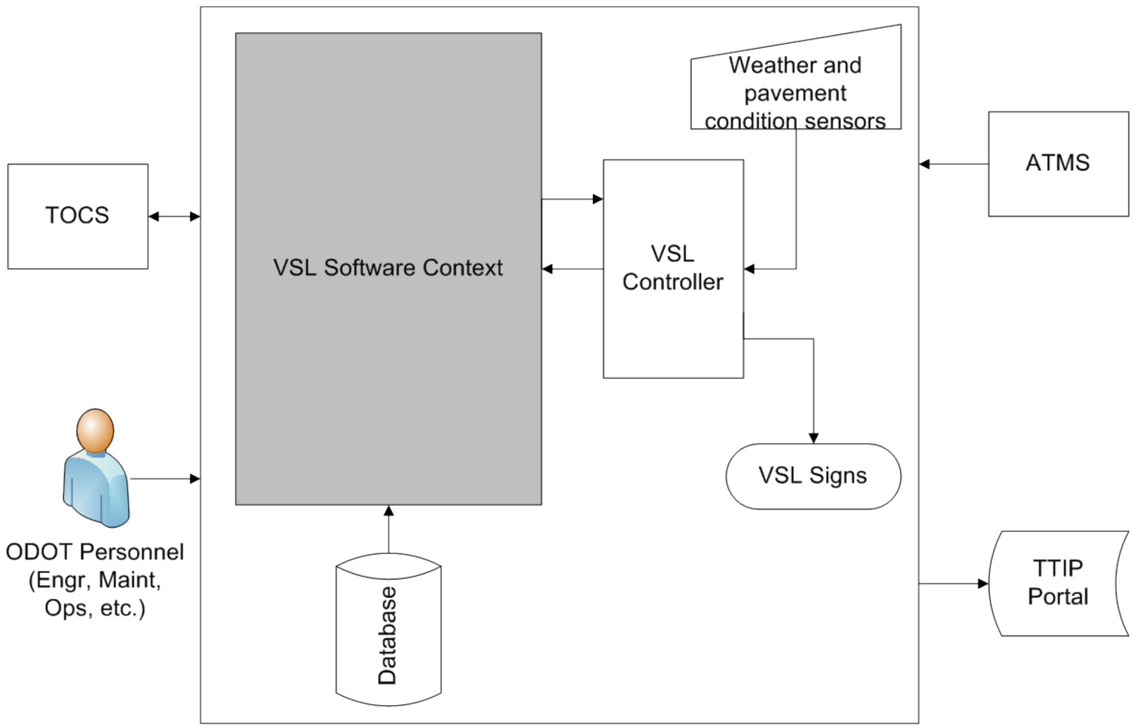

Figure 13: System Context

B-4.2 SYSTEM SECURITY

The administrative module will utilize standard TOCS security. Those intending to use that module must be TOCS users and have the appropriate security approval as part of their profile. Communications with signs and sensors will be secured through the same software and hardware techniques currently used throughout ODOT's network.

B-4.3 SYSTEM PERFORMANCE

Reqmnt Number	Requirement Description	Priority
H101	The Variable Speed Limit signs shall be available and operational at a level of time to be established by ODOT.	H
D102	The Variable Speed Limit signs shall be available 100% of the time, excluding service outages, power outages, vehicle strikes/damage, vandalism and other events beyond ODOT control.	H

Reqmnt Number	Requirement Description	Priority
D103	When communication is lost with a single VSL sign (either the full regulatory sign or the number board associated with the advisory speed sign), the default shall be to have that single VSL sign go blank, but remaining VSL signs that are operating at the interchange continue to display.	H
D104	When communication is lost with more than one VSL sign or the controller that runs them, the VSL signs shall go blank. In this case, the system will not post any speed limit information to the signs, in effect defaulting to the 30 mph advisory speed limit. In such a case, ODOT personnel would need to go to the interchange and deploy static signage displaying a speed limit until the VSL system becomes operational once again.	H
D105	When a problem causes an individual VSL sign or signs to display an invalid speed value (such as "10 mph" during clear, dry conditions), the technician or operator shall shut down the affected sign(s) or take other needed action so it is blanked out.	H
D106	Under a "worst-case" scenario where multiple signs are unavailable or are malfunctioning due to failure of the sign, the controller, the network or other cause, the VSL signs shall be put to a blank condition. In this case, ODOT personnel will need to travel to the interchange and deploy static signage displaying an advisory speed limit until the VSL system is again operational.	H
D107	Because the "worst-case scenario" is to allow VSL signs to go blank and the default speed limit for the ramp(s) set by ODOT personnel via static signage, central control systems do not require redundant high-availability uptimes. As a result, a redundant "fall-back" software and hardware environment shall not be developed or provided.	H

B-4.4 ASSUMPTIONS AND DEPENDENCIES

- TAD will perform the software designer role and implement the surface state and weather condition algorithm for assigning variable speed limits developed by the Western Transportation Institute (WTI).
- WTI shall assist ODOT as needed in making decisions and identifying additional requirements.
- This system requires the interface of complex software to multiple types of hardware, located in a busy traffic area. As this system cannot function without it, it is assumed that all hardware components will be installed, tested and functioning correctly by the time the software has been developed.
- All NTCIP-compliant signs and radar sensors will be accessed via controllers specified and selected by ODOT.
- Incorrect sensor data (from grip/surface state and RWIS sensors) will be filtered out.
- The default permanent message for all VSL signs – used when the system cannot access the sign – is a blank speed value.
- One full matrix and one LED panel Variable Speed Limit sign will be installed on each interchange ramp, with placement such that all drivers will see and have the opportunity to read them. Each of the two signs installed on a ramp will operate individually; i.e.

when a regulatory speed limit is in effect, only the full matrix sign will post a speed limit and the advisory LED panel will be blank.

B-5.0 SOFTWARE REQUIREMENTS SPECIFICATIONS

B-5.1 SOFTWARE OVERVIEW

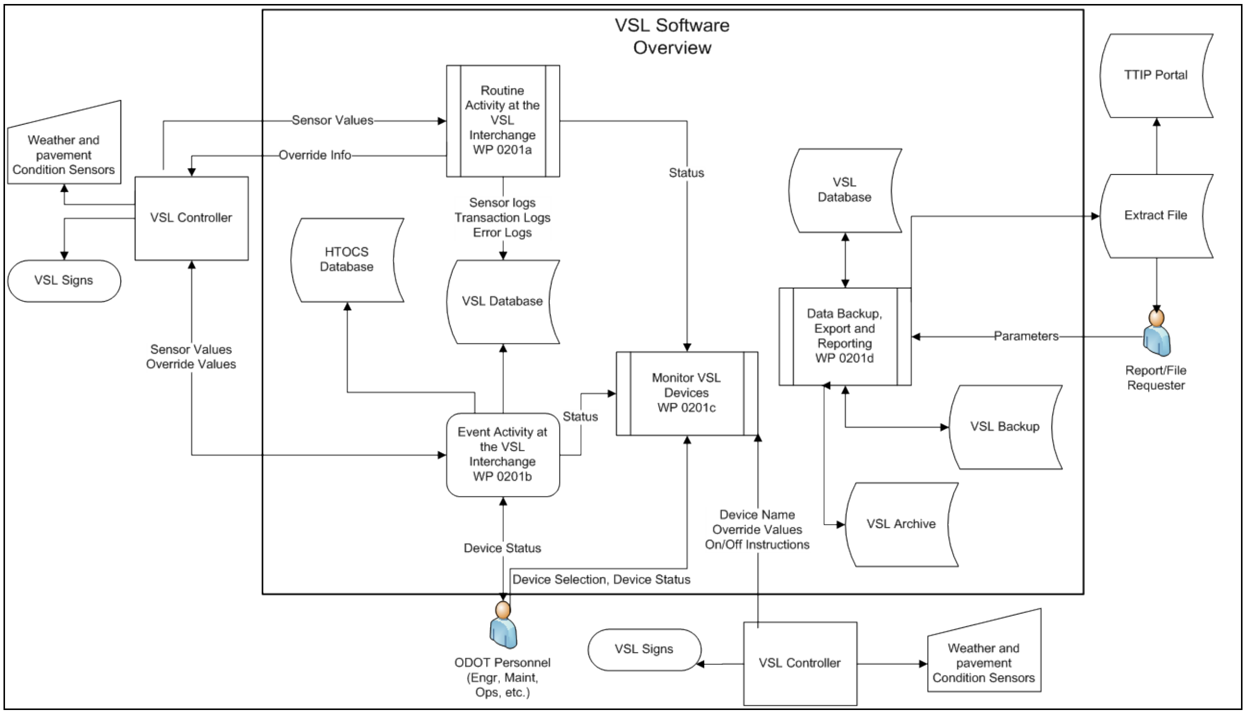

Figure 14: Software Overview

The work processes within the VSL perform the following general functions:

- WP 0201a – Routine Activity at the VSL Interchange: This work process captures sensor information and computes the variable speed limit values.
- WP 0201b – Incidents like crashes, hardware failures of sensors and signs and other issues impact the normal operation of the VSL system on one or more ramps. This work process determines whether these external issues are present, and communicates the result with the first work process, so any necessary adjustments to the posted speed limit(s) can be made.
- WP 0201c – This work Process is used to detect device failure or data problems that show that a device has or is developing a problem. It is used to send the information to a technician automatically so the problem can get addressed, and the device can be placed back in service.
- WP 0201d – In addition to performing routine backup, archive and restore functions, this work process allows a user to extract reports and/or data from the VSL database. Such a capability is necessary to evaluate the performance and effectiveness of the system

B-5.2 WORK PROCESS 0201A – ROUTINE ACTIVITY AT THE VSL INTERCHANGE

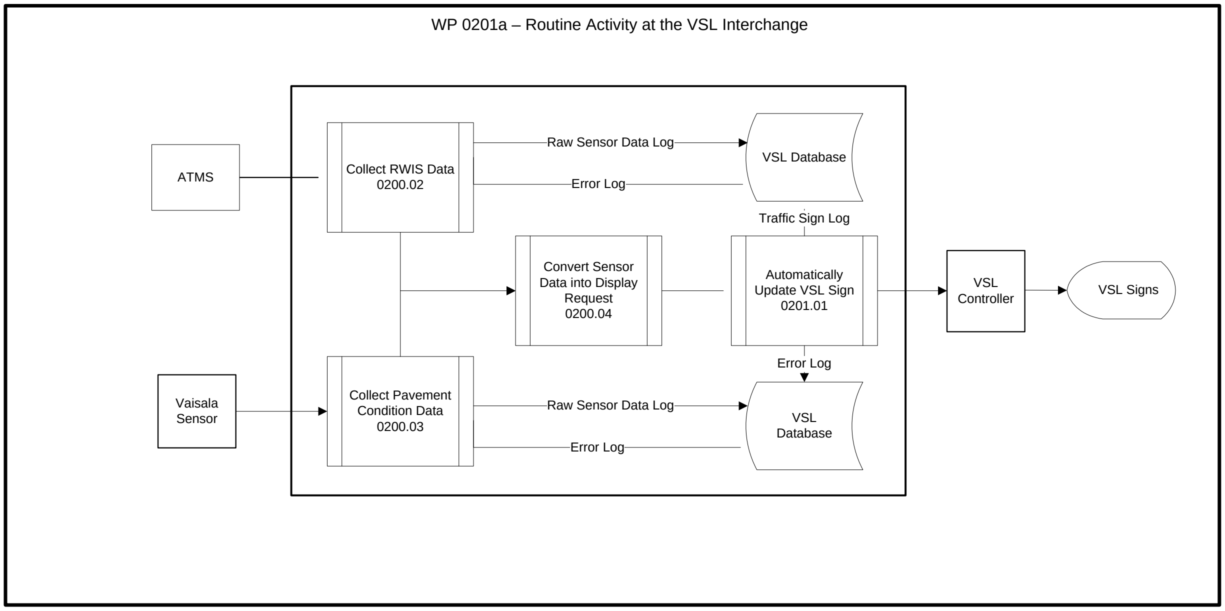

Figure 15: Routine Activity at the VSL Interchange

The Unit Tasks in this Work Process perform the “routine” processes for the weather and pavement condition sensors and VSL signs on the interchange ramps. The processes collect condition data from the sensors, apply calculations and rules to process the data into the speed limit values for all ramps, apply specific business rules to ensure the validity of speed limit values, and then display the resulting values on VSL signs where they can be seen by drivers on the interchange ramps.

