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Using Real-Time Data from Road Weather Information Systems (RWISs) to Affect Driver Behavior During Inclement Weather – Part I

Final Report

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16. Abstract

During inclement weather, there are numerous vehicle crashes that occur on Interstate 40 (I-40) in New Mexico near the Continental Divide at “Top of the World” (mm 50). A major contributing factor in the vicinity of the “Top of the World” as identified by NMDOT based on crash report information is the failure of drivers to reduce their speed to a level at which they can maintain control of their vehicle. The objective of this project was to determine the feasibility of using the existing road weather information system (RWIS) data in conjunction with a variable speed limit (VSL) system to influence motorist behavior with the goal of reducing crashes in the vicinity. To accomplish this a literature search, interviews of other state department of transportation (DOT) personnel and local transportation agencies and a survey of New Mexico DOT personnel were conducted. Based on this effort VSL systems were identified as a cost-effective technology that can be used to improve safety, reduce speeds, and reduce crash rates in hot spots or corridors with high crash rates. In this report, information has been summarized on the use of RWIS data used in the VSL system, infrastructure and hardware architecture needs for VSL systems, advisory versus enforced VSL, signage and recommended sign locations for VSL and supplemental informational signs, recommended speeds for various conditions, the application of urban versus rural VSL, Operation Plans and Concept of Operations developed for VSL systems, driver feedback to reinforce VSL implementation, and the role of law enforcement in the successful implementation of VSL. The interviews and survey conducted for this project highlighted the importance of educating the public, establishing an effective communication team with a point person at the DOT, and creating a stakeholder group early in the process that engages all potential users/owners, law enforcement, etc. to ensure the success of the VSL system. The researchers also gathered information and considered intelligent transportation systems beyond VSL including dynamic speed feedback signs and advisory information provided by DMS. Recommendations for moving forward include moving to Phase II of Using Real-Time Data from Road Weather Information Systems (RWIS) to Affect Driver Behavior During Inclement Weather. Recommended steps include: 1) analyze crash data to provide recommended bounds of the application area, 2) obtain access to and analyze the usability of RWIS data for ITS alternatives, 3) perform outreach to law enforcement and the maintenance shed responsible for the identified road segment to discuss potential roles and responsibilities of alternative ITS options, 4) work with NMDOT to determine the extent of fiber optic cable, as highlighted in numerous other DOT interviews as imperative to communication, 5) determine placement, if applicable, of closed-circuit televisions (CCTV) in the area, 6) investigate horizontal and vertical curvature of the segment which may influence the recommended ITS solution, and 7) review and map locations of existing speed limit and advisory signs within the identified segment. Any implemented system would be one of the first of its kind on a rural interstate in New Mexico. There is other potential ITS applications (i.e. dust storms in southern New Mexico) that could learn from any ITS implementation at Top of the World. Therefore, the researchers recommend that NMDOT perform an evaluation study of any implemented ITS.

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USING REAL-TIME DATA FROM ROAD WEATHER INFORMATION SYSTEMS (RWISs) TO AFFECT DRIVER BEHAVIOR DURING INCLEMENT WEATHER

Part I Final Report

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PREFACE

The research reported herein investigated the use of the variable speed limit as an option for affecting driver behavior at an identified area of concern where speeds have been observed to be excessive during inclement weather. The purpose of this work is to investigate the feasibility of using variable speed limits in conjunction with available RWIS data and make recommendations on the feasibility of implementation.

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ABSTRACT

During inclement weather, there are numerous vehicle crashes that occur on Interstate 40 (I-40) in New Mexico near the Continental Divide at “Top of the World” (mm 50). A major contributing factor in the vicinity of the “Top of the World” as identified by NMDOT based on crash report information is the failure of drivers to reduce their speed to a level at which they can maintain control of their vehicle. The objective of this project was to determine the feasibility of using the existing road weather information system (RWIS) data in conjunction with a variable speed limit (VSL) system to influence motorist behavior with the goal of reducing crashes in the vicinity. To accomplish this a literature search, interviews of other state department of transportation (DOT) personnel and local transportation agencies and a survey of New Mexico DOT personnel were conducted. Based on this effort VSL systems were identified as a cost-effective technology that can be used to improve safety, reduce speeds, and reduce crash rates in hot spots or corridors with high crash rates. In this report, information has been summarized on the use of RWIS data used in the VSL system, infrastructure and hardware architecture needs for VSL systems, advisory versus enforced VSL, signage and recommended sign locations for VSL and supplemental informational signs, recommended speeds for various conditions, the application of urban versus rural VSL, Operation Plans and Concept of Operations developed for VSL systems, driver feedback to reinforce VSL implementation, and the role of law enforcement in the successful implementation of VSL. The interviews and survey conducted for this project highlighted the importance of educating the public, establishing an effective communication team with a point person at the DOT, and creating a stakeholder group early on in the process that engages all potential users/owners, law enforcement, etc. to ensure the success of the VSL system. The researchers also gathered information and considered intelligent transportation systems beyond VSL including dynamic speed feedback signs and advisory information provided by DMS. Recommendations for moving forward include moving to Phase II of Using Real-Time Data from Road Weather Information Systems (RWIS) to Affect Driver Behavior During Inclement Weather. Recommended steps include: 1) analyze crash data to provide recommended bounds of the application area, 2) obtain access to and analyze the usability of RWIS data for ITS alternatives, 3) perform outreach to law enforcement and the maintenance shed responsible for the identified road segment to discuss potential roles and responsibilities of alternative ITS options, 4) work with NMDOT to determine the extent of fiber optic cable, as highlighted in numerous other DOT interviews as imperative to communication, 5) determine placement, if applicable, of closed-circuit televisions (CCTV) in the area, 6) investigate horizontal and vertical curvature of the segment which may influence the recommended ITS solution, and 7) review and map locations of existing speed limit and advisory signs within the identified segment. Any implemented system would be one of the first of its kind on a rural interstate in New Mexico. There is other potential ITS applications (i.e. dust storms in southern New Mexico) that could learn from any ITS implementation at Top of the World. Therefore, the researchers recommend that NMDOT perform an evaluation study of any implemented ITS.

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INTRODUCTION

During inclement weather, there are numerous vehicle crashes that occur on Interstate 40 (I-40) in New Mexico near the Continental Divide at the "Top of the World" (mm 50). A major contributing factor as documented in crash reports in the vicinity is the failure of drivers to reduce their speed to a level at which they can maintain control of their vehicle. Recently, a roadside weather information system (RWIS) has been installed at that location (I-40, Top of the World, mm 50), and it is equipped with environmental sensors that collect information on road surface and ambient environmental conditions. Specifically, it is capable of monitoring wind speed and direction, visibility, rain, humidity, temperature, pressure, and roadway surface conditions (i.e., presence of ice/snow and road temperature).

Dynamic message signs (DMS) (also called variable message signs (VMS) or changeable message signs (CMS)) were found to sometimes be paired with VSL to increase the effectiveness of the systems. For consistency, these signs will always be referred to as DMS in this report.

The objective of this project was to determine the feasibility of using the existing RWIS data in conjunction with a variable speed limit (VSL) system to influence motorist behavior with the goal of reducing crashes in the vicinity. To accomplish this, a comprehensive literature search was performed, with the collected information summarized in the Literature Review section. Additionally, the research team conducted interviews of other state DOT personnel and local transportation agencies and a survey of New Mexico DOT personnel. Summaries are provided of each interview and of the survey findings. All of the information collected for this report was synthesized to describe the state-of-the-practice with regard to the application of a VSL that utilizes RWIS data, to identify lessons learned and considerations, and to develop recommendations for implementation of VSL by the New Mexico DOT.

LITERATURE REVIEW

The literature search sought information on past and current use of VSL, with a focus on finding information on rural applications of VSL and the use of RWIS or data from environmental sensors as inputs or triggers for VSL systems. The following literature review presents a summary of information found to be particularly relevant to the application of VSL by New Mexico DOT on I-40 at the Top of the World (mm 50).

SUMMARY OF LITERATURE REVIEW FINDINGS

Relevant examples of VSL applications have been identified in over a dozen U.S. states, (i.e., Arizona, California, Michigan, Minnesota, Nevada, New Jersey, New Mexico, Oregon and Washington State, Alabama, Delaware, Florida, Maine, Missouri, Pennsylvania, South Carolina, Tennessee, Utah, Virginia, and Wyoming), and in many European countries. The previous application in New Mexico was in very urban Albuquerque, on I-40. It was removed when the "Big I" was constructed, but observations about the system suggested glare was a problem with this early system. The applications of VSL range from urban speed harmonization, to rural speed control, and speed reduction due to limited visibility from inclement weather and dust in both urban and rural environments.