B-5.2.1 Unit Task 0200.02 – Collect RWIS Data

In conjunction with the installation of the VSL system, an RWIS station will also be deployed at the interchange site. The RWIS will provide current weather condition data (temperature, precipitation intensity and type, etc.) that will be used as data inputs for the VSL controller to consider when establishing speed limits. This data will also serve as a cross reference to check pavement condition data being collected by a separate sensor (ex. if the RWIS indicates no precipitation but the pavement sensor detects moderate wetness, the status of the system would be flagged for an operator to check).

Upon periodic request, the RWIS will transmit data to VSL system controller. The controller will incorporate this data into the system algorithms for determining the speed limit and type (regulatory versus advisory) displayed by each sign.

Actor	The system
Circumstances of Use	Data is gathered from the RWIS station.
Frequency of Use	Extreme – runs continuously, 24 x 7 x 365
Mode of Automation	Automated

Triggers	Data requests set at periodic intervals
Dependencies	Server processes must be running and communication established between the RWIS and VSL controller.
Pre-Conditions	Weather information has been collected by the RWIS but not yet requested and transmitted to the VSL controller.
Post Conditions	The data has been received by the VSL controller
Step 1	Store raw weather sensor readings in the device log, identified by the name of the device.
Step 2	Ongoing for the RWIS – detect weather conditions and parameters and provide the information to the VSL controller.
Step 3	On a scheduled basis (such as in one minute intervals), this process sends a request to the RWIS for weather data from the past “X” number of minutes (where X is a user-defined parameter, such as 5).
Step 4	RWIS transmits the requested data to the requesting process.
Step 5	Data from the RWIS is passed on to the process that computes the speed limit for a given ramp (UT 300.03).

Rqmnt Number	**Requirement Description**	**Priority**
H210	The system shall be able to receive and process data from two types of sensors: an RWIS station and a pavement condition/temperature device.	H
D211	The data from the RWIS station at the interchange shall be associated with conditions on all three VSL system ramps.	H
D212	The RWIS shall provide data to the VSL system’s calling process on the calling schedule (example: every minute).	H
H216	When expecting to receive information from the RWIS, the VSL system will detect and report any failure to successfully communicate with the device.	H
D217	If the signal to/from RWIS and/or the VSL controller computation module indicates that the gathering and/or transmission of the condition data were unsuccessful, the system shall report a module failure by sending a Support Alert to support staff using Unit Task “0360.01 Poll Integrated VSL Device”.	H
D218	When the VLS system detects a failure in communicating with the RWIS and/or its controller, and/or the computation module, the system shall write an entry into the error log, including the name of the device, the timestamp, the identification of what this process was attempting to do when the error occurred, and a detailed description of the error itself, such as the error message received from the network.	H

B-5.2.2 Unit Task 0200.03 – Collect Pavement Condition Data

The second sensor type used to detect conditions at the site will collect data on pavement surface state (wet, dry, snow, etc.), temperature and grip (friction)[7]. The pavement condition sensors are

[7] During previous project work, ODOT selected the Vaisala DSC 111 as this sensor. For the purposes of this document, this sensor will be referred to in general terms as “the pavement condition sensor”.

installed at a height and angle that allow them to measure conditions for a fixed point in the travel lane. This data allows the system to identify changes in friction and surface state/conditions on a specific ramp and provide that data to the system controller for consideration in the speed limit algorithm. This data will also serve as a cross reference to check RWIS data being collected by a separate system (ex. if the RWIS indicates no precipitation but the pavement sensor detects moderate wetness, the status of the system would be flagged for an operator to check).

Upon periodic request, the pavement condition sensor controllers will transmit data to the VSL system controller.

Actor	The system
Circumstances of Use	Data is gathered from pavement conditions sensors on each specific VSL ramp.
Frequency of Use	Extreme – runs continuously, 24 x 7 x 365
Mode of Automation	Automated
Triggers	Data requests set at periodic intervals
Dependencies	Server processes must be running and communication established between the pavement condition sensors and VSL controller.
Pre-Conditions	Condition information has been collected by the sensor but not yet requested and transmitted to the VSL controller.
Post Conditions	The data has been received by the VSL controller
Step 1	Ongoing for each sensor – detect pavement conditions and provide the information to the controller.
Step 2	On a scheduled basis (such as in one minute intervals), this process sends a request to each of the pavement condition sensors controllers for data from the past "X" number of minutes (where X is a user-defined parameter, such as 5).
Step 3	Sensor transmits the requested data to the requesting process.
Step 4	Data from all sensors is passed on to the VSL system controller that determines the speed limit for each ramp (UT 0200.04).

Rqmnt Number	Requirement Description	Priority
H225	The system shall keep a log of the raw sensor readings.	H
D226	Each time a pavement condition sensor reads data, the system shall create an entry in the device log. This entry shall include the name of the device, the timestamp, and the raw sensor readings.	H
H227	When expecting to receive information from a pavement condition sensor, the VSL system will detect and report any failure to successfully communicate with the device.	H
D228	If the signal to/from the pavement condition sensor and/or its controller and/or the VSL controller indicates that the gathering and/or transmission of the data were unsuccessful, the system shall report a module failure by sending a Support Alert to support staff using Unit Task "0300.03 Poll Integrated VSL Device".	H

Rqmnt Number	Requirement Description	Priority
D226	When the VSL system detects a failure in communicating with a pavement condition sensor and/or the VSL controller, the system shall write an entry into the error log, including the name of the device, the timestamp, the identification of what this process was attempting to do when the error occurred, and a detailed description of the error itself, such as the error message received from the network.	H

B-5.2.3 Unit Task 0200.04 – Compute Speed Limit Request

This process runs automatically on a short cycle (such as every minute) to use the sensor data supplied by Unit Tasks 0200.02 and 0200.03 in order to perform calculations to determine the appropriate Speed Limit based on current weather and pavement conditions. Before actually sending the computed value to the VSL signs, the system applies several business rules, determining whether the sensor data correspond to similar conditions (ex. rain, snow, dry, etc.), and determining whether the computed speed limit is reasonable (i.e. 15 mph under dry conditions, not reasonable).

If the above rules are passed and the new speed limit is sent to the sign, the system then creates a log entry documenting the new speed limit set for each ramp, and includes the data that was used to make the decision to set/change the speed limit.

Actor	The VSL system
Circumstances of Use	Calculations are performed in a central controller location, and then transmitted to VSL sign controllers for each interchange ramp in the system.
Frequency of Use	Extreme – runs continuously, 24 x 7 x 365
Mode of Automation	Automated
Triggers	When speed limits for each ramp need to be computed/determined.
Dependencies	RWIS and pavement condition data must be provided by Unit Tasks 0200.02 and/or 0200.03
Pre-Conditions	RWIS and pavement condition data are available, but speed limit values have not been determined using that data.
Post Conditions	The new speed limit value has been determined for each ramp.
Step 1	Combine RWIS and pavement condition sensor data to get information for determining the appropriate speed limit and its type.
Step 2	Determine if conditions are dry and pavement grip is good. In this case, set the speed limit to 30 mph and advisory.
Step 3	If pavement conditions are not dry, determine the surface grip (friction) as well as the amount of precipitation present and set the speed limit appropriately based on existing threshold values.
Step 4	Check whether an existing Incident Flag requires a lower speed limit than determined necessary. (Refer to Work Process 0300b)
Step 5	Determine if this speed limit and type is the same as the one already posted. If not, continue. If it is, update the "time since last change" value.

Step 6	Determine if enough time has passed to be able to post a new speed limit. If so, continue. If not, repeat this Unit Task at next time interval.
Step 7	Send the speed limit change to the controller for the VSL signs.
Step 8	Log the speed limit change, including the data and decisions used in making the change.

Rqmnt Number	Requirement Description	Priority
H230	The system will compute the speed limit for a given interchange ramp using RWIS and pavement condition sensor data as input, along with the application of formulas, business rules, and table lookups as appropriate.	H
D231	The system shall be automated and speed limits for each ramp shall change without requiring operator interaction.	H
D232	The VSL application shall be managed from the TMOC, which is staffed 24 hours per day.	H
D233	At regular time intervals (such as 1 minute), the system shall process data from all sensors and determine speed limit values for all ramps before issuing values to all signs.	H
D234	Once a sensor is flagged (by the system or by an operator) as failed, the system shall exclude the data produced by that detector from the VSL algorithm. After the detector has been repaired, re-establishes communications, or data quality improves, the detector shall be returned to normal operating status.	H
D235	The System shall use data from sensors on other ramps if a pavement condition sensor on a ramp has failed. This value shall be referenced as the "default speed limit". If the RWIS has failed but pavement condition sensor data is still available, the system may continue operating.	H
D236	The system shall operate normally as long as the pavement condition sensors are working. The System shall create a support alert reporting the sensor failure.	H
D237	There shall be a maximum speed limit of 30 mph and a minimum speed limit of 20 mph for all ramps in the VSL system.	H
D238	The system shall not change sign displays – increase or decrease - for a business specified period of time after a change in display occurs. This is known as "the specified minimum time lapse (MTL)" and is defined as the time interval that the system must wait before updates to the speed limit displayed by the signage can be made. When a variable speed limit sign changes to a lower speed, this is called the "Downward Minimum Time Lapse (DMTL)". When a VSL sign changes to a higher speed, this is called the "Upward Minimum Time Lapse (UMTL)". Once the VSL sign values have been changed on a ramp, the next update shall be subject to the MTL rules: another change downward cannot happen for DMTL minutes; another change upward cannot happen for UMTL minutes.	H

Rqmnt Number	Requirement Description	Priority
D239	The variable speed control software shall check for an override status before sending an updated display request to each VSL sign. [This override status is set in Unit Task 0300.03 Administer VSL Devices.] If the override status is set for a given ramp, the system shall not automatically change the speed limit on that ramp until the override status is removed.	H
D240	Before a display request is sent to a sign, the system shall determine if the new value is the same as the old value. If it is the same, the value is not sent to the sign. However, the expiration time value for that ramp is updated so the speed limit message does not show as expired.	H
D241	When an individual sign is flagged as failed, the Management (Administration) process shall send a final command to turn the sign display off and not attempt to update the sign until it has been set back to normal operating status.	H
D242	When the system determines an advisory speed limit of 30 mph is warranted, the system will only send a display request to the advisory LED panel and blank out the regulatory sign.	H
D243	If a regulatory speed limit is warranted, the system will send a display request only to the regulatory sign and blank out the advisory panel.	H

B-5.2.4 Unit Task 0201.01 – Update Variable Speed Limit Sign

Variable Speed Limit signage is chiefly employed to manage variable conditions on motorways, freeways and major arterial routes. VSL is effective for reducing speeds in adverse weather driving conditions e.g. rain, snow, wind, ice, fog.

Within the VSL system, the Variable Speed Limit signs are the primary method by which traffic will be managed in a way that helps it slow down during times of inclement weather conditions.

Actor	The VSL system software
Circumstances of Use	Weather and pavement conditions have changed and a different speed limit needs to be put in place on one or more interchange ramps.
Frequency of Use	Medium
Mode of Automation	Automated
Triggers	The module that determines the speed limit for each ramp has requested that a change be made on the VSL signs on one or more ramps.
Dependencies	Signs must be working and the application must be able to communicate with the VSL controllers.
Pre-Conditions	A new speed limit has been determined, but is not displayed on the applicable signs.
Post Conditions	The new speed limit is displayed correctly on the applicable signs.
Step 1	Receive new speed limit value
Step 2	Display value

Rqmnt Number	Requirement Description	Priority
H250	Each VSL sign on each interchange ramp shall display the appropriate speed limit value.	H
D251	Each VSL sign shall be assigned to one interchange ramp.	H
D252	All VSL signs that are on the same ramp shall act independently with only one displaying a speed limit at any given time, with its counterpart blanked out.	H
D253	VSL signs shall only display predefined messages – those from a pre-defined list of acceptable messages. (Acceptable speed limit values of 30, 25, 20 mph or blank.)	H
D254	The System is allowed to change to any allowed speed without incrementing what is displayed, i.e., the System can change from 30 MPH directly to 20 MPH.	H
D255	The System shall contain a VSL sign default, currently “blank”.	H
D256	During power outages, each affected VSL sign shall display a blank screen.	H
D257	VSL signs shall not display a speed limit below a user-defined value.	H

B-5.3 WORK PROCESS 300B – EVENT ACTIVITY AT THE VSL INTERCHANGE

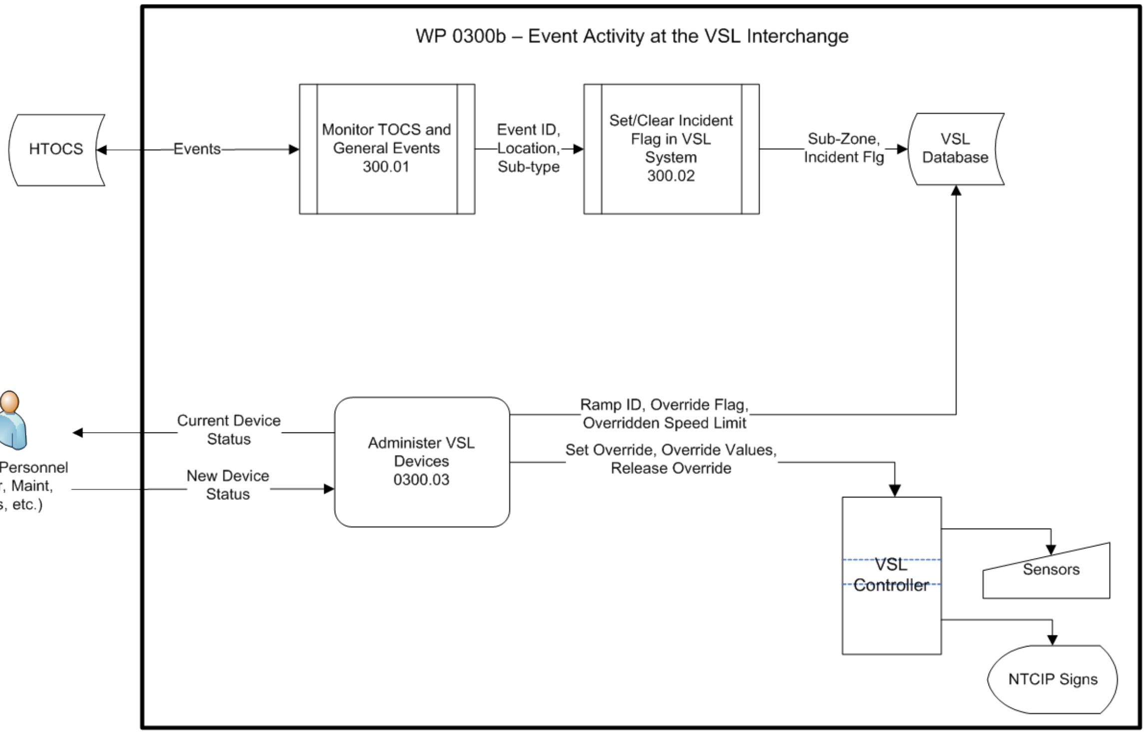

Figure 16: Event Activity at the VSL Interchange

While the previous Work Process performs the routine tasks of setting speed limits based on the routine traffic data, this Work Process checks for activity that can adversely impact the flow of traffic on the interchange ramps (specifically crashes). It relies on external data feeds (traffic detectors, camera images, TOCS data, etc.) examined by TOC operators to establish that a problem near the interchange or on one of its ramps has occurred.

When the operator has identified or been notified of an event at the VSL interchange, they may use existing cameras to monitor the situation or to determine if additional action is required. If necessary, the operator may utilize the Administrative application to override one or more VSL signs, put one or more devices out of service, or bring device(s) back into service.

B-5.3.1 Unit Task 0300.01 – Monitor TOCS and General Events

This Unit Task monitors potential events occurring at or near the interchange which may have an impact on the variable speed limits set on one or more ramps. This monitoring is to be performed by TOC personnel, with the VSL system not acquiring any sensor data for detection purposes. Event information will come from the TOCS database, observation of CCTV feeds, loop detector data, and so forth. Based on an event or condition, different actions may be taken with respect to the VSL system, including:

- Do-nothing throughout entire event (maintain posted speed limit and allow the system to continue operating as normal).
- Manually override at the onset of an event (manually set a specific, pre-determined speed limit at the beginning of an event and maintain it until the event has ended).
- Monitor and potentially override if needed (allow the system to operate normally and only override if traffic conditions make it necessary).

Actor	TMOC operator and ODOT personnel; TOCS and other data streams
Circumstances of Use	This activity applies to all events
Frequency of Use	Medium
Mode of Automation	Manual
Triggers	Observation of an event that impacts one or more of the ramps covered by the VSL system.
Dependencies	Sensors must be running, the database and servers must be available, and TOC personnel must be aware of and monitoring conditions.
Preconditions	An event has not yet occurred.
Post Conditions	The event has concluded and the VSL system can return to normal operations.
Step 1	TOC personnel monitor events as they occur and set incident flag as needed.
Step 2	Make decision regarding if/when VSL system is overridden as needed.
Step 3	Once an event concludes, clear the incident flag: Information about the Event is sent to Unit Task "0300.02 Set / Clear Incident Flag for VSL".

Rqmnt Number	Requirement Description	Priority
H301	The VSL system shall include the ability to allow an administrator to override the speed values on any or all VSL signs at the interchange, to put one or more signs out of service, and perform other administrative tasks.	H
D302	The operator shall have the ability, using an administration screen, to flag a sensor, VSL sign, controller or other component as failed.	H

Rqmnt Number	Requirement Description	Priority
D303	At any time, the traffic engineer or ODOT TMOC operator may initiate manual operation of the display of the VSL signs through the use of an administrative screen. Once a portion of the system has been put into manual control, the system shall not attempt to automatically set a speed limit value on the overridden signs.	H
D304	When the operator removes manual control, the variable speed control software shall resume sending new display requests to the signs that had been under manual control.	H

B-5.3.2 Unit Task 0300.02 – Set/Clear Flag in VSL System

This existing Unit Task closes out all responses to an event. When an Operator indicates that their response is complete, the event is marked as closed and the VSL is returned to automatic operation.

Actor	TMOC operator, ODOT personnel
Circumstances of Use	TOCS event response is closed by the Operator
Frequency of Use	High
Mode of Automation	Manual
Triggers	Crew or on-scene agency (e.g. law enforcement, haz mat, etc.) notifies TOC Operator that scene is clear or event has ended.
Dependencies	Active event has been responded to
Precondition	The event is ongoing, and one or more responses may be in progress.
Post Conditions	Responses to event are cleared, including any manual override to the VSL system.
Step 1	When applicable, sends information to Unit Task “0300.02 Set / Clear Incident Flag for VSL” returning the VSL to automatic control.

Rqmnt Number	Requirement Description	Priority
H305	When anevent that required manual override of the VSL is closed, a notification of the event closure will be sent by the user (ODOT) to the system.	H
D306	When an event is closed, if manual override of the system has occurred, the incident flag shall be removed and the system returned to automatic control with information sent to Unit Task “0300.02 Set / Clear Incident Flag for VSL”.	H

B-5.3.3Unit Task 0300.03 – Administer VSL Devices

This Unit Task allows the authorized user to enable or disable the VSL operation in selected sub-zones, set the system to test mode or normal mode, view traffic values in each sub-zone, and override the speed limit in any sub-zone if necessary. This override function will primarily be used when an event has occurred and the operator needs to slow the traffic in upstream sub-zones when the system has not done so automatically, or when the automated process is not functioning correctly.

This process will be again used when the problem has been corrected, and the system is to be set back to automated mode.

Actor	TMOC operator, ODOT personnel
Circumstances of Use	The system needs to be put in test or normal mode, or on one or more ramps needs to be disabled, or the speed limit on one or more ramps needs to be manually set, or a previous override now needs to be canceled.
Frequency of Use	Occasional
Mode of Automation	Interactive
Triggers	Routine maintenance is to take place, or an event or problem has been detected that the automated VSL system is not correctly handling, or a problem or event has been resolved.
Dependencies	Power and communication must be available to the VSL controllers and signs.
Pre Condition	A circumstance has arisen that requires a manual override of the system.
Post Conditions	The override has been successfully implemented, or a previous override has been removed, with the system set back to normal operation.
Step 1	Access the VSL administration module
Step 2	Set the normal / test mode if applicable
Step 3	Enable / Disable selected ramp system/sign
Step 4	Enter overridden speed limit value(s)
Step 5	When problems are resolved, set system back on automatic execution.

B-5.4 WORK PROCESS 0350C – MONITOR VSL SYSTEM DEVICES

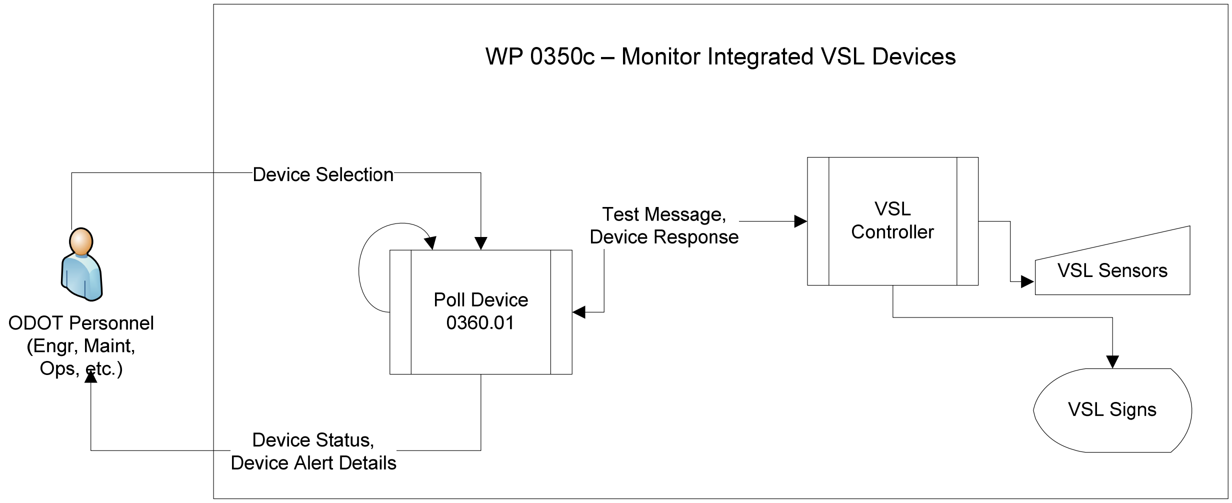

Figure 17: Monitor Integrated VSL Devices

The Unit Task in this work process runs in the background to ensure the VSL system is functioning properly, and notifies technicians if a failure is detected.

A technician may also run this process manually in order to test a new device, or to trouble-shoot devices after an alert has been received by a technician, indicating that a device may be failing.

B-5.4.1 Unit Task 0360.01 – Poll Integrated VSL Devices

This is an existing process, currently in use at ODOT.

An appropriate device monitor routinely polls all connected VSL devices in the field to ensure that processes are running, devices are connected and can receive and send communications, and that the signs are displaying the speed limit the system believes they should be displaying.

If this Unit Task can see from the latest timestamp put in the database from the speed limit algorithm module that the module is not running, the device monitor shall have the capability to restart the process.

If a problem is detected and the device monitor cannot solve it by restarting the process, a message is sent to the technician. If the problem continues, the device monitor has and uses the ability to escalate the issue.