Key resources identified in the literature review process include the Federal Highway Administration (FHWA) *Guidelines for the Use of VSL in Wet Weather* by Katz et al. (*1*). This report provides guidance on the use of VSL systems in wet weather in locations where operating speeds exceed the design speeds and stopping distance exceeds the available sight distance. The report provides information on the design, installation, operation, maintenance, and enforcement of wet weather VSL systems that are regulatory and advisory. The report also identifies challenges, obstacles, and issues that organizations have encountered when implementing VSL systems. This report will likely serve as a key resource for the development of the Concept of Operations for New Mexico DOT.

Other relevant work includes the summary of presentations from a Transportation Research Board (TRB) workshop on VSL systems used domestically and internationally (*2*). While technology has significantly advanced from 2000 to the present time, these provide good examples on which to build the body of knowledge in the area of VSL. Examples are provided for Arizona, California, Michigan, Minnesota, Nevada, New Jersey, New Mexico, Oregon, and Washington State. International examples include Australia, Finland, France, Germany, The Netherlands, and the United Kingdom. Another overview document of VSL applications and guidance for implementation of VSL provides examples from Australia, Denmark, the Netherlands, England, and other parts of the United Kingdom (*3*).

Specific to the needs of this project, work by Buddemeyer et al. (*4*) discusses a VSL system in southeastern Wyoming on I-80 designed with the intention of improving safety (e.g., reducing the number of crashes) and reducing closure frequency and duration by reducing speed variability during adverse weather conditions on the Elk Mountain corridor. This report discusses examples of VSLs used by DOTs, and driver speed behaviors in both ideal and non-ideal conditions were found and baseline speeds determined. Weather (visibility, wind speed, precipitation rate and type, surface condition/status and temperature, relative humidity, dew point) and speed data (car and truck, calculated 85^{th} percentile) were analyzed to determine key variables (weather and road condition) and threshold values. Once installed, car and truck reactions to VSL systems were analyzed individually for changes in speed, level of speed compliance was simulated, and driver reactions to VSL systems were determined. A decision support system was created to allow for effective and consistent implementation of the Elk Mountain VSL system. The VSL system consisted of 20 VSL signs at 10 locations (5-east bound, 5-west bound), and 10 speed sensors. Eight additional VSL signs were added in four new locations (2-east bound, 2-west bound) during the project.

Work by Smith and Dodge (*5*) discusses using the Rural Safety Innovation Program (RSIP), funding which is a component of the Rural Safety Initiative (RSI), for VSL implementation. Three projects applied to this research effort including:

- South Carolina had its first experience with a VSL system by using it on a two-mile segment of rural US 25, a mountainous area that experiences unusual weather patterns.
- The Arizona project discusses the need to address blowing dust on a 60-mile segment of Interstate 10 between Bowie and the New Mexico State Line. This project is discussed in more detail in the Arizona DOT interview summary.
- The Kansas DOT deployed an intelligent transportation system (ITS) on US 75 to improve winter road maintenance using RWIS data. Kansas DOT was interviewed for this effort, and as discussed in the interview summary, reported that they do not currently have VSL.

Work by Saha and Young (*6a,b*) looked at the use of VSL systems on rural interstate highways in Wyoming where adverse winter conditions caused high crash rates and frequent road closures. The study focused on the impacts of weather and the use of a VSL on crash frequency, respectively. These publications provide a foundation for the use of VSL to improve safety by showing reduced crash rates and road closures following implementation, and calculating a safety benefit rate of about $2.5 million annually, with a two-year return on investment.

The following sections summarize key aspects of VSL implementation as it relates to New Mexico DOT needs.

Data Needs for VSL Implementation

From the literature review the following factors were identified as relevant to the implementation of VSL systems.

Factors to consider in the implementation of VSL (*1, 7*):

- Roadway geometry characteristics
  - Horizontal curvature
  - Road grade/Steep grades
- Adverse weather conditions/weather information
  - Snow
  - Ice
  - Frost
  - Wind
- Roadway surface condition
  - Dry, wet, icy

    - Coefficient of adhesion (friction) (If actual data is not available, coefficient of adhesion can be estimated for rain, $\mu = 0.6$, and snow or ice, $\mu = 0.25$.)
- Traffic volume
- Vehicle operating speeds
    - 85^{th} percentile operating speed data
- Sight distance

Additionally, the following data collected from typical RWIS or environmental monitoring stations is recommended for consideration in VSL implementation *(4, 6a, 6b; 8).*

- Pavement temperature
- Air temperature
- Relative humidity
- Dew point
- Average wind speed
- Precipitation rate and type
- Surface condition/status
- Gust wind speed
- Wind direction
- Visibility

Milliken and Young (*8*) used data collected every 5 minutes, plus radar speed sensors collected data from 28 locations along the corridor, collecting information on vehicle speeds, lengths, vehicle counts, lane occupancies, and headway gaps.

In addition to the factors listed above that should be considered in the implementation of VSL, work by Buddemeyer et al. (*4*) recommends using data from more than one RWIS station in a corridor to have more accurate data with better resolution. Another project discussed considerations in the development of a system that would automatically generate alerts to be displayed on a DMS using input from an RWIS (*9*).

Improved Safety with VSL and Dynamic Speed Feedback Signs

The installation of VSL on I-80 in Wyoming realized a decrease in vehicles crashes after implementation of the system (*4*). The VSL system was found to slow vehicle speed by 5.9 to 8.6 mph for every 10 mph reduction in speed limit. Work by Saha and Young *(6a,b)* showed that use of a VSL system led to a significant reduction in winter crashes (by 27.7% annually) and road closures. The monetized annual safety benefit calculated for this project was approximately $2.8 million per year (related to crash reductions and comprehensive crash cost estimates).

The METANET traffic flow model along with VISSIM were used to evaluate the impacts of deploying VSL on a mountainous freeway in Colorado (I-70 east of Denver) where the number of lanes was reduced from 3 to 2 *(10).* The authors concluded that traffic safety improvements that are intended by VSL are particularly sensitive to the level of **compliance** by drivers. They found that for moderate and high compliance levels, traffic safety improves. The authors note that the results are **not transferable**, applying only to this specific location.

In a survey conducted by Buddemeyer et al. *(4)*, results found that most urban VSLs monitor incidents and speeds, whereas rural systems monitor visibility, weather, and pavement conditions.

Work by Hallmark et al. (*11*) used Dynamic Speed Feedback Sign (DSFS) systems to improve safety on rural two-lane roadways with high speed hot spots and areas with curve-related crashes. On average, most sights observed a decrease in mean speed, with decreases up to 10.9 mph noted for curves. Changes in 85^{th} percentile speed were observed (~3 mph), and large reductions in the number of vehicles traveling over the posted or advisory speed occurred, showing that the signs were effective at reducing the high-end speeds, as well as the average, and 85^{th} percentile speeds. Before and after crash analysis determined a crash modification factor (CMF) from 0.93-0.95 depending on crash type and direction of the crash (a decrease in crashes of 5 – 7%). Raffkin et al. (*12*) looked at VSL technology in Utah, with a focus on driver response to VSL sign usage. From a single site on I-80, VSL signage aided in the reduction of average speed and speed variation by 1.5 to 5 mph, which could potentially lead to improved safety (re: reduced crashes). Based on these findings, the authors recommend long term use of VSL signs in target areas in Utah.

Infrastructure and Hardware Architecture for VSL

Four basic infrastructure requirements for VSL were identified by Katz et al. (*13*):

1) changeable speed limit signs,
2) weather/environmental sensors (such as RWIS),
3) communications equipment to transmit data, and
4) traffic speed/volume sensors.

Sabawat and Young (2014) describes a VSL project in Wyoming, which directly relates to the project at hand. This work indicated that for rural interstate corridors subject to severe weather conditions, the control strategy can be transferable under specific, limited conditions, although the effectiveness of the strategy is primarily linked to the "self-learn" aspect of the developed algorithm. The document discusses how the Wyoming DOT changed from a manual to an automated protocol because of the significant workload of operators at the Traffic Management Center (TMC) and how rapidly weather conditions change on the corridor. In fact, the results indicate that the self-learning control strategy out-performed the manual protocol. Of interest to NMDOT is the Laramie-Cheyenne corridor, which is at a higher elevation. Its control strategy was based on experience from the Elk Mountain corridor. The data input for the control strategy comes from seven RWIS and radar speed sensors. Sabawat and Young (*14*) indicated that the best performance is obtained from using both data sources, which is a departure from work by Katz et al. (*13*). This potentially reflects the limited application and evaluation of ITS in the rural context and is a gap that future research may address. The RWIS in Wyoming provides information about pavement (i.e. surface condition) and atmospheric conditions (i.e. air temperature, relatively humidity, average wind speed) every 5 minutes. There are 28 radar speed sensors along the corridor, collecting information on vehicle speeds, lengths, vehicle counts, lane occupancies, and headway gaps. They are typically installed near the VSL. The VSL signs are placed on both sides of the road in the same direction to account for the potential for them to be blocked by large trucks. There were 19 VSL pairs, 9 and 10 for the eastbound and westbound directions, respectively. The report implied that the Wyoming Highway Patrol can enforce the speed limits.