Actor	This process generally runs automatically. However, ODOT personnel can run the process as needed to check specific devices.
Circumstances of Use	When a new VSL component is set up, or routinely to ensure the VSL system is working, or to troubleshoot performance issues, done periodically by the system to check the status of signs
Frequency of Use	High
Mode of Automation	Automated (Interactive is possible when a technician is installing a new component or researching a problem)
Triggers	Various
Dependencies	VSL system components are installed
Preconditions	Status of communication between device monitor and the device needs to be checked
Post Conditions	Status of communication between device monitor and the device has been checked
Step 1a	Select device for polling
Step 2a	Poll device
Step 3a	Device monitor checks the communication link and returns the status to the requestor
Step 1b	Set up polling schedule
Step 2b	Device monitor automatically checks the communication link on a scheduled basis and returns the status.
Step 4	Device monitor sends a notification to the technician (via e-mail) when a problem is detected.
Step 5	If the problem continues, device monitor uses escalation rules to notify others of the issue so it can be addressed.

Rqmnt Number	Requirement Description	Priority
H361	[Existing requirement – not specifically for VSL system]: TOCS shall provide 2-way communications and information flows with existing ODOT systems.	H
H362	[Existing requirement – not specifically for VSL]: TOCS shall support the ability for any ODOT Regional TOC and/or TMOC to have 2-way communications to all of ODOT's TOCS-integrated (NTCIP) signs (regardless of location) for control and/or information-sharing purposes.	H
H363	[Existing requirement – not specifically for VSL]: TOCS shall provide monitoring and management functionality equivalent to what is currently available in Skyline.	H
H364	[Existing requirement – not specifically for VSL]: The system shall maintain device status; the default status for a new device is 'Active'	H
H365	When a VSL device is down, continued polling will not be interpreted by the system as an indication that the device is actually working.	H
D366	When a VSL sign has failed, the device manager shall stop polling the sign so the system does not take the polling action as an indication that the sign is still functioning.	H

Rqmnt Number	Requirement Description	Priority
D367	When a device manager (controller) has failed, the system shall stop communicating with the device manager until the Operator indicates that the device is again in service.	H
D369	If more than one data sensor for a ramp fails (i.e. both the RWIS and pavement condition sensor), the respective VSL sign will default to a blank message	H
D370	When a controller has failed, the technician shall set the signs to their default status of blank. The signs shall remain in this state until the controller is back in service.	H
D371	If a communications failure is detected, the System shall create a "lost comm." alert for support staff.	H
D372	When communications are restored, the system shall clear the existing lost comm. alert.	H
D373	In the event of a power or communications failure to an individual component, the system shall maintain normal operations without that component.	H
H273	The System shall support requests to reload the VSL module	H
D375	The System shall send a Support Alert to support staff when the VSL module fails to load, reload, start, or restart. The System shall log the error in the Error Log.	H
H376	The System shall maintain a System Error Log (database table LOG) which logs system errors under different log categories which will drive different Support Alerts to maintenance staff.	H
D377	The System shall send a Support Alert to support and maintenance staff when an effort requiring maintenance occurs.	H

B-5.5 WORK PROCESS 0400D – DATA BACKUP, EXPORT AND REPORTING

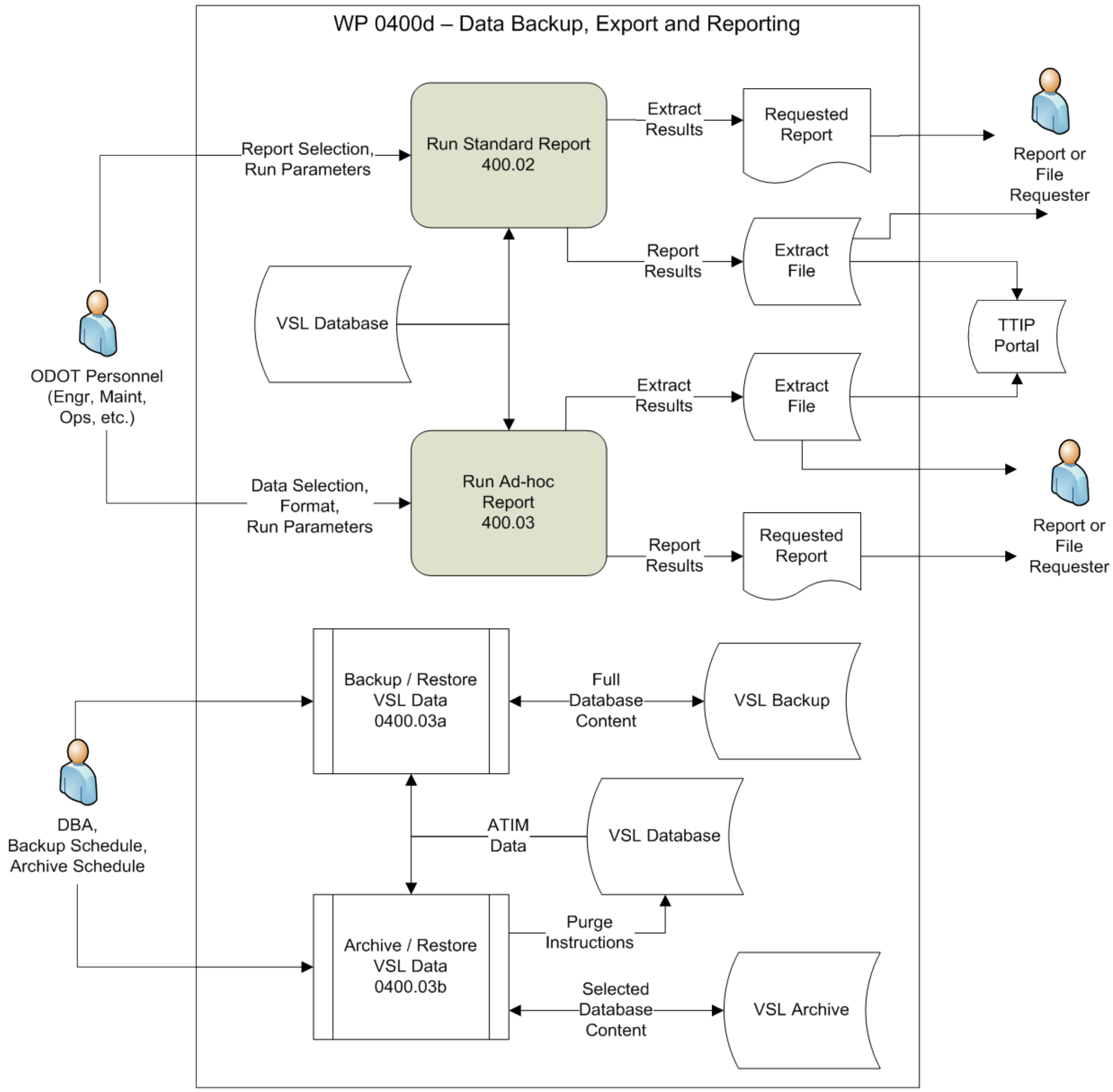

Figure 18: Data Backup, Export and Reporting

The Unit Tasks in this work process allow the user to produce reports and/or extract files using the VSL database as the data source. The extract file may be made available to the public via the TTIP Interface if desired by ODOT.

Another Unit Task in this work process provide for automatic (scheduled) and on-request backups of the database using existing SQL utilities and process schedulers. A restore of backed up data can also be performed when needed using existing SQL utilities.

The final Unit Task in this work process will allow data that is no longer needed on a day-to-day basis to be moved to an archive, where it will continue to be available when required, but will not be using space and filling indexes in the primary database with old values.

B-5.5.1 Unit Task 400.03 – Run Ad-hoc Report

This unit task allows certain users to run ad-hoc reports on an as-needed basis where there is not a standard report that meets the reporting need.

Actor	ODOT personnel
Circumstances of Use	Run from any office with access to the ODOT network
Frequency of Use	Medium
Mode of Automation	Interactive
Triggers	User needs information about a device, history of speed limits on ramps, etc.
Dependencies	VSL database is available and the user has security authorization to run the desired reports
Preconditions	User needs information that is available in the database, but a report or export has not already been developed to meet this need.
Post Conditions	User has received the report / data requested.
Step 1	Open the report query tool
Step 2	Set up reporting parameters
Step 3	Extract data from database
Step 4	Format the report
Step 5	View, print, save, export or cancel report as desired
Step 6	Save query (if applicable)

Rqmnt Number	**Requirement Description**	**Priority**
H407	The System shall have the capability to configure and export custom format sensor and sign message data to TTIP and other external users, when one of the pre-defined formats does not meet the needs of the situation.	H
D377	The System shall be capable of generating user-requested data reports and support querying functions.	H

B-5.5.2 Unit Task 0400.03a – Backup / Restore VSL Data

As with any database, the data stored for the VSL system needs to be backed up on a routine schedule so it can be recovered (restored) in case of an application failure that causes the database to become corrupt, or due to a hardware failure that destroys the production database.

No software process needs to be developed for this Unit Task. Existing backup tools and processes shall be used to backup VSL data, and to restore it if and when it is needed.

Although this is primarily an automated process, it can be run manually by a Data Base Administrator (DBA). The DBA routinely takes a backup of a production database immediately before making any structure changes required by a new release of a system. This way, the prior structure and data can be reloaded if the new release has to be “rolled back” for any reason.

Actor	Database Administrator, or routine backup process
Circumstances of Use	Run from the State Data Center or, if the database server is not under SDC control, from another central location.
Frequency of Use	Interim logs are taken with each transaction. A full backup is generally taken once a week.
Mode of Automation	Generally automated, but can be run manually when appropriate
Triggers	“Time to run backup” has occurred, or a new release of the database is about to occur.
Dependencies	Must have security access to the database, the database must be available, the backup media must be available, and the backup tools must be installed and available for use.
Preconditions	Transactions have occurred since the last backup of a database.
Post Conditions	The backup is complete.
Step 1	Establish backup schedule.
Step 2	Add database to a backup schedule
Step 3	Execute Backup
Step 4	When necessary to restore, check the logs to find the applicable backup file.
Step 5	Run the restore process from the backup
Step 6	Add transactions from the interim transaction logs that were saved after the last backup and prior to the desired restore point.
Step 7	Verify database structure is correct.
Step 8	Verify database content (data) is present up to the desired restore point.

Rqmnt Number	**Requirement Description**	**Priority**
H408	The VSL system back-up capabilities shall operate without requiring users to log-out or the System to be shut down.	H
D409	The system shall take a full back-up of the database (structure and data) using a fully automated process, taking place no less often than weekly.	H
D410	The system shall utilize a Database Management System that includes automatic transaction logging, so the database can be restored to the point of the last successful completed transaction before failure.	H
D411	The system shall utilize a Database Management System that allows for a restore using the last full backup and the transaction logs.	H

B-5.5.3 Unit Task 0400.03b – Archive / Restore VSL Data

Because of the volume of data being stored from the raw sensor feeds and the frequency with which the speed limits are established for the three ramps, the VSL database may increase in size quickly. While a backup makes a copy of the entire database, it leaves all of the data intact. The purpose of an archive is to *remove* selected data from the primary database to free up space, yet store it elsewhere so it can still be used in reporting, research and for other needs, such as for evidence in legal matters.

Archiving tools are available, but some configuration or customization may be needed, in order to store the data in such a way that it can be recovered when needed, in spite of any schema changes that may have taken place since the data was archived.

Actor	System Administrator
Circumstances of Use	Run from the State Data Center or, if the database server is not under SDC control, from another central location.
Frequency of Use	Infrequently
Mode of Automation	Automated
Triggers	Data archive schedule
Dependencies	TOCS communicates with applicable server processes
Preconditions	Database has become very large, and contains older data that is rarely needed for reporting or other day-to-day processes.
Post Conditions	Selected data has been archived, and the size of the primary database has been reduced.
Step 1	Establish data archive schedules
Step 2	Back up data per schedule
Step 3	Log archive process date and result

Rqmnt Number	**Requirement Description**	**Priority**
H412	The VSL system shall provide an automated archiving function for all data within its database files.	H
D413	The system shall utilize a Database Management System to archive data.	H
H414	The system data shall be archived based on set archive schedule. Data will be retained for at least the required retention period	H
D415	The schedule for data archiving shall be specified by ODOT, but should not be less than once per day.	H
H416	Archived data shall be logged as unique records by calendar date.	H
D417	The calendar date format shall be specified by ODOT.	H
H418	The system shall provide a function that allows archived data to be written to an archive media or device.	H
D419	The archive device may consist of an external hard drive, ODOT data server, or other device.	H

Rqmnt Number	Requirement Description	Priority
H420	The system data archiving functionality shall not provide access to the general public.	H
D421	A user account and password shall be employed in the archive system to limit user access.	H
H422	The system database files shall be restored without restoring all application software, and vice versa.	H
D423	The system database and software will be capable of being restored without a reinstallation of software and capable of retrieving archived data.	H
H424	The system shall store data obtained from each polled sensor until it is successfully sent to the archive.	H
D425	After the data is archived, and the longest aggregated data time period (60 minutes) has passed, the poll data shall be stored for 24 hours then can be removed. Data archiving durations shall be configurable. Unless otherwise specified, data logs will be retained for one year after the life of the system per OAR 166-300-0030.	H

B-6.0 DATA REQUIREMENTS

The following requirements detail only a portion of the information that will actually need to be stored for VSL. The data items listed here reflect user-defined variables, log files and other data requirements that are specifically referenced in the software requirements above.

Rqmnt Number	Requirement Description	Priority
H500	The system shall include storage for user-specified parameters that are used in VSL system processes and calculations	H
D501	The span of time between cycles when the system recalculates speed limits throughout for each ramp shall be user-configurable. I.E, stored in a table so it can be changed, and the resulting system activity modified, without requiring a change to the software, hardware or other infrastructure.	H
D502	The constant value used to determine the expiration time for a message (speed limit display on a VSL sign) shall be user-configurable. IE, stored in a table so one, two or all three can be changed, and the resulting system activity modified, without requiring a change to the code, hardware or other infrastructure.	H
D503	The list of predefined messages that can be displayed in a VSL sign shall be user-configurable. IE, stored in a table so it can be changed, and the resulting system activity modified, without requiring a change to the code, hardware or other infrastructure.	H
D504	The VSL sign default shall be user-configurable. IE, stored in a table so it can be changed, and the resulting system activity modified, without requiring a change to the code, hardware or other infrastructure.	H

Rqmnt Number	Requirement Description	Priority
D505	The minimum-allowed speed limit value shall be user-configurable. IE, stored in a table so it can be changed, and the resulting system activity modified, without requiring a change to the code, hardware or other infrastructure.	H
H506	The system shall include storage for a device log of raw sensor readings	H
D507	The sensor log shall include the name of the device (not the ID number), the timestamp, and the raw values returned from that sensor at that date/time represented by the timestamp.	H
H508	The system shall include storage for a transaction log of sensor data and resulting speed limit values. This information shall provide a legal record that can be used in a court of law in the event of disputes with vehicle operators.	H
D509	The transaction log table shall include fields for the ramp to which the speed limit applies, the timestamp showing when the data was calculated, a production / test indicator, a reason code, the pavement condition sensor and RWIS data, an Incident Flag, an Override flag, and the determined speed value displayed on the sign.	H
H510	The system shall include storage for an error log.	H
D511	The error log shall include the ramp name/id, the name of the device, the timestamp, the process that was running when the error occurred, and a description of the error encountered.	H
H512	The system shall include storage for flags and indicators that are used in controlling decisions in the system.	H
D513	The system shall include an Incident Flag for each ramp VSL, which has true/false capability, with a default value of False.	H
D514	The system shall include an Override Flag for each ramp VSL, which has true/false capability, with a default value of False.	H
H515	The System shall be capable of storing all data within the Common System Database so it is available to System users including all pertinent sign and sensor data, and errors.	H
D516	The data storage capability in support of this function shall match the approaches employed by ODOT for similar system logs.	H

B-6.1.1 Unit Task 400.02 – Run Standard Report

This Unit Task allows an authorized user to run reports and export data based on information gathered from the devices and processes that support the VSL system.

All reporting and archive management functionality and data aggregation functionality will be undertaken by ODOT.

Actor	ODOT personnel
Circumstances of Use	Run from any office with access to the ODOT network
Frequency of Use	Medium
Mode of Automation	Interactive
Triggers	User needs information about a device, history of speed limits on ramp,

	etc.
Dependencies	VSL database is available and the user has security authorization to run the desired reports
Preconditions	User needs information that is available via a report and/or data extract
Post Conditions	User has received the report / data requested.
Step 1	User selects report or export process
Step 2	User specifies run-time parameters, such as from and to dates, locations, etc.
Step 3	The system displays the report information or creates the extract file.
Step 4	The user prints the report, or saves the report or extract file.

Rqmnt Number	Requirement Description	Priority
H520	The System shall have the capability to configure and export sensor and sign message data to TTIP and other external users.	H
D521	The data exported by the System shall be of a format that allows for import to TTIP.	H
H522	The System Software shall have the ability to display the records of System user login and the user's message and status activations.	H
D523	The log GUI must allow users to see the records based on a calendar or date range. The System must allow ODOT users to query database records for all sign activities. It must be possible to view, export, and print reports, filtered by date and or device.	H
H524	The System archived data shall be available for reporting device status, detector data, and external data from connected Systems.	H
D525	The archived data shall remain available for a period of five years, unless specified otherwise by ODOT.	H
H526	The System shall provide control of data collection and data distribution processes to produce dynamic graphic displays of data as needed by ODOT.	H
D527	The System interface for report generation shall incorporate tools that can generate data reports, including graphical displays of data when such data supports them.	H
H528	The System shall provide the ability to fulfill data requests for sign and sensor data, retrieved from the database, based on date range, device name, or ID.	H
D529	The System interface will allow queries to be made based on the parameters specified by H528.	H

B-6.2 DATA CONVERSION

This is a new system in a business area where one did not exist before. As a result, there is no data to be converted.

B-7.0 HARDWARE REQUIREMENTS

The software portion of the VSL system receives data from and sends data to a variety of hardware. This is not intended to be a comprehensive list of hardware required, or to provide engineering details. That information is a part of the appropriate engineering and construction plans to be developed by ODOT staff.

The requirements presented here are actual requirements of the system, and shall be implemented just as those in other sections are.

Rqmnt Number	Requirement Description	Priority
H700	The system shall include hardware for detecting pavement conditions, weather conditions and signs on which to display speed limits.	H
D701	To ensure proper communications, the sign controller and the VSL signs shall use the same or compatible versions of the NTCIP standards. If one or the other is upgraded to a newer standard, it shall use "reverse compatibility" so it continues to interface correctly with the older devices.	H
D702	Advance notification signs shall be used at the entry of the variable speed zone to alert motorists of the variable speed limit system. The advance notification signs may be be static signs with the text "VARIABLE SPEED LIMIT PRESENT ON RAMP". Conversely, a Dynamic Message Sign (DMS) and flashers may be employed to alert motorists that a variable speed limit is in effect using a similar message.	H
D703	The VSL signs shall be installed on each of the interchange ramps as indicated by guidance provided in the Concept of Operations document.	H
D704	Communications infrastructure between the Center and all VSL signs shall be specified and selected by ODOT..	H
Rqmnt Number	**Requirement Description**	**Priority**
H720	The system shall be able to receive and process data from two types of sensors: an RWIS station and a pavement condition/temperature device.	H
D721	The system shall utilize pavement condition sensors and applicable controllers on all ramps that will have variable speed limits employed.	H
D722	Each pavement condition sensor shall be assigned to one and only one interchange ramp.	H
D723	Each pavement condition sensor shall be placed in such a way that it is able to collect data from the travel lane.	H
D724	The pavement condition sensor controller shall be able to return the requested values for the requested span of time (example: the past 5 minutes) to the calling process on the calling schedule (example: every minute).	H

The following points are to be treated as informational only. The hardware information and options are addressed in much more detail in the ATIM Concept of Operations document. Refer also to final engineering plans for details on the hardware required for this system.

No.	Hardware Informational Points
a.	The type of VSL signs used when regulatory speed limits are in effect shall be capable of displaying different numbers in order to facilitate the different speed limits being posted. The type of VSL signs used when advisory speed limits are in effect shall be static metal signs with insert panels below the metal portion of the sign capable of displaying different numbers.
b.	An RWIS station is planned to be deployed at the interchange in conjunction with the deployment of the VSL on ramps.
c.	Pavement condition sensors shall be installed on each ramp to provide information on surface state and grip (friction) levels.

No.	Hardware Informational Points
e.	The main communication pathway between field devices and the ODOT TMOC shall utilize existing infrastructure.
f.	In cases where a new device installation is not close to an existing communication infrastructure, a new wireless connection to the device may be a cost effective option. If wireless communication is used, the goal would be to bring the wireless connections from multiple field devices to a central location where the signals could be collected, combined, and sent back to the TMOC on ODOT's existing fiber optic network. This type of topology can be referred to as a "point to multipoint"

B-8.0 SERVICE REQUIREMENTS

The VSL shall utilize services from the following systems and tools:

- TOCS process to examine all Events to detect ones that meet specified criteria. Refer to Unit Task "0300.01 Monitor TOCS and General Events"
- TOCS process to close an Event. Refer to Unit Task "0300.02 Set/Clear Flag in VSL System"

B-9.0 TRAINED PERSONNEL REQUIREMENTS

TMOC Operators, Traffic Engineers and ITS maintenance personnel responsible for the VSL system shall need to be trained on the VSL software.

B-10.0 MATERIALS REQUIREMENTS

An Installation Guide and a User Guide will need to be developed for the VSL system.

B-11.0 PROCESS REQUIREMENTS

If any new or modified work processes are required as a result of this system, they will be examined and developed as needed.

B-12.0 FACILITIES REQUIREMENTS

The following are informational only and will need to be implemented by ODOT at the time of system design and deployment.

No.	Facilities Informational Points
a.	As the system will be deployed in the field to address weather conditions, weatherproof boxes shall be used to contain wiring, controllers and other devices that are not weatherproof in and of themselves.
b.	Boxes containing system components shall be secured (locked).
c.	Boxes shall be ruggedized to protect devices from gravel and other debris created by normal traffic conditions to protect said devices from environmental damage.

B-13.0 LIST OF INCOMPLETE REQUIREMENTS

The purpose of this list is to identify requirements for which more information is needed in order to correctly categorize and/or fully state the requirement.

Before this document is approved, any requirements that have been listed in this section shall be resolved and either removed as a requirement, or identified and placed in the applicable section of this document.

Req. ID #	Proposed SRS Section	Brief Requirement Description	Issue	Status
(none)				

APPENDIX C: POLICY REVIEW

C-1.0 STATUTES AND RULES REGARDING VSL

At least twelve states currently have statutes that specifically address using variable speed limits for varying weather conditions. In all cases, weather is one of several conditions specifically mentioned. These statutes are given below.

Two other states have included use of variable speed limits in administrative rules.

The review of other states' statutes and rules indicates that Oregon may be the only state that has a statute that requires an additional rule to specify locations and conditions on an interstate highway under which speeds can be varied. The pertinent statutes are listed below:

ORS 811.111 (1) A person commits the offense of violating a speed limit if the person: (a) Drives a vehicle on an interstate highway at a speed greater than 65 miles per hour or, if a different speed is posted under ORS 810.180 (3), at a speed greater than the posted speed.

ORS 810.180 (3) The Department of Transportation may establish by rule designated speeds on an specified section of interstate highway if the department determines that speed limits established under ORS 811.111 (1) are greater or less than is reasonable or safe under the conditions that exist with respect to that section of the interstate highway…

An administrative rule which is in the final review stages will respond to the requirements of the above statute and will specify locations on the interstate where variable speed limits can be implemented as well as establish requirements for their use at other locations on the state highway system or local roads. The rule names certain type of situations that allow the use of variable speed limits including weather conditions.

C-1.1 STATE STATUTES ALLOWING VARIABLE SPEEDS DUE TO WEATHER CONDITIONS

C-1.1.1 Alabama

32-5A-172. Maximum speed; time and area considerations.

Whenever the Director of Public Safety and the Highway Director, with the approval of the Governor, shall determine upon the basis of an engineering and traffic investigation that any maximum speed hereinbefore set forth is greater or less than is reasonable or safe under the conditions found to exist at any intersection or other place or upon any part of the state highway system, said directors may determine and declare a reasonable and safe maximum limit thereat, which shall be effective when appropriate signs giving notice thereof are erected. Such a maximum speed limit may be declared to be effective at all times or at such times as are indicated upon the said signs; and differing limits may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe speeds, which shall be effective when posted upon appropriate fixed or variable signs.