A report by Foss et al. (*15*) discusses eight international examples of DMS and VSL systems from Finland, Denmark, Sweden, Iceland, Austria, Germany, Canada, and the U.S. This report describes the different types of weather and road information systems in each country, as well as the physical and functional architecture, the roles and responsibilities, objectives, and evaluations of each system. The report identified that the systems are similar but there are differences in the type of information collected and how it is distributed to users. There are also differences in channels used (e.g., web interface, smart phone app, etc.). This work focused on how VSLs were used and when the provision of real-time local weather and road condition information led to speed limit changes. In all of the examples, the goals of using VSL were to increase traffic efficiency and reduce accident rates. The report presents an example from the U.S., in which the Oregon DOT used a non-invasive friction sensor to identify pavement conditions. Based on the conditions, advisory or regulatory VSL could be triggered, and prescribed speeds were posted.

DePinto (*16*) developed a framework of details, rules, and ITS requirements for proper VSL operation for Colorado DOT. This document reviews policy directives, state statutes, requirements for uniform traffic control devices, a review of past studies on VSL in other states (Alabama, Delaware, Florida, Maine, Missouri, New Jersey, Pennsylvania, South Carolina, Tennessee, Utah, Virginia, Washington, and Wyoming), guidance for VSL on the I-70 mountain corridor, system automation (review of manual, semi-automated, and fully automated implementation of VSL), peak period shoulder lane considerations, and suggested VSL speed adjustments. This report provides tables with VSL thresholds used for Alabama, New Jersey, South Carolina, Tennessee, Utah, Washington, and Wyoming, as well as those recommended for use by Colorado.

Several problems were reported by separated DOTs when implementing VSL including: communication and data storage issues, software programs producing variables that did not coincide, companies producing the ITS going out-of-business. Following installation and implementation of a VSL project on I-80 in Wyoming, Buddemeyer et al. (*4*) reported that the primary data was collected from speed sensors, which encountered issues with communications and data storage throughout the project. Another issue encountered was that two software programs used by Wyoming DOT during the project produced different variables. From the interview of Nevada DOT personnel, respondents also reported issues with past VSL technology. The Nevada DOT no longer has this company on its Qualified Product List, as the company has since gone out of business (Personal communication, A. Wolfson, July 24, 2017). The Alabama DOT used VSL for its Low Visibility Warning System, and there were some reported problems with the technology used, although what they were was not specifically outline in the literature (*17*).

Advisory versus Regulatory VSL

Work by Katz et al. (*13*), discussed the difference between a regulatory, or enforceable, versus advisory VSL. They suggest that if the section of road impacted (e.g., requiring VSL) is greater than two miles, then you should consider using an enforceable VSL. Whereas, road segments shorter than two miles may be better suited for an advisory VSL systems. It is important to note that they recommend all VSL systems be regulatory because of higher compliance rates by drivers to the posted VSL.

For some states like New Mexico, where modifying a state statute would be required to allow for enforceable VSL, the use of an advisory VSL may be the reasonable option. One study was found that looked at the use of advisory VSL. Riggins et al. (*18*) found that Oregon DOT chose to use an advisory VSL following discussions with the Oregon State Patrol, who were able to still enforce the VSL based on the law which reads "the basic speed rule for enforcement where a driver is not allowed to drive at a speed greater than is reasonable and prudent for conditions." Georgia State Patrol used as similar approach (*13*).

Signage and Recommended Sign Locations

For VSL signage, Katz et al. (*13*) recommends displaying the VSL in 5 mph increments for at least one minute, and to not reduce speeds more than 1 mile upstream of the impacted road segment, although the majority of the document was drawn from urban examples.

A project examining the use of VSL technology during a bridge expansion project measured the effectiveness of the VSL system by speed, capacity, travel time, queues, and delays (*19*). It was determined that the VSL deployment as a "work zone management tool is viable if motorists are informed of work zone conditions, automated speed limit is enforced, and if motorists have adequate time to utilize alternate routes." A net decrease in travel times was observed from use of the VSL system. A lesson learned from this project related to the use of Portable DMS (PDMS) with travel information, which were found to be highly successful.

Work by Staszcuk and McGowen (*20*) discusses the use of advanced traveler information systems (ATIS) that provide portable real-time traffic information during special events, natural disasters (i.e. unusual extreme flooding), construction projects, and other events that can cause delays. While natural disasters may be weather-related, they are often different than naturally reoccurring seasonal weather (i.e. the expectation of snowstorms in the winter in cold climates). ATISs provide information on advanced travel times, delay times, and reduced average speeds by updating PDMS with real-time messages based on the data collected. Portable ATISs can also be connected to regional or city TMCs. This report discusses available ATIS technology and best practices, and provides an overview of a portable ATIS field demonstration. The demonstration considered the accuracy, reliability, and usability of the portable ATIS.

Recommended Speeds for VSL

Katz et al. (*13*) idenfied a potential wet weather algothrithm and flow chart to determine speed limits for VSL systems. They note that "speed limits should be set to the next lowest 5 mph increment and that the selected speed limit will be no higher than the maximum allowable posted speed and no lower than the minimum predetermined speed." Katz et al. (*13*) make a point to note that "all speed limit algorithms and manual display calculations should be approved by a traffic engineering professional."

Saha et al. (*7*) examined the interactions between roadway geometry characteristics including horizontal curvature, steep grades, and adverse weather conditions (such as snow, ice, frost, and wind) and found that all had significant impacts on crash occurrence. The authors suggest VSL strategies be implemented on road segments with challenging road geometry. A key outcome of this work was that roadway geometry should be considered in the calculation of VSL in addition to real-time weather variables for road segments where roadway geometries play a large role in safety.

DePinto (*16*) developed VSL speed tables for Colorado DOT based on congestion and speed harmonization, weather, incidents and accidents, and construction and maintenance. Table 1 presents the recommended VSLs for weather only based on data from RWIS and closed-circuit televisions (CCTVs).

Table 1. Recreation of VSL speed table showing speeds based on weather data inputs, developed by DePinto (2016) for Colorado DOT.

		Suggested VSL Speeds (I-70 Mountain Corridor)							
Condition Factor	Indicator	General Purpose lanes							
	Speed	**65**	**60**	**55**	**50**	**45**	**40**	**35**	**30 and below**
Weather (based on RWIS data and CCTV's	Coefficient of Friction (slush/ice/other)	resting state	N/A	N/A	Between .6 and .5	Between .5 and .4 and implement chain law	.4 or less and implement chain law	Between .4 and .1	Between 0 and .10
	Visibility (clear, fog, smoke, clouds, blowing snow, other)	resting state	N/A	1 mile	Between 1 mile and 1/2 mile	Between 1/2 mile and 1/4 mile	Between 1/2 mile and 1/4 mile	Between 1/4 mile and 1/8 mile	< 1/8 mile
	Precipitation (snowfall/slush)	resting state	light	light/slush	moderate	moderate/heavy	heavy	heavy	heavy
	Precipitation (rain)	resting state	light	light	moderate	moderate/heavy	heavy	heavy	heavy

Operation Plans and Concept of Operations

Katz et al. (*13*) recommend using the FHWA System Engineering Guidebook for Intelligent Transportation Systems (ITS) in the development of a Concept of Operations to ensure that system operations and maintenance are the primary focus in developing a VSL system, with the goal of reducing speed variance and avoiding accidents from unsafe speeds.

Work by Al-Kaisy et al. (*21*) evaluated the feasibility of a variable speed limit system for wet and extreme weather conditions in Oregon. Based on the findings of this first phase of the project, the VSL system was not implemented. (Note that an interview was requested of Oregon DOT for this project but no response was received.)

Driver feedback (actual speed versus VSL reported speed) to reinforce VSL implementation

This work investigated the use of radar-based speed feedback to motorists to improve compliance with speed limits in work zones (*22*). Typically speed feedback to motorists is a component of speed photo enforcement. Within a few days following deployment, average speeds decreased by 4.4 mph. Three weeks after deployment, the average speed was further reduced by 2.3 mph; showing that speed feedback alone can influence driver behavior.