C-1.1.2 Arizona

§ 28-702. State highway speed limits

A. If the director determines on the basis of an engineering and traffic investigation that any maximum **speed limit** is greater or less than is reasonable or safe under the conditions found to exist on any part of a state highway, the director may determine and declare a reasonable and safe maximum **speed limit** or varying **speed limits** for the location.

B. The maximum **speed limit** determined pursuant to this section is effective when appropriate signs giving notice of the maximum **speed limit** are erected.

C. The director may declare a maximum **speed limit** that is determined pursuant to this section to be effective at all times or at such times as indicated on the **speed limit** signs. The director may establish varying **speed limits** for different times of day, different types of vehicles, varying weather conditions and other factors bearing on safe **speeds**. The varying **limits** are effective when posted on appropriate fixed or **variable** signs.

C-1.1.3 Delaware

21 Del. C. § 4169. Specific speed limits; penalty

(b) Whenever the Department of Transportation shall determine, on the basis of engineering studies and traffic investigations or upon the basis of a federal law or directive by the Congress or the President, that a maximum **speed limit** set pursuant to subsection (a) of this section in any particular place on the state maintained highway system is greater or less than is reasonable or safe, the Department shall declare a reasonable and safe maximum **limit** thereat, which **limit** shall be effective when posted. Such maximum **limit** may be declared to be effective either part or all of the time and differing **limits** may be established for different times of the day, for different types of vehicles, for different weather conditions and when other significant factors differ. Such maximum **limits** may be posted on fixed or **variable** signs. Any **speed** in excess of such displayed **limits** shall be absolute evidence that the **speed** is not reasonable or prudent and that it is unlawful.

C-1.1.3 Georgia

§ 40-6-182. Establishment of state speed zones

Whenever the commissioner of public safety or the commissioner of transportation shall determine upon the basis of an engineering and traffic investigation that any maximum speed set forth in this article is greater or less than is reasonable or safe under the conditions found to exist at any intersection or other place or upon any part of the state highway system, they may jointly determine and declare a reasonable and safe maximum speed limit at such place, which shall be effective when appropriate signs giving notice thereof are erected. Such a maximum speed limit may be declared to be effective at all times as are indicated upon such signs; and differing limits may be established for different times of day, different varying weather conditions, and other factors bearing on safe speeds, which shall be effective when posted upon appropriate fixed or variable signs. In no case shall the maximum speed limit for any highway be established at higher than the maximum speed limits set forth in Code Section 40-6-181 for that type of highway.

C-1.1.4 Indiana

9-21-5-12. Alteration of speed limits at intersections or on parts of highways -- Establishment of differing limits for different times of day, different types of vehicles, and other factors.

(a) Whenever the Indiana department of transportation determines on the basis of an engineering and traffic investigation that a maximum **speed** set forth in this chapter is greater or less than is reasonable or safe under the conditions found to exist at an intersection or other place or on part of the state highway system, the Indiana department of transportation may determine and declare a reasonable and safe maximum **limit** at the intersection or on the part of the state highway system. The differing **limit** is effective when appropriate signs giving notice of the **limit** are erected.

(b) A maximum **speed limit** under this section may be declared to be effective at all times or at times indicated on the signs. Differing **limits** may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**. The differing **limits** are effective when posted on appropriate fixed or **variable** signs.

C-1.1.5 Kansas

K.S.A. §8-1559 Alteration of maximum speed limits; establishing speed limits in road construction zones; powers of secretary of transportation.

(a) The secretary of transportation may determine and declare:

(1) Based on an engineering and traffic investigation that an existing **speed limit** is greater or less than what is reasonable or safe under the conditions found to exist at any intersection or other place or upon any part of the state highway system, or upon any city street which is a state highway connecting link; or

(2) based on information or circumstances known to the secretary, without an engineering or traffic investigation, that a **speed** less than the maximum otherwise allowed is warranted. If the secretary determines to designate a **speed limit** under authority of this paragraph the secretary shall prepare a statement and notice of alteration of maximum **speed limit**. The statement shall be in writing, shall specify the designated maximum **speed limit**, the route or routes affected, or any segment thereof, the factors upon which the decision is based and the date on which the **speed limit** shall be effective. The notice shall specify the route or routes affected, or segments thereof, the designated maximum **speed limit** and the effective date. The notice required under this paragraph shall be sent to the Kansas highway patrol and the sheriff of any county in which the affected route or routes are located prior to the effective date of the new maximum **speed limit**.

(b) Any maximum **speed limit** declared under subsection (a) may be effective at all times or at designated times; and differing **speed limits** may be established for different times of day, different types of vehicles, varying weather conditions, or other factors bearing on safe **speeds**. In addition to any other requirement imposed on the secretary of transportation, no alteration in the **speed limits** under subsection (a) shall be effective until posted upon appropriate fixed or **variable** signs.

C-1.1.6 Maryland

§ 21-802. Establishment of State speed zones

(a) Determination by State Highway Administration. -- If, on the basis of an engineering and traffic investigation, the State Highway Administration determines that any maximum **speed limit** specified in this subtitle is greater or less than reasonable or safe under existing conditions on any part of a highway under its jurisdiction, it may establish a reasonable and safe maximum **speed limit** for that part of the highway.

(b) When investigation not required. -- An engineering and traffic investigation is not required to conform a posted maximum **speed limit** in effect on December 31, 1974, to a different **limit** specified in § 21-801.1 (b) of this subtitle.

(c) **Variable limits** permitted. -- Under this section, the State Highway Administration may:

(1) Establish a maximum **speed limit** to apply at all times or only at specified times; and

(2) Establish differing **limits** for different times of day, different types of vehicles, different weather conditions, or other factors bearing on safe **speeds**.

(d) When altered **limits** effective. -- An altered maximum **speed limit** established under this section is effective when posted on appropriate signs giving notice of the **limit.**

C-1.1.7 North Dakota

39-09-04. Alteration of maximum speed limits on state highways.

The maximum **speed limits** specified in section 39-09-02 may be altered on all or any part of the state highway system by an administrative order by the director after a public hearing has been held. Such determination must be based on engineering and traffic investigations with primary consideration given to the establishment of reasonable and safe **speeds**, highway conditions, enforcement, and the general welfare. **Speed limits** established pursuant to this section shall be effective only when appropriate signs giving notice thereof are erected and such maximum **speed limits** may be declared to be effective at all times or at such times as are indicated upon said signs. Differing **limits** may be established for different times of the day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**, which shall be effective when posted upon appropriate fixed or **variable** signs.

C-1.1.8 North Carolina

§ 56-5-1530. Alteration of speed limits on State highway system by Department of Transportation; signs.

(a) Establishing **speed** zones. Whenever the Department of Transportation shall determine upon the basis of an engineering and traffic investigation that any maximum **speed** hereinbefore set forth is greater or less than is reasonable or safe under the conditions found to exist at any intersection or other place or upon any part of the state highway system, the Department of Transportation may determine and declare a reasonable and safe maximum **limit** thereat, which shall be effective when appropriate signs giving notice thereof are erected. Such maximum **speed limit** may be declared to be effective at all times or at such times as are indicated upon such signs; and differing **limits** may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**, which shall be effective when posted upon appropriate fixed or **variable** signs.

C-1.1.9 Virginia

§ 46.2-881. Special speed limitation on bridges, tunnels and interstates

It shall be unlawful to drive any motor vehicle, trailer, or semitrailer on any public bridge, causeway, viaduct, or in any tunnel, or on any interstate at a **speed** exceeding that indicated as a maximum by signs posted thereon or at its approach by or on the authority of the Commonwealth Transportation Commissioner.

The Commonwealth Transportation Commissioner, on request or on his own initiative, may conduct an investigation of any public bridge, causeway, viaduct, tunnel, or interstate and, on the basis of his findings, may set the maximum **speed** of vehicles which such structure or roadway can withstand or which is necessitated in consideration of the benefit and safety of the traveling public and the safety of the structure or roadway. The Commonwealth Transportation Commissioner is expressly authorized to establish and indicate **variable speed limits** on such structures or roadways to be effective under such conditions as would in his judgment, warrant such **variable limits,** including but not limited to darkness, traffic conditions, atmospheric conditions, weather, emergencies, and like conditions which may affect driving safety. Any **speed limits,** whether fixed or **variable**, shall be prominently posted in such proximity to such structure or roadway as deemed appropriate by the Commonwealth Transportation Commissioner. The findings of the Commissioner shall be conclusive evidence of the maximum safe **speed** which can be maintained on such structure or roadway.

C-1.1.10 Washington

§ 46.61.405. Decreases by secretary of transportation

Whenever the secretary of transportation shall determine upon the basis of an engineering and traffic investigation that any maximum **speed** hereinbefore set forth is greater than is reasonable or safe with respect to a state highway under the conditions found to exist at any intersection or upon any other part of the state highway system or at state ferry terminals, or that a general reduction of any maximum **speed** set forth in RCW 46.61.400 is necessary in order to comply with a national maximum **speed limit**, the secretary may determine and declare a reasonable and safe lower maximum **limit** or a lower maximum **limit** which will comply with a national maximum **speed limit**, for any state highway, the entire state highway system, or any portion thereof, which shall be effective when appropriate signs giving notice thereof are erected. The secretary may also fix and regulate the **speed** of vehicles on any state highway within the maximum **speed limit** allowed by this chapter for special occasions including, but not limited to, local parades and other special events. Any such maximum **speed limit** may be declared to be effective at all times or at such times as are indicated upon the said signs; and differing **limits** may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**, which shall be effective (a) [(1)] when posted upon appropriate fixed or **variable** signs or (b) [(2)] if a maximum **limit** is established for auto stages which is lower than the **limit** for automobiles, the auto stage **speed limit** shall become effective thirty days after written notice thereof is mailed in the manner provided in subsection (4) of RCW 46.61.410, as now or hereafter amended.

§ 46.61.410. Increases by secretary of transportation -- Maximum speed limit for trucks -- Auto stages -- Signs and notices

(1) (a) Subject to subsection (2) of this section the secretary may increase the maximum **speed limit** on any highway or portion thereof to not more than seventy miles per hour in accordance with the design **speed** thereof (taking into account all safety elements included therein), or whenever the secretary determines upon the basis of an engineering and traffic investigation that such greater **speed** is reasonable and safe under the circumstances existing on such part of the highway.

(b) The greater maximum **limit** established under (a) of this subsection shall be effective when appropriate signs giving notice thereof are erected, or if a maximum **limit** is established for auto stages which is lower than the **limit** for automobiles, the auto stage **speed limit** shall become effective thirty days after written notice thereof is mailed in the manner provided in subsection (4) of this section.

(c) Such maximum **speed limit** may be declared to be effective at all times or at such times as are indicated upon said signs or in the case of auto stages, as indicated in said written notice; and differing **limits** may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**, which shall be effective when posted upon appropriate fixed or **variable** signs or if a maximum **limit** is established for auto stages which is lower than the **limit** for automobiles, the auto stage **speed limit** shall become effective thirty days after written notice thereof is mailed in the manner provided in subsection (4) of this section.

§ 46.61.415. When local authorities may alter maximum limits

(1) Whenever local authorities in their respective jurisdictions determine on the basis of an engineering and traffic investigation that the maximum **speed** permitted under RCW 46.61.400 or 46.61.440 is greater or less than is reasonable and safe under the conditions found to exist upon a highway or part of a highway, the local authority may determine and declare a reasonable and safe maximum **limit** thereon which

(a) Decreases the **limit** at intersections; or

(b) Increases the **limit** but not to more than sixty miles per hour; or

(c) Decreases the **limit** but not to less than twenty miles per hour.

(2) Local authorities in their respective jurisdictions shall determine by an engineering and traffic investigation the proper maximum **speed** for all arterial streets and shall declare a reasonable and safe maximum **limit** thereon which may be greater or less than the maximum **speed** permitted under RCW 46.61.400(2) but shall not exceed sixty miles per hour.

(3) The secretary of transportation is authorized to establish **speed limits** on county roads and city and town streets as shall be necessary to conform with any federal requirements which are a prescribed condition for the allocation of federal funds to the state.

(4) Any altered **limit** established as hereinbefore authorized shall be effective when appropriate signs giving notice thereof are erected. Such maximum **speed limit** may be declared to be effective at all times or at such times as are indicated upon such signs; and differing **limits** may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**, which shall be effective when posted upon appropriate fixed or **variable** signs.

(5) Any alteration of maximum **limits** on state highways within incorporated cities or towns by local authorities shall not be effective until such alteration has been approved by the secretary of transportation.

C-1.1.11 Wyoming

§ 31-5-302. Establishment of specific maximum speed limits by superintendent.

Whenever the superintendent determines upon the basis of an engineering and traffic investigation, or in the event of a vehicle or weather emergency, that a maximum **speed** greater or less than that authorized herein is required for safe and reasonable vehicle operation under the conditions found to exist at any intersection or other place or upon any part of the state highway system, the superintendent, except as provided for in W.S. 31-5-303(b), may determine and declare a reasonable and safe maximum **limit** thereat, which shall be effective when appropriate signs giving notice thereof are erected. The maximum **speed limit** may be declared to be effective at all times or at such times as are indicated upon the signs and differing **limits** may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe **speeds**, which shall be effective when posted upon appropriate fixed or **variable** signs. This section does not grant power to the superintendent to declare statewide or countywide maximum **speed limits** but grants power to declare maximum **speed limits** for the public safety in localized geographic areas.

C-1.2 STATE ADMINISTRATIVE RULES ALLOWING VARIABLE SPEEDS DUE TO WEATHER CONDITIONS

C-1.2.1 Alaska

13 AAC 02.280. Alteration of limits by state and municipalities

(a) When the Department of Transportation and Public Facilities with the assistance of the department, or a municipality, in their respective jurisdictions and consistent with AS 28.01.010, determines upon the basis of an engineering and traffic investigation that a maximum speed prescribed in 13 AAC 02.275 is greater or lesser than is reasonable or safe under the conditions found to exist at an intersection, or an arterial street, or at any other place or part of the state or municipal highway system, the respective authority may determine a reasonable and safe maximum limit at the location. The maximum speed limit is effective when signs giving notice of the maximum limit are erected.

(b) Alteration of a speed limit under (a) of this section may
(1) decrease the limit at an intersection or other place where a full stopis necessary;
(2) increase the limit outside of an urban district;
(3) increase the limit inside an urban district on controlled access highways;
(4) decrease the limit within an urban district to less than 20 miles perhour, except as otherwise provided under AS 28.01.010(b); or
(5) decrease the limit outside an urban district.

(c) A maximum speed limit may be effective at all times or at times indicated by the signs required by (a) of this section. Limits may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe speeds. The limits are effective when posted upon fixed or variable signs.

(d) The Department of Transportation and Public Facilities or a municipality, in their respective jurisdictions, may regulate the timing of traffic signals to permit the movement of traffic in an orderly and safe manner at speeds slightly at variance from the speeds otherwise applicable within the district or at intersections when they erect signs giving notice of the variance.
13 AAC 02.295. Minimum speed regulation

13 AAC 03.280. Alteration of limits by state and municipalities

(a) If the Department of Transportation and Public Facilities, with assistance from the department or a municipality in accordance with AS 28.01.010, determines upon the basis of an engineering and traffic investigation that a maximum speed prescribed for a commercial motor vehicle in 13 AAC 03.275(b) is greater or lesser than is reasonable or safe under the conditions found to exist at an intersection, an arterial street, or at any other place or part of the state or municipal highway system, the department or municipality with jurisdiction may determine a reasonable and safe maximum limit at the location. The maximum speed limit is effective when signs identifying the maximum limit are erected.

(b) An alteration of a speed limit under (a) of this section may

(1) decrease the limit at an intersection or other place where a full stop is necessary;
(2) increase the limit outside of an urban district;
(3) increase the limit inside an urban district on controlled access highways;
(4) decrease the limit within an urban district to less than 20 miles per hour, except as provided under AS 28.01.010(b); or
(5) decrease the limit outside an urban district.

(c) A maximum speed limit may be in effect at all times or at the times indicated by the signs required in (a) of this section. A maximum speed limit may be established for different times of day, different types of vehicles, varying weather conditions, or any other factor that has a bearing on safe speed. The maximum speed limit is in effect when posted upon fixed or variable signs.

(d) The Department of Transportation and Public Facilities or a municipality, in their respective jurisdictions, may regulate the timing of traffic signals to permit the movement of traffic in an orderly and safe manner at speeds slightly different from the speeds otherwise applicable within the district or at an intersection if signs are erected notifying drivers of the change in speed limits.

C-1.2.2 Pennsylvania

§ 212.108. Speed limits

(a) General . This section applies to maximum speed limits established according to 75 Pa.C.S. §§ 3362 and 3363 (relating to maximum speed limits; and alteration of maximum limits). Engineering and traffic studies are not required for statutory speed limits, but documentation should be on file for urban districts and residence districts to show that the requirements defined in the Vehicle Code are satisfied.

(b) Engineering and traffic studies. Speed limits established in accordance with 75 Pa.C.S. § 3363 may be established in multiples of 5 miles per hour up to the maximum lawful speed. The speed limit should be within 5 miles per hour of the average 85th percentile speed or the safe-running speed on the section of highway, except the speed limit may be reduced up to 10 miles per hour below either of these values if one or more of the following conditions are satisfied:

(1) A major portion of the highway has insufficient stopping sight distance if traveling at the 85th percentile speed or the safe-running speed.

(2) The available corner sight distance on side roads is less than the necessary stopping sight distance values for through vehicles.

(3) The majority of crashes are related to excessive speed and the crash rate during a minimum 12-month period is greater than the applicable rate in the most recent high-crash rate or high-crash severity rate table included in the appendix of Official Traffic-Control Devices (Department Publication 212). Crashes related to excessive speed include those crashes with causation factors of driving too fast for conditions, turning without clearance or failing to yield right-of-way.

(c) Variable speed limits. To improve safety, speed limits may be changed as a function of traffic speeds or densities, weather or roadway conditions or other factors.

(d) Special speed limits.

(1) Within a rest area or welcome center, a 25 mile per hour speed limit may be established without the need for an engineering and traffic study if pedestrians walk across the access roadways between the parking lot and the rest facilities.

(2) Within a toll plaza or a truck weight station, an appropriate speed limit may be established without an engineering and traffic study by the authorities in charge to enforce the safety of the operations or to protect the scales.

(e) Posting of speed limits. A Speed Limit Sign (R2-1) or variable speed limit sign showing the maximum speed limit shall be placed on the right side of the highway at the beginning of each numerical change in the speed limit, but an additional sign may also be installed on the left side of the highway. If the new speed limit begins at an intersection, the first sign should be installed within 200 feet beyond the intersection. The placement of this sign must satisfy both the requirement to post the beginning of the new speed limit and the requirement to post the end of the previous speed limit. Additional requirements for posting are as follows:

(1) Speed limits of 50 miles per hour or less shall be posted as follows:

(i) A Reduced Speed (   ) Ahead Sign (R2-5), or a Speed Reduction Sign (W3-5), shall be placed on the right side of the highway 500 to 1,000 feet before the beginning of every speed reduction unless one of the following applies:

(A) The speed reduction is 10 miles per hour or less.

(B) The speed reduction begins at an intersection and all traffic entering the roadway with the speed reduction has to either stop at a Stop Sign (R1-1) or make a turn.

(C) The new speed limit is posted on variable speed limit signs.

(ii) Speed Limit Signs (R2-1) or a variable speed limit sign showing the maximum speed shall be placed on the right side of the highway at the beginning of the speed limit and at intervals not greater than 1/2 mile throughout the area with the speed limit.

(iii) The end of a speed limit is typically identified by the placement of a sign indicating a new speed limit, but the End Plaque (R2-10) may be placed above a Speed Limit Sign (R2-1) at the end of the zone if the appropriate speed limit is not known on the following section of roadway.

(2) On freeways, a Speed Limit Sign (R2-1) shall be installed after each interchange unless insufficient space exists for the signs.

C-1.2.3 Oregon Administrative Rules

Oregon has adopted administrative rules (OAR 734-020-0018 to -0019) that allow use of variable speed limits for a variety of conditions including weather on specified portions of interstate highways and on other highways in the state. The rules identify specific requirements and an approval process for the establishment of variable speed limits. The intent of the rules is to require a pilot study phase and two year evaluation period for all VSL systems.

C-1.2.4 OR 217/US 26 Requirements

Administrative Rule

Sections (2) and (6) of OAR 734-020-0018 are relevant for the Oregon 217/US 26 location. Section (2) relates to the pilot project status we can expect the system to have initially and Section (6) relates to the permanent status that would be given to the system if the evaluation shows that the system is effective.

(2)The State Traffic Engineer may apply this rule to establish a limited number of Variable Speed Zone pilot projects around the state. The State Traffic Engineer, subject to the following limitation, will decide the appropriate number of pilot projects to test the criteria and procedures in this rule. There will be at least one pilot project but no more than three for a particular recurring condition such as congestion, road conditions, reduced visibility or weather conditions.

(a) An evaluation of each pilot project Variable Speed Zone will be completed by the State Traffic Engineer after two years from the start of operation of that pilot project until each pilot project has been evaluated for an identified recurring condition under Section (1).

(b) The Speed Zone Review Panel will review the evaluations for each identified recurring condition. The Speed Zone Review Panel will make a recommendation to the State Traffic Engineer to continue the evaluation period, terminate the evaluation, amend this rule to revise the criteria and procedures or remove the pilot project requirement.

(c) The State Traffic Engineer will consider the recommendation of the Speed Zone Review Panel and decide whether to continue the evaluation period, terminate the evaluation, amend this rule to review the criteria and procedures or remove the pilot project requirement.

(d) The State Traffic Engineer may continue the established pilot projects pending further evaluation, Speed Zone Review Panel review and final decision on establishing Variable Speed Zones.

6) Establishing a Variable Speed Zone on state highways inside city limits, city streets, county roads and any other rural public roads except unpaved public roads: the following procedures apply when the applicable Road Authority proposes to establish variable speed zones on sections of state highways inside city limits, city streets, county roads and any other rural public roads except unpaved public roads:
(a) The road authority must make a recommendation to the State Traffic Engineer to establish a variable speed zone. The recommendation will include all of the information required in this section including the engineering study.
(b)The Department may establish variable speed zones on a section of state highways inside city limits, city streets, county roads and any other rural public roads except unpaved public roads based on an engineering study of the characteristics such as congestion, road conditions, reduced visibility or other weather conditions. For each section of public road under consideration an engineering study must be completed that will include all of the following:
(A) The Maximum speed.
(B) Crash patterns in the section of highway under consideration by time of day, day of week or season of year or other period exhibiting recurring crash patterns.
(C) Law enforcement input.
(D) Traffic characteristics by time of day, day of week or season of year or other periods where recurring congestion levels and reduced average speeds occur, such as hourly congestion levels and calculated eighty-fifth percentile speeds (85% speeds).
(E) Type and frequency of adverse road conditions, including weather, environment, and visibility.
(c) The road authority, or the Department on state highways, will submit an engineering study to the State Traffic Engineer, which includes the analysis and recommendation of the boundaries and algorithms for the variable speed zone. The recommendation will include all of the following:
(A) Locations of each sign,
(B) Set of algorithms,
(C) The speed change intervals,
(D) The means, responsibilities and procedures for changing posted speed and
(E) The means, responsibilities and procedures for keeping the speed change records.
(d) A written variable speed zone order must be issued by the department to establish a variable speed zone.
(e) The original written variable speed zone order must be retained in the Department of Transportation's records for each speed zone issued.
(f) The speed change record must be retained and maintained for at least 3 years by the traffic operations center responsible for maintaining and operating the variable speed signs.
(g) The speed zone becomes enforceable when variable speed signs are installed and operated.

C-1.2.5 Engineering Investigation Report

An Engineering Investigation Report for requesting the establishment of variable speed limits at the OR217/US26 interchange is being developed. Appendix B is an "in-progress" draft.