The role of law enforcement in the successful implementation of VSL

Work by Katz et al. (*2013*) found that a lack of law enforcement support for regulatory VSL systems is an obstacle to successful implementation of VSL. One recommendation was to allow law enforcement officers direct access to the data, as was done by Georgia DOT. Instead of Highway Patrol in Georgia enforcing speed limit based on VSL posted speed limits, officers use “reckless driving” or “driving too fast for conditions” to ensure that drivers are going at an appropriate speed for conditions. The Oregon State Patrol used a similar methodology to enforce advisory VSL. However, at times, using a VSL can also be problematic for law enforcement personnel, as it is not recommended that they exceed the posted speed limit either. No issues with liability were identified, although Nevada DOT recommended involving lawyers early to address tort liability.

As previously mentioned, DOTs in other states like Oregon were able to work with the Oregon State Patrol to enforce the VSL based on the basic speed rule, which requires a driver’s speed to be reasonable and prudent for conditions (*18*).

Other uses of VSL

Other applications of VSL include the DUST (Dual Use Safety Technology) monitoring system that uses weather stations to monitor and trigger warning signs that direct drivers to radio alerts (*23*). More information on a dust warning system being developed by Arizona DOT on I-10 between Phoenix and Tucson can be found in the Summary of Interviews in this report.

Another application of VSL is the Alabama DOT Low Visibility Warning System. The DOT upgraded the system about 10 years after its installation, including the communication between the VSL devices and those controlling them at the command center (*24*). There were some reported problems with the technology but these were not specified.

METHODOLOGY

The research team conducted a comprehensive Literature Review to understand existing information regarding the use of VSL in response to inclement weather. Researchers reviewed methodologies used by state DOTs, local transportation agencies, and private service providers (i.e. New Jersey Turnpike Authority), focusing on those associated with winter weather events, and the use of RWIS data for VSL systems on rural corridors.

The following sources were reviewed for relevant information: Transportation Research Information Services (TRIS); Transportation Research Thesaurus (TRT); publications from the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program (NCHRP), Strategic Highway Research Program (SHRP), University Transportation Centers (UTCs), American Association of State Highway and Transportation Officials (AASHTO), and transportation research organizations (WTI, TTI, CTR, etc.); and proceedings from the National Rural Intelligent Transportation System Conference (NRITS). Researchers participated in the webinar, *Variable Speed Limit Systems: Are They for Everyone?* to identify additional relevant sources.

Based on findings from the literature review, a list of interview questions and a list of potential state DOT interviewees were developed. These were submitted to the Technical Panel for review and comment. Interviews were set up via email and were conducted over the phone during the month of July and August 2017. Interview questions were tailored to each state DOT's unique VSL experience and therefore interview summaries vary greatly in content. A summary of each interview was developed and sent to the interviewee for review and approval and is provided in the following section, and a list of interview contacts can be found in Appendix A.

A survey was developed in Survey Monkey, an online survey tool, and submitted to the Technical Panel for beta testing, review, and comment. Once revised, the survey was sent to the Technical Panel and disseminated to New Mexico DOT personnel. The survey was open from July 21 to August 3, 2017 and received 11 responses. As the NMDOT was asked to distribute the survey to those individuals they deemed applicable, it is unclear how many people were specifically asked/encouraged to take the survey. A summary of the survey results is provided in following section and the survey questionnaire is included in Appendix B.

SUMMARY OF INTERVIEWS

ARIZONA DOT

Background on Arizona DOT VSL

Summary of Issue Resolved

Arizona regularly experiences dust storms caused by particles raised by the wind, which create rolling dust clouds that can lower driver visibility and create dangerous driving conditions. While dust storms are historically associated with summer monsoons, it has become common for Arizona to experience dust storms nearly year-round. Interstate 10 is often affected by these dust conditions. Severe accidents related to low visibility have been recorded, particularly along the segment of I-10 near Eloy, AZ, which is located between Phoenix and Tucson. Since I-10 is the only direct route between Phoenix and Tucson, any closure of this roadway has significant and severe impacts to statewide travel for the duration of the closure.

Action Taken

The purpose of Arizona's VSL project is to respond more effectively to these dust storm events and improve the safety of roadways during storms using ITS technology. Arizona DOT (ADOT) is implementing a pilot dust detection and warning system for a segment of I-10 located in Pinal County from milepost (MP) 209 to MP 219, which should be in place in 2018.

Advanced technologies will be deployed to allow for real-time monitoring of weather conditions and activation of a warning system for drivers that implements strategies to improve safety during dust storms. The proposed dust storm early warning system uses both spot detection technology and remote sensing technology to measure the visibility along the roadway and to detect the development of dust events at a distance from the highway, thus allowing for the advanced warning of approaching dust events.

Visibility detection will be integrated with automated response capability using DMS, VSL signs, and in-pavement detection to warn travelers of conditions ahead during actual or potential dust events prior to encountering them within the corridor.

Results (what was improved, amount and extent of improvement)

The proposed project improvements include the installation of ITS infrastructure along a 10-mile segment of I-10 including the following:

1. **Spot detection visibility sensors** will be deployed throughout the project limits. These sensors will utilize forward scatter technology to measure the Meteorological Optical Range (MOR) and corresponding visibility measurement in real time.

Figure 1. Spot detection visibility sensor. Image provided by AZDOT.

*Note that all images in the Arizona DOT section were provided by R. Karimyand and their original source is unknown at this time.

2. **Long Range Weather Detection sensor** consisting of an X-band radar system will be installed within the project limits to detect approaching dust storms. The X-band radar system will include a 360-degree rotating radar unit that can detect dust storms several miles away.

Figure 2. Long range radar weather detection sensor. Image provided by AZDOT.

3. **DMS** will be strategically placed to allow drivers to make real time decisions on weather events, reduced speed and visibility, routes, avoiding delays, accidents, and construction.

Figure 3. Dynamic message sign (DMS) used to provide messages to the traveling public. Image provided by AZDOT.

4. **VSL signs** will replace existing static speed limit signs and will display a speed limit at all times. VSL will be used to lower the speed limit during periods of low visibility conditions.
5. **Closed Circuit Television Cameras (CCTV)** will be placed at selected locations to provide complete video coverage of the project limits.
6. **In-Pavement Loop Detectors** will be installed to measure speed and occupancy within the project limits. This information will be used to provide alerts to approaching motorists of slower speeds ahead.
7. **Fiber Optic Infrastructure** will be installed along the project limits to allow all the devices included in this project to talk to one another and communicate conditions within the corridor to the ADOT Traffic Operations Center (TOC).

Figure 4. Traffic Operation Center (TOC). Image provided by AZDOT.

Benefits
The ITS improvements will help to manage traffic, and allow traffic to safely navigate the corridor at lower speeds during dust events.

The I-10 Dust Warning System will involve a series of devices to provide condition information as well as disseminate traveler information. Overhead DMS will be placed to alert drivers of hazardous conditions ahead. VSL signs adjacent to the highway will be used to lower the speed limit from 75 mph. CCTV cameras will allow staff at the ADOT TOC in Phoenix to see the current conditions on the roadway, while in-pavement sensors will report the speed and flow of traffic.

This project will improve safety by decreasing the number and severity of crashes on this segment of I-10. Fewer crashes will improve the travel time reliability for motorists travelling between Phoenix and Tucson.

<u>Additional background information from the interview</u>
Arizona DOT applied for Highway Safety Improvement Program (HSIP) funding, which was approved by the FHWA, and applied for a Fast Lane grant. The funding will be used to design and construct the dust warning system along with a much larger road widening project, and will include approximately $8 million for the safety project equipment and to improve the dust detection component. The project will take approximately 18 months to complete. A large part of this project is installing fiber optic cables along I-10 from mile posts 209-219.