C-1.3 CONCLUSION

Unlike many states which have statutes in place to allow use of variable speed limits for extreme weather conditions, Oregon statute required the development of an administrative rule for this purpose. When Oregon's proposed administrative rules allowing use of variable speed limits for a variety of conditions, are finalized, a process will be in place that will allow establishment of a variable speed limit system for wet and extreme weather conditions at the Oregon 217/US 26 interchange upon State Traffic Engineer approval of an Engineering Investigation Report for this location. All potential legal implications that would prevent the proposed VSL system will have been addressed.

C-2.0 OREGON ADMINISTRATIVE RULES

734-020-0018
Establishment of Variable Speed Zones

(1) Purpose:

(a) This rule is adopted for the purpose of the Department and other road authorities establishing variable speed zones on public roads under ORS 810.180. A variable speed zone may be established on a section of highway when an engineering study determines that a range of speeds in response to recurring conditions provides for better traffic safety and operation than a single set speed.

(b) A variable speed zone is established by a written order or rule defining the criteria, boundaries and procedures for speed changes in a designated manner over a given range of speeds at minimum specified intervals. At a particular time and place, the applicable speed zone reflects some of the same factors a prudent driver also considers. Examples include the effects of congestion, road conditions, reduced visibility or weather conditions. Improving the consistency between a responsible driver's speed selection and the speed zone can keep traffic moving smoothly and improve safety. An engineering study is required.

(c) This rule applies to all public roads except where the Department has delegated its authority to establish designated speeds on low volume or unpaved roads under ORS 810.180(5) (f). The delegation of authority for low volume roads and unpaved roads is covered in OAR 734-020-0016 and OAR 734-020-0017.

(2) The State Traffic Engineer may apply this rule to establish a limited number of Variable Speed Zone pilot projects around the state. The State Traffic Engineer, subject to the following limitation, will decide the appropriate number of pilot projects to test the criteria and procedures in this rule. There may be pilot projects for a particular recurring condition such as congestion, road conditions, reduced visibility or weather conditions.

(a) An evaluation of each pilot project Variable Speed Zone will be completed by the State Traffic Engineer after two years from the start of operation of that pilot project until each pilot project has been evaluated for an identified recurring condition under Section (1).

(b) The Speed Zone Review Panel will review the evaluations for each identified recurring condition. The Speed Zone Review Panel will make a recommendation to the State Traffic Engineer to continue the evaluation period, terminate the evaluation, amend this rule to revise the criteria and procedures or remove the pilot project requirement.

(c) The State Traffic Engineer will consider the recommendation of the Speed Zone Review Panel and decide whether to continue the evaluation period, terminate the evaluation, amend this rule to review the criteria and procedures or remove the pilot project requirement.

(d) The State Traffic Engineer may continue the established pilot projects pending further evaluation, Speed Zone Review Panel review and final decision on establishing Variable Speed Zones.

(3) Definitions: the following definitions apply to this rule in addition to the speed zone definitions in OAR 734-20-0010 and 734-020-0014,

(a) "Algorithm" means the method or procedure by which the optimum speed is determined based on road, traffic or weather conditions.

(b) "Maximum Speed" means the maximum designated speed or statutory speed that may be posted in the variable speed zone, typically when conditions such as congestion, road conditions, reduced visibility or weather conditions are not present to support a reduced variable speed. A

maximum designated speed is determined per OAR 734-020-0010, 734-020-0015 or 734-020-0016. A maximum statutory speed is established as a speed limit under ORS 811.111 or basic speed rule under 811.105.
(c) “Speed Change Interval” means the magnitude of allowed change in miles-per-hour when the posted speed is changed in response to conditions.
(d) “Speed Change Record” is the long term storage of each activated change including the reason or condition, in the posted speed at each variable speed sign in a manner such that the posted speed at a given location and time within a variable speed zone can be determined and reported.
(e) “Transportation Operations Center” (also called a Traffic Management Center or Traffic Management Operations Center) means the facility through which the road, traffic and/or weather conditions are monitored and collected, processed, distributed and communicated to the variable speed signs.
(f) “Variable Speed Zone” means a designated speed that changes based on congestion, road conditions, reduced visibility or weather conditions.
(4) Establishing a Variable Speed Zone on Interstate Highways: the following procedures apply when the Department of Transportation proposes establishing a variable speed zone on any section of interstate highway under ORS 810.180:
(a) The Department may establish variable speed zones on a section of interstate highway based on an engineering study of the characteristics such as congestion, road conditions, reduced visibility or weather conditions. For each section of interstate highway under consideration the Department will prepare an engineering study that will include all of the following:
(A) The Maximum speed.
(B) Crash patterns in the section of highway under consideration by time of day, day of week, season of year or other period exhibiting recurring crash patterns.
(C) Law enforcement consultation and input.
(D) Traffic characteristics by time of day, day of week, season of year or other periods where recurring congestion levels and reduced average speeds occur, such as hourly congestion levels and calculated eighty-fifth percentile speeds (85% speeds).
(E) Type and frequency of adverse road conditions, including weather, environment, and visibility.
(b) The Department will prepare a written analysis and recommendation of the boundaries and algorithms for the variable speed zone. The recommendation will include:
(A) Locations of each sign,
(B) Set of algorithms,
(C) The speed change intervals,
(D) The means, responsibilities and procedures for changing posted speed and
(E) The means, responsibilities and procedures for keeping the speed change records.
(c) If appropriate, the Department will institute rulemaking to make changes to the interstate speed designations which are included in OAR 734-020-0019.
(d) The speed change record must be retained and maintained for at least 3 years.
(e) The speed zone becomes enforceable when variable speed signs are installed and operated.

(5) Establishing a Variable Speed Zone on rural state highways except unpaved roads: the following apply when the Department of Transportation proposes to establish variable speed zones on sections of state highway outside city limits:

(a)The Department may establish variable speed zones on a section of rural state highway based on an engineering study of the characteristics such as congestion, road conditions, reduced visibility or other weather conditions. For each section of rural state highway under consideration the Department will prepare an engineering study that will include all of the following:

(A) The Maximum speed.

(B) Crash patterns in the section of highway under consideration by time of day, day of week, season of year or other period exhibiting recurring crash patterns.

(C) Law enforcement consultation and input.

(D) Traffic characteristics by time of day, day of week or season of year or other periods where recurring congestion levels and reduced speeds occur, such as hourly congestion levels and calculated eighty-fifth percentile speeds (85% speeds).

(E) Type and frequency of adverse road conditions, including weather, environment, and visibility.

(b) The Department will prepare a written analysis and recommendation of the boundaries and algorithms for the variable speed zone. The recommendation will include all of the following:

(A) Locations of each sign,

(B) Set of algorithms,

(C) The speed change intervals,

(D) The means, responsibilities and procedures for changing posted speed and

(E) The means, responsibilities and procedures for keeping the speed change records.

(c) A written variable speed zone order must be issued by the department to establish a variable speed zone.

(d) The original written variable speed zone order must be retained in the Department of Transportation's records for each speed zone issued.

(e) The speed change record must be retained and maintained for at least 3 years.

(f) The speed zone becomes enforceable when variable speed signs are installed and operated.

(6) Establishing a Variable Speed Zone on state highways inside city limits, city streets, county roads and any other rural public roads except unpaved public roads: the following procedures apply when the applicable Road Authority proposes to establish variable speed zones on sections of state highways inside city limits, city streets, county roads and any other rural public roads except unpaved public roads:

(a) The road authority must make a recommendation to the State Traffic Engineer to establish a variable speed zone. The recommendation will include all of the information required in this section including the engineering study.

(b)The Department may establish variable speed zones on a section of state highways inside city limits, city streets, county roads and any other rural public roads except unpaved public roads based on an engineering study of the characteristics such as congestion, road conditions, reduced visibility or other weather conditions. For each section of public road under consideration an engineering study must be completed that will include all of the following:

(A) The Maximum speed.

(B) Crash patterns in the section of highway under consideration by time of day, day of week or season of year or other period exhibiting recurring crash patterns.

(C) Law enforcement consultation and input.
(D) Traffic characteristics by time of day, day of week or season of year or other periods where recurring congestion levels and reduced average speeds occur, such as hourly congestion levels and calculated eighty-fifth percentile speeds (85% speeds).
(E) Type and frequency of adverse road conditions, including weather, environment, and visibility.
(c) The road authority, or the Department on state highways, will submit an engineering study to the State Traffic Engineer, which includes the analysis and recommendation of the boundaries and algorithms for the variable speed zone. The recommendation will include all of the following:
(A) Locations of each sign,
(B) Set of algorithms,
(C) The speed change intervals,
(D) The means, responsibilities and procedures for changing posted speed and
(E) The means, responsibilities and procedures for keeping the speed change records.
(d) A written variable speed zone order must be issued by the department to establish a variable speed zone.
(e) The original written variable speed zone order must be retained in the Department of Transportation's records for each speed zone issued.
(f) The speed change record must be retained and maintained for at least 3 years.
(g) The speed zone becomes enforceable when variable speed signs are installed and operated.
Stat. Auth.: ORS 184.616, 810.180 & Ch. 819, OL 2003
Stats. Implemented: ORS 810.180 & Ch. 819, OL 2003
Effective: 1/27/2012

734-020-0019
Locations and Criteria of Variable Interstate Speed Limits
(1) All locations of mainline interstate highways have speed limits set in OAR 734-020-0011 or a maximum speed limit of 65 MPH per ORS 811.111(1)(a). The speed limit for vehicles listed in 811.111(1)(b) is 55 mph unless a lower speed is posted under sections (2 and 3) of this rule or in section (2) of OAR 734-020-0011.
(2) Under the provisions of ORS 810.180(3), variable speed limits on the following sections of interstate highways are established as follows for all vehicles except as provided in section (1) of this rule:
(a) I-5 Southbound, MP 301.36 – MP 298.90: The following sections each may have different speed limits based on the criteria in section (3) of this rule:
(A) Morrison Bridge to Madison Avenue, MP 301.36 – MP 300.79
(B) Madison Avenue to Marquam Bridge, MP 300.79 – MP 300.26
(C) Marquam Bridge to Ross Island Bridge, MP 300.26 – MP 299.75
(D) Ross Island Bridge to SW Hood Avenue, MP 299.75 – MP 299.36
(E) SW Hood Avenue to SW Corbett Avenue, MP 299.36 – MP 298.80
(b) I-405 Southbound, MP 1.45 – MP 0.00: The following sections each may have different speed limits based on the criteria in section (3) of this rule:
(A) Between SW Montgomery Street and SW 12th Avenue structures to SW Broadway structure, MP 1.45 – MP 1.12
(B) SW Broadway structure to between SW 4th Avenue and SW 1st Avenue structures, MP 1.12 – MP 0.80

(C) Between SW 4th Avenue and SW 1st Avenue structures to the Ross Island Bridge, MP 0.80 – MP 0.40

(D) Ross Island Bridge to the juncture with I-5 southbound, MP 0.40 – MP 0.00.

(3) Criteria for Changing Speeds.

(a) Normal automated variable speed limits:

(A) The minimum traffic volume for variable speed limit system operation shall be greater than 1,200 vehicles per hour in any lane.

(B) Speed limits between subsequent highway sections shall not be reduced by more than 10 MPH.

(C) The speed limit shall be lowered in 5 MPH increments.

(D) The speed limit shall not be changed more than once within a 5 minute period.

(E) The minimum variable speed limit shall not be less than 30 MPH.

(F) The variable posted speed limit shall be within 10 MPH below the 85^{th} percentile speed and posted in accordance with the following Table:

VARIABLE POSTED SPEED TABLE

85^{TH} percentile speed (MPH)	Posted Speed (MPH)
➢ 55	50
➢ 50-54	45
➢ 40-49	40
➢ 30-39	35
➢ Less than 30	30

(b) During periods of crashes and other traffic lane blockage incidents the Transportation Operations Center may establish variable speed limits other than the normal automated variable speed limits in accordance with the following:

(A) The speed increment of 5 MPH for changing the speed under normal conditions may be system overridden.

(B) The minimum traffic volume criteria may be system overridden.

(C) The minimum 5 minute period for changing speeds may be system overridden and the posted speed changed immediately to the minimum of 30 MPH.

Stat. Auth.: ORS 184.616, 184.619, 810.180 & 811.111
Stat. Implemented: ORS 810.180 & 811.111
Effective: 1/27/2012