Along I-10 between mile posts 209-219 (with MM 214 being the epicenter of dust issues), existing signs will be used, but new signs will be added. CCTV will allow TOC staff to have a visual feed of the actual conditions. Both spot detection and radar will be used to detect dust. CCTV will be located every two miles within the corridor. Additionally, expanded Doppler radar that will look for dust and low visibility conditions within a 40-mile radius will be installed. Visibility sensors will be placed along the corridor every mile, and every 0.5 mile between mile post 212-214, as ADOT wanted closer density visibility sensors in the hot spot area. Loop detection will collect traffic information including volume, speed, and occupancy of vehicles in the corridor. Arizona DOT is using a hybrid VSL (as opposed to a full metric VSL which has much more capability and allows for alternate text for alerts, but is more expensive than the hybrid VSL system). The posted speed along the route is 75 mph, and when triggered, the VSL will report slower speeds in 10 mph increments every 1000 ft down to 35 mph. The lowest speed posted to the VSL will be based on what is detected by the visibility sensor; the speed may drop down to 55 but then hold there for the corridor. If visibility is less than 1/4 mile, the VSL will report 35 mph. Arizona DOT has designed in the threshold speeds for specific visibility readings. If the visibility sensors detect dust, the system will automatically send an alert to the TOC and the Department of Public Safety (DPS), will trigger the lower speed limit on the VSL, and will display a predefined message on the DMS to make people aware of the changing conditions. In some instances, the dust can clear within 15-20 minutes. Closing the road for this short period of time may be a viable option to keep the driving public safe.

As a part of the system, a driver’s speed will be provided as feedback to the driver.

<u>ADOT Enforceable VSL system</u>

ADOT looked into regulatory versus advisory VSL, and ultimately chose to use regulatory VSL. Arizona Highway Patrol agreed with this decision. Overall, the ADOT believes the regulatory VSL will have better compliance.

<u>Lessons Learned</u>

- For dust related issues, visibility sensors are best. Proxy sensors, or sensors that do not directly measure visibility, are not recommended as there can be issues with how close and how accurate the readings are. In the case of New Mexico, if the RWIS can connect to the VSL, then the application can integrate the RWIS data without complicating the system.
- ADOT required a very tight spot detection system, for this reason they needed to expand the Doppler radar.
- Make sure the system that conveys the message to the TOC and highway patrol is very solid (e.g., internet connectivity is good). Microwave or wireless systems can fail/not work, and in as little as one minute a major problem can occur. This was in part the justification for installing more fiber optic cable.
- Expand the stakeholders to include road users, maintenance staff, and everyone who can provide relevant input. Have a very large stakeholder group to get to the nitty-gritty of the system. Include the communication people at your agency in the stakeholder group. Arizona DOT has had one communication point person for this project and this has

worked really well because once the media knows about the project they will be contacting the DOT for more information.

- Communicate well and often with the public to let them know where you are with the project.

*Additional information provided to the researchers included a copy of the Project Assessment (PA), the engineering plans, and the safety data report, and will be provided to NMDOT as a resource.

IDAHO TRANSPORTATION DEPARTMENT (ITD)

Background on ITD VSL

ITD District 6 was first to install VSL due to low visibility associated with dust from agriculture and wind. Historically, at times of low visibility ITD has closed I-15. While not a high-volume interstate, the closures became an issue. ITD detoured traffic onto surface streets, which are not designed to handle the oversized vehicles and triple length trucks. In addition, the detour route passed through many school zones. It was proposed that VSL could keep traffic on I-15 longer and limit the need for the full length of the detour route. (In the past ITD has seen twelve car pile-ups that they are trying to prevent but they are also trying to limit the time the vehicles are on the surface streets.) ITD used the Geometric Design Guide (Table 3.1 in the “Green Book”) as a basis for sight distance, speed limits, and stopping distances. ITD has an RWIS station that provides visibility readings, but the data is highly variable and is often a moving target that requires human judgement. The VSL system is not automated thus requires a manual speed limit change. If reduced visibility occurs, ITD will decrease the speed limit from 60 mph.

Currently, ITD is looking to go out to bid for six more VSL in three zones. The VSL system will determine speeds limits based on 85th percentile using radar. Use of VSL at these locations is specifically meant to address weather and the desire to harmonize speeds during inclement weather. The goal is to slow down the aggressive drivers. Though weather is the motivation behind using VSL at these location, only changes in driver speed, 85th percentile to 50th percentile, are being used in the algorithm (e.g., no RWIS is being used). The VSL reported speeds will be time stamped and posted for a defined amount of time before being removed. The cost for every sign is $6,000 to $8,000, plus an additional monthly fee of $25 to connect to the system.

VSL is viewed favorably in the state, but extensive implementation is not likely due to the costs (e.g., $6,000 to $8,000 per sign). In the future, the interviewee sees autonomous vehicles determining safe driving speeds, and therefore no need for VSL systems, as well as limited to no striping. With autonomous vehicles, speeds will be based on the weather and how fast the car can safely travel. In the future with autonomous vehicles, the green, brown and blue signs (which are supplemental) will likely become irrelevant and be removed. Sign overload is an issue, so the advisory signs will likely be the first to go. (70-80% of his district has cell coverage, looking at blue tooth sensors to get data). He sees the future as being safer for travel.

ITD Enforceable VSL

Regulatory speeds are used in all VSL situations. The state laws are already set up for regulatory speed limits and night time speed limits. While ITD has advisory speeds on curves, etc. the agency perceives less compliance than with the enforceable VSL

Lessons Learned

- The standard sign size for ITD is 48 x 60 inches but many of the vendors could not supply a sign this size with 24 inch characters, so the agency ultimately used a smaller sign. The light emitting diodes (LEDs) were so close to the edge of the sign, the messages all washed out and blended together, so ITD added a 2 in thick black plate as a border to help make the LEDs easier to read.

- In areas where snow accumulation can occur, amber LEDs appear to show through the snow better than white LEDs. Utah DOT and ITD have tested using the amber LEDs for this reason, but white is regulatory so ITD has gone back to using white LEDs.
- Have a standard policy to not drop by more than 25 mph at a time. So they have transition zones (80 to 60 to 40; each being 2/10 of mile, but recommend 1/2 to 1/3 miles transition zones. Give the cars more time to get down to lower speeds.

KANSAS DOT

The research team requested an interview with Kansas DOT about the VSL project associated with the Prairie Band Potawatomie Nation (PBPN). The following information was provided by Kansas DOT;

> “The project with PBPN involved installing two dynamic message signs and one camera in which control is shared between KDOT and PBPN. The camera is located on the same pole as a KDOT RWIS station, but we are not actively using the information for sign messages.”

No response for an interview was provided by the PBPN.
Additional input from Kansas DOT included:

> “KDOT has only used variable speed limits once and in a Smart Work Zone (to my knowledge). Permanent VSL have been discussed, but are not being pursued at this time.”

MINNESOTA DOT (MNDOT)

Background on VSL

MnDOT installed a VSL system that was operational for five years, from June 2010 to approximately June 2015, and was located on Highway 35W south of Minneapolis, and Highway 94 from Minneapolis to St. Paul, both urban corridors. The VSLs were part of a larger active traffic and demand management (ATDM) project that involved high occupancy vehicle (HOV)/high occupancy toll (HOT) expansion, dynamic hard shoulder running, VSL, and incident management signage. The ATDM project was a portion of the Urban Partnership Agreement (UPA) with FHWA that provided funding for several innovative projects. The ATDM signage uses 4 foot by 5 foot full color matrix signs over each lane, on gantries spaced 1/3 to 1/2 mile apart.

The VSL system was fully automated. The system looked at downstream traffic speeds up to 1.5 miles away and was intended to reduce approach speeds prior to congested areas. The upper limit of the VSL was 5 mph below the posted speed, and the lower limit was 30 mph. The system would step speeds down in 5 to 10 mph increments until the congestion point. For inclement weather, the system looked at the average speeds in an uncongested state, if that average was below the posted, then it reset to use that average speed as the upper maximum.

The VSL was phased out because of many problems, including issues with the lane control display devices. The signs had several reliability issues including weather related (Minnesota summer heat and winter cold). About two years after the system was activated, the manufacturing consortium that won the bid *declared bankruptcy*. At this point spare parts and tech support were no longer available. Additionally, the sub-contractor agency performing the field maintenance no longer existed so MnDOT had to shift maintenance in-house. This required two dedicated full-time staff that had to be pulled from their existing TMC maintenance projects. To keep the system going, the staff scavenged spare parts from lesser used signs. The specific issues included:

- The lane control devices were unreliable and frequently had communications issues, such as failure to display messages, partial messages, and stuck messages.
- The ATDM project did not update the speed detection system. The existing MnDOT system primarily uses single loop detectors, buried every half mile, in each lane. The detection data is averaged over a 30 second period in the 170 controllers and then uploaded to the TMC software. The TMC software added further smoothing of 1 to 3 minutes to eliminate outliers such as heavy truck traffic. This system has been sufficient for ramp metering and for travel times but was found to be too slow for the VSL system to adjust to fast moving queues and shockwaves.
- In congested areas, this detection delay resulted in “30 MPH” speed advisories being posted over stopped traffic.
- In another section of I-35W, the average speed is typically 15 to 20 mph over the posted speed. This area feeds into a frequently congested area. The VSL system would correctly post an advisory speed 5 mph below the posted starting about 1.5 miles before the congested area. However, at this point, the VSL is 20 mph below the average traffic speed, so the signs were routinely ignored.

- Conversely, in the more congested areas, shockwaves went back and forth so quickly they needed a much faster response time, seconds rather than minutes.
- Comments from the public on the VSL reported speed included not understanding what the VSL was reporting - should they go the VSL speed, or was the VSL reporting the speed traffic is driving ahead? Because of this feedback from the public, it was recommended that MnDOT incorporate DMS signs to report what the problem is – e.g., "slow traffic ahead.
- Currently MnDOT has a research project in progress, which involves using one lane control on three gantries feeding into a densely-populated area with high shockwaves and high crash rates. The VSL algorithm detects shockwaves and then uses the lane control sign to post "SLOW TRAFFIC AHEAD" rather than an advisory speed. The intent is to see if there is a reduction in crashes in this corridor. This interchange will be demolished and rebuilt soon, and therefore the research component will end at that time. The study is being conducted by University of Minnesota and will hopefully be able to investigate whether the DMS signs alone help to reduce crashes?
- Overall outcome of active traffic demand system is that the dynamic hard shoulder HOT/HOV lane provided MnDOT with an additional lane of capacity to bridge several years between major construction projects. Other than that, can this new research project determine if a DMS or static signs with flashing lights perform the same job of warning traffic of unexpected shockwaves or queues (outside of construction related use of VSL)? For the cost of the ATDM system, MnDOT could have added two service patrol routes on the corridor, which overall would be more effective for incident management, but would not have been funded by the UPA project. (Note: It is unclear regarding what data this conclusion is based upon).

The MnDOT interviewee offered several other observations based on efforts in other states and countries. … Minnesota has a very mature and aggressive ramp metering program with a 15:1 cost benefit ratio. Some European VSL and ATDM estimates suggested a 10% increase in capacity when used. *MN found that combining ramp meters and VSL did not have a multiplying increase in capacity*. Ramp metering may be most effective in dense urban areas with short distances between on-ramps, while VSL may be best used in suburban or more rural areas with longer spacing between ramps.

<u>Future of VSL in Minnesota</u>

MnDOT is taking down as many lane control signals as possible. It has become a huge drain on resources to fix and maintain them. MnDOT plans to leave the gantry hardware, but instead of lane controls above every lane every ½ mile, the agency will use one 18 ft. DMS board every 1 to 2 miles and continue with ramp meters. The DMS will be used primarily to transmit informational messages to the driving public, but they may also post VSL.

<u>The choice of Advisory VSL by MnDOT</u>

In Minnesota, for VSL to be regulatory (enforceable), the Legislature would have had to change a state statute, which was politically unlikely (at least within the construction time frame), so MnDOT implemented an advisory VSL instead. The interviewee recommends that agencies should first investigate compliance with the static posted speed limit signs before considering an enforceable/regulatory VSL. Agencies should not assume that adding electronic or dynamic speed signs will automatically reduce speeding.

The interviewee was asked if state patrol was involved. He was not aware if police were involved, and added that Minnesota patrol is one of the lowest staffed patrols per mile/population, so active enforcement of the VSL was not likely. MnDOT does pay police to enforce HOV/HOT lanes, but enforcement is limited to that corridor and that function.

Lesson Learned

- If considering enforceable/regulatory VSL consider: What is the state of enforcement? How are people obeying the posted speeds? Take this honestly to determine what you can achieve.

Another use of VSL in Minnesota

MnDOT has done some detection and warning in rural and urban *construction* areas, with systems that report the average speed of traffic ahead. The signage provided more than just saying stopped traffic ahead or expect delays. For example, signage might read "traffic 1 mile ahead 30 mph.". The system utilized trailers with Wavetronix sensors that were moved around construction areas. Some trailers had DMS boards, and they used the same algorithm as the other VSL projects (e.g., reported average speed 1 mile ahead with rounding and not exceeding the posted speed, in the construction zones).

NEVADA DOT

Background on Nevada DOT VSL

In the past Nevada DOT wanted to change speeds around the Washoe Valley because of safety issues presented by high wind speeds along the US alternate route south of Reno (on an old road next to the interstate). Nevada DOT implemented a VSL system and the associated software worked well, but problems with the VSL hardware itself emerged. The VSL signs would stop working, or only half of the signs would work. Nevada DOT did not get sufficient support from the manufacturer to help fix the problems. Ultimately, VSL was terminated at this location. When the project was launched, there were two vendors, and the vendor with the lower bid was selected. This manufacture is no longer on the Qualified Product List because of the poor-quality parts and issues with the VSL signs. It was an all-in-one system that was poorly designed. Most of the complaints came from law enforcement officers, who were reluctant to enforce the VSL because only some of the signs worked.

Currently, Nevada DOT is planning to implement VSL on I-80 through the urban core of Reno based on weather information (RWIS data) and flow detectors. The approximately 10-mile section has flow detectors in place every 1/3 of mile; additionally there are RWIS stations along the stretch. Nevada DOT may have to consider installing more pavement sensors. Currently, Nevada DOT is working with a consultant. Together, they have developed a very robust plan, and have already determined sensor locations and other components. At this time prior to implementation Nevada DOT needs political approval and to identify additional vendors (at least two) for the VSL system hardware to ensure selection of a good quality product. There is still some work to be done, including determining needs for cables/fiber optics and installing software. The congestion algorithm has already been developed and is in the testing phase, and the weather algorithm still needs to be developed. Implementation is likely to be completed within two to five years. There is a lot of support for this project, but there is also a lot of work to be done still.

Nevada DOT also uses VSL in Las Vegas to address congestion and to harmonize traffic/speeds. This use of VSL was not explored further.

Nevada DOT Enforceable Regulatory system

Nevada DOT uses enforceable VSL which is allowed by the state’s regulatory system. The interviewee was not sure, but it is likely Nevada DOT did not need to change state statutes to allow for a regulatory system. With this being said, Nevada DOT requires all VSL display boards to be full color with a white background to match other regulatory signs. For an ongoing project, VSLs will be enforceable. In addition, a non-enforceable reduce speed ahead advisory system will likely be used.

The interviewee noted that the agency has observed greater compliance with the enforceable VSL. The highway patrol supports the enforceable system. When comparing advisory versus enforceable VSL, the interviewee noted that involving the highway patrol seems to help change driver behavior, even when the VSL is advisory. For example, the highway patrol can assist with post-crash assessment and tickets. Moreover, if the DOT makes changes but does not coordinate with or inform the highway patrol, it can strain working relationships.

Lessons Learned

- Make sure you test the hardware/software extensively. Make sure you have a bench test in operation, so if components start to break, the ITS staff can respond quickly. Even if the system is advisory, it is important to complete repairs as quickly as possible. You do not want to have any high-profile system failure.
- VSL signs are designed to be noticed. They will be noticed for good and bad reasons, so make sure they are working.
- The software testing/development appears to be the most challenging aspect of the project.
- There is a need to educate the public on the VSL system (maybe through a press release).

NEW JERSEY TURNPIKE AUTHORITY

The New Jersey Turnpike Authority (NJTA) used to have an operational VSL that posted varying speed automatically. The system had 1,000 copper loops in the road that collected data real-time that fed into the VSL algorithm. The loops detected speed and decreased the speed at the next upstream VSL. Due to maintenance costs of copper inductive loops, the NJTA could not maintain this system. Next, NJTA started installing sensor pucks, but this requires the system to be manually operated. The agency is now looking for a way to make the system automatic with the newer sensor pucks.

Currently they have 240 VSLs and 115 changeable message signs (drums).

VSL and DMS boards are now updated manually but the staff wants the process to be automatic again. Under normal conditions, the staff can put messages up on the board promptly, but it can become unmanageable to clear them at times when there are multiple incidents and crashes. This leads to "sign noise," where the signs display inaccurate messages that mean nothing.

<u>How VSL is used</u>

- Weather – for example: a state trooper reports how many delineators he can see, then corresponding speed reduction goes into effect.
- Maintenance – winter operations example: posted for snowy condition 50 mph, plow 45 mph, plowing in teams 35 mph
- Construction– lane closure leads to a drop in speed
- Down-stream traffic congestion – no additional information was provided (see example in introductory paragraph, in which an upstream VSL has reduced speed posted)

<u>New Jersey Turnpike Authority Enforceable VSL</u>
When a speed limit is lowered in New Jersey, law enforcement officers have the authority to enforce this new speed. When State Police officers write a ticket or write up a crash report, they ask for supporting information from the turnpike on the posted speed at that time.

On average, there are warning boards and VSL every two miles in both directions on the turnpike (enforceable, white and black signs). By contrast, on the parkway there are warning boards and VSL every 4 miles (Advisory, black and yellow bitmaps). The interviewee believes that drivers observe better adherence of the VSL on the turnpike because it is enforceable.

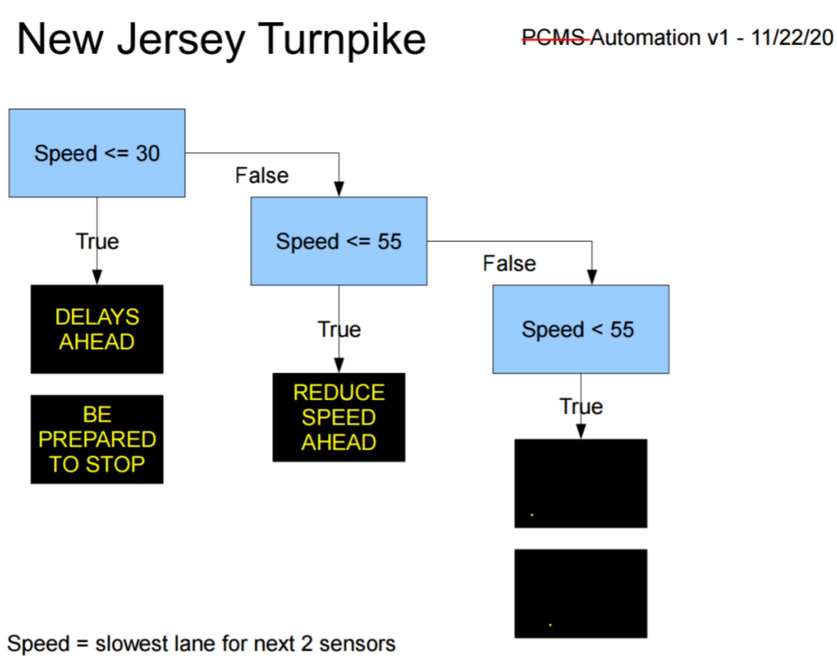
The interviewee also provided the following excerpt from the NJTA speed reduction guidelines:

A. The following guidelines will be used in implementing speed reductions on the New Jersey Turnpike in areas where the Maintenance Department is involved in salting and plowing operations. The posting of these speed limits is to alert motorists to the presence of salt/plow vehicles traveling at reduced speeds on the mainline, as well as other slower traveling vehicles following the salt/plow crews, in order to enhance the safety of the motorists and the workers/contractors alike. The requested speed reductions of the State Police will also be honored.

1. **50 MPH** shall be posted when the Maintenance Department begins a spot salting operation or if they are salting a specific area or structure. In that case, the speed shall be reduced in the specific areas where they are salting. This speed limit shall also be posted during the clean-up operation following a storm when the Maintenance Department is cleaning up Z-turns and U-turns, etc.

2. **45 MPH** shall be posted when the Maintenance Department is salting an entire district with their salt crews. Again the speed limit shall be reduced only in those districts where this activity is occurring.

3. **35 MPH** shall be posted when plow teams, be they Maintenance Department or contractor plow teams are actively plowing the roadway.



These procedures serve as a guideline for the actions of employees involved in the operations of the New Jersey Turnpike. They are the result of many years of experience in operating the New Jersey Turnpike during periods of poor visibility, whether caused by fog or other conditions.

Speed reductions are based on sight distance through the affected area. The following guidelines are used to appropriately post a speed reduction:

Visibility		Recommended Speed	
		65 mph Roads	55 mph Roads
More than 800 yds	14 or more delineators	No change	No change
700 to 800 yds	11 to 14 delineators	60 mph	No change
500 to 700 yds	8 to 11 delineators	55 mph	No change
300 to 500 yds	5 to 8 delineators	50 mph	50 mph
200 to 300 yds	3 to 5 delineators	45 mph	45 mph
100 to 200 yds	2 to 3 delineators	35 mph	35 mph
Less than 100 yds	Less than 2 delineators	Consider closing the affected area	

NJTA also provided the following additional information, which is available as reference for NMDOT:

- "Emergency Fog or Limited Visibility Manual" from the New Jersey Turnpike Authority
- "History of VSL (on the New Jersey Turnpike)" from the New Jersey Turnpike Authority
- "Automatic Surveillance and Control on the New Jersey Turnpike" (circa 1960s) reports on the original design and installation.
- PowerPoint presentation titled "New Jersey Turnpike Authority" that provides an overview of the system, the signage used, the operating system, messaging options, state of emergency use, and the following lessons learned
    - Lesson Learned:
        - Plan for extended power loss
        - Have back up power for electronic signs
        - Design traffic management system for a Category 2 storm surge.

WASHINGTON STATE DOT

<u>Background on Washington State DOT VSL</u>

Washington State DOT uses VSL in a rural application on mountain passes along I-90, Snoqualmie Pass, and US 2, Stevens Pass. These are manual systems that do not connect to RWIS directly. The VSL system uses information from within 10 miles of each side of the pass, and the agency locates the VSLs near existing power and communication, usually within one mile of the interchanges. Washington State DOT relies heavily on on-site feed-back from highway patrol, maintenance personnel, and RWIS data to accurately post VSL. If ice or snow is present the system will post a lower speed limit. The manual VSL at the mountain passes is changed by an operator in an office that has communication to the sign. Operators have a look-up table (Table 2) to determine the posted VSL for various conditions such as snow, ice, wet, or rain. They implement speed adjustment in increments of 5 mph down to 35 mph. The operators are then responsible for monitoring the conditions and traffic speeds and returning or increasing the speed once conditions improve and traffic speeds increase.

Table 2. Look up table used by Washington State DOT (courtesy Washington State DOT).

TRACTION REQUIREMENTS	SPEED LIMIT	PAVEMENT CONDITIONS	VISIBILITY	WEATHER	BLOCKING INCIDENTS
NONE	65	DRY OR BARE / WET	GOOD: CLEAR>0.5 MILES	FAIR TO MODERATE RAIN	INCIDENT ON SHOULDER
TRACTION ADVISORY	55	LIGHT SNOW, SLUSH, OR ICE IN PLACES	MODERATE: FOG<0.2 MILES	HARD RAIN	INCIDENT ON SHOULDER
TTREQ / VEH OVER 10000 GVW CHAINS REQUIRED	45	COMP. SNOW/ICE, DEEP SLUSH, SHALLOW WATER	POOR: BLOWING SNOW<0.1 MILES	HEAVY RAIN OR SNOWFALL	LANES BLOCKED TRAFFIC MOVING
CHAINS REQUIRED ALL VEH EXCEPT ALL WHEEL DRIVE	35	SEVERE FREEZING RAIN, DEEP SNOW, SLUSH OR STANDING WATER	POOR: BLOWING SNOW<0.1 MILES	HEAVY RAIN OR SNOWFALL	LANES BLOCKED TRAFFIC STOPPED AHEAD
EMERGENCIES or EXTREME CONDITIONS ONLY	25	USE THIS SPEED FOR SEVERE CONDITIONS AS REQUESTED BY CREWS ON THE SCENE. CONFIRM WITH SUPV., WHEN AVAILABLE. POOREST POSSIBLE ROAD CONDITIONS AND HUMAN LIFE ENDANGERED. Conditions should be well documented. Return to higher speed limit as soon as possible.			

For Stevens Pass on US 2, Washington State DOT uses 12 VSL signs and 6 DMS boards to broadcast roadway condition and speed limits (Figure 5). For Snoqualmie Pass on I-90, the agency uses 15 VSL signs and 6 DMS. In addition to the VSL signs and DMS, the DOT uses DMS to convey chain requirements when needed. Washington State DOT started using VSL on I-90 at Snoqualmie Pass in 1998, and at Stevens Pass on US 2 in 2005.

Figure 5. Examples of DMS board language and posted VSLs used by WSDOT (courtesy of Washington State DOT).

Washington State DOT uses automatic VSL in urban areas for speed harmonization, and DMS boards to aid in traffic management.

<u>Washington State DOT uses Enforceable VSL</u>
Along both I-90 and US 2, VSL is enforceable and the revised speeds are posted on white signs with black numbers to meet regulations. In the past VSL was posted in amber on black signs. Washington State DOT uses hybrid signage for enforceable VSL. The signs replace the normal speed limit with the VSL using LEDs.

Washington State Patrol often calls in to WSDOT recommend the VSL speed limits be changed (lowered). Officers observe how traffic moves through area, and use radar to monitor speeds, so they provide great feedback (and support) for the system. They also support the use of the 85th percentile speed limit.

<u>Lessons Learned</u>

- Speed limit when posted should reflect the immediate condition where people are driving. Within a mile or two downstream of the posted VSL, the driver should encounter the condition.
- Measure speed downstream of the VSL sign location. This will reflect the condition the driver will encounter and will increase compliance.
  - In an urban application, the system measures speed at multiple places throughout the corridors to reduce saw-toothing of speeds and apply a smoothing factor. The art is in figuring out where to calculate the downstream speed. Washington State DOT developed the algorithm in-house so it has the luxury of testing and fine-tuning it.
- In the future, Washington DOT would like to have the snow plows and maintenance drivers provide additional direct feedback for the VSL system and connect the VSL to the RWIS. But there is a need to have a human hand in VSL to make sure it is all working. Ideally, it would be an automated system with ground truthing (in-person verification of sensor readings and VSL output).
- Washington State DOT had the VSL operating, collecting data, and running for three months before deploying. The agency believes this was very important to make sure the speed data being collected was accurate, the algorithm was functioning, and the posted VSL was correct. The DOT recommends setting up the VSL system and letting it run in the background for a while to “work the kinks out.” As a result, staff members were able

to answer the following questions prior to implementation: Is the speed recommendation changing drastically? Is the speed changing every 5 minutes? Does this work or does the algorithm need to be modified?

- Additional lessons learned from the Power Point:
    - Design –
        - Software development should adhere to a Systems Engineering process.
        - Standardize sign memory address
    - Operation -
        - All displays must be credible and reasonable
        - Use speed trap to measure speed at fine granularity (20 sec)
        - Update display frequency (1 min)
        - Staff must be trained to recognize anomalies and override any automatic processes promptly.

WSDOT provided additional documents, including a PowerPoint presentation titled “Variable Speed Limit, how is it working for WSDOT?” The presentation provides a summary of WSDOT’s transition to automation in the urban areas, provides a description of its system, describes how the speed limit was established, provides a sample operator interface and detailed explanation, and explains the urban VSL displays used.

WYOMING DOT

Wyoming statute allows for regulatory variable speed limits as opposed to advisory. The statute was modified in 2007 to allow VSL. There are six current VSL zones (4 on I-80, 1 on I-25, and one on WY28) with two more being constructed.

Wyoming DOT uses the following protocol to change speeds:

- Wyoming Highway Patrol (WHP) – initiate speed limit reduction based on visual inspection of conditions
- Maintenance Foreman – may lower speed limit based on conditions if a WHP is not on duty.
- TMC – may lower the speed limit if average vehicle speeds drop 15 mph and no one else is available to confirm conditions.

The use of VSL has been shown to harmonize speeds of all traffic types. With the automated VSL higher speed compliance and reduced speed variance were observed. It was also found that automated speed limited recommendations are more responsive to changing conditions, and have a higher speed limit change frequency.

Wyoming DOT provided additional information on the VSL project listed above. The two reports provided on these projects were included in the Task 2 Summary of Literature and therefore it was deemed unnecessary to conduct a full interview. Wyoming DOT also provided a PowerPoint presentation titled “Variable Speed Limit System in Wyoming,” Rhoda Young, R. Vince Garcia, Feb. 7, 2013. This presentation appears to be a Final Report Presentation from the Rural Variable Speed Limit project. The PPT provides an outline for the methodology of using speed data and RWIS data in the algorithm to determine VSLs.

SUMMARY OF NMDOT SURVEY

New Mexico DOT personnel were asked to participate in a five-question survey regarding the potential use of VSL in their state. The survey was distributed by the Research Advisory Committee and Technical Panel to NMDOT personnel. The following responses were gathered from 11 respondents.

When asked about their overall impression of VSL use, the majority responded that they felt somewhat positive. Responses ranged from not positive (n=2), positive (n=3), somewhat positive (n=5), to very positive (n=1). No respondents indicated that they “will not even consider” VSL.

Respondents were then asked for their general impression of VSL, particularly the maintenance needs or requirements. The following responses were received:

- I am concerned about maintenance needs and legal ramifications.
- NMDOT does not have the resources to maintain these types of signs. A specification would need to be developed, and devices(s) work to get on our Approved Product List.
- Who does the maintenance and who pays for the maintenance? NMDOT or the local communities? It will be hard for the local communities to maintain the equipment.
- Reducing speeds when weather issues exist may reduce crashes.
- Maintenance could be extensive including possible frequent checks for system operations and additional staff with technical background.
- Solar installs of radar feedback signs have been my only experience with similar technology. Theft was an issue, but systems were otherwise reliable.
- If it is advisory, no issue but if it is enforceable then it is not known how can it be enforced!
- VSL is a good concept and will get the drivers attention. Initially maintenance may need training on installing it.
- Difficult to enforce.
- While VSL use during heavy peak traffic conditions as well as adverse weather can improve safety by reducing speed variations, maintenance and operations can be expensive in which a VSL plan and route/corridor/segment prioritization needs to be developed.

Overall the feedback from this question is valuable highlighting the concern of enforcing VSL, and who will own and maintain the technology.

The next question asked respondents what they thought would be the main challenges with setting up and maintaining VSL in New Mexico. The following responses were received:

- Legal ramifications, enforcement, compliance, and maintaining equipment in good working order.
- Costs
- Would require a maintenance agreement with the local governments which already are unable to maintain existing facilities.
- We do not have enough money to maintain our roads as it is. Now the additional costs to the infrastructure? Will the signal shop be expected to maintain the VSL equipment?

Who pays for the maintenance? Who pays for the electricity? We already have an issue with communities not wanting to pay for the upkeep on roadway lighting and traffic signals. This is another burden on the various communities if they are expected to pay.

- An education component will need to be implemented. The DOT will need to be diligent in getting messages on electronic message boards.
- Who would be monitoring it? Would the signs be independent of staff oversight or just engage based on weather monitoring equipment? Could be useful in urban areas during congested times (AM peak, PM peak, noon). The speed differential may be present if motorists do not "believe" the information. The real-time effectiveness is essential to gain the public trust of the information.
- Ensuring reliable operation.
- The driving population has not been educated.
- One challenge could be the power source and ensuring the VSL is functioning properly before bad weather occurs. And the possible legality if the device is not functioning properly and an accident occurs.
- Establishing based on safety data.
- Cost considerations, hardware, software.
- VSL enforcement
- Collecting and processing big data
- VSL speed control algorithms properly designed to include driver response/compliance.

The feedback from survey respondents on this question is very valid and echoes much of what was found in the interviews of other state DOTs regarding informing and educating the public, making sure the system is functioning well, and ensuring that the information can be trusted by the driving public to promote compliance. Many of the cost issues can be considered early on in the process. At locations where VSL is being considered, it may be helpful to include local road authority and or community members in the stakeholder group.

Next, respondents were asked what institutional policy hurdles might be encountered if implementing VSL. The following responses were received:

- Justifying benefits to the legislature and public.
- Maintenance and enforcement
- Educating the driver to follow the reduced speeds. Drivers do not slow down for construction work zones already! Do not underestimate the [lack of attention] of the American driver! Look at how many people text and drive at the same time currently. Now you want the driver to actually pay attention to a changing speed limit depending on weather or time of day?
- Enforcement. How could officers keep track of the changes in speed? Compliance for drivers is challenging. Need public outreach to understand the concept.
- Typical for new technology to have slow acceptance within NMDOT. I hear "it doesn't work" routinely.
- One policy hurdle would be if the maintenance would fall back on the individual district or the maintenance bureau at the general office. Also ensuring there is statewide consistency on where these are installed. Local entities may want to implement these on their routes so there will need to be criteria or warrants to follow before installing one.

- Convincing administration of the benefits of VSL.
- Whether it should be enforced or advisory?
- How, where, and why to institute speed changes for speed reduction and speed recovery?
- Calculating a suitable and safe speed limit(s) that is accepted by the public.

Overall these responses provide NMDOT with insight before starting the process. There is some pessimism within NMDOT that could be challenging to overcome. The responses highlight the importance of having an encompassing group of stakeholders, and developing an education/communication plan.

The final questions asked survey respondents how they would use VSL if implemented. As shown in Figure 6, NMDOT personnel would use VSL primarily for weather, work zones, congestion and to improve safety. Other responses included:

- Roadway surface condition,
- Dust storm mitigation, and
- Driver safety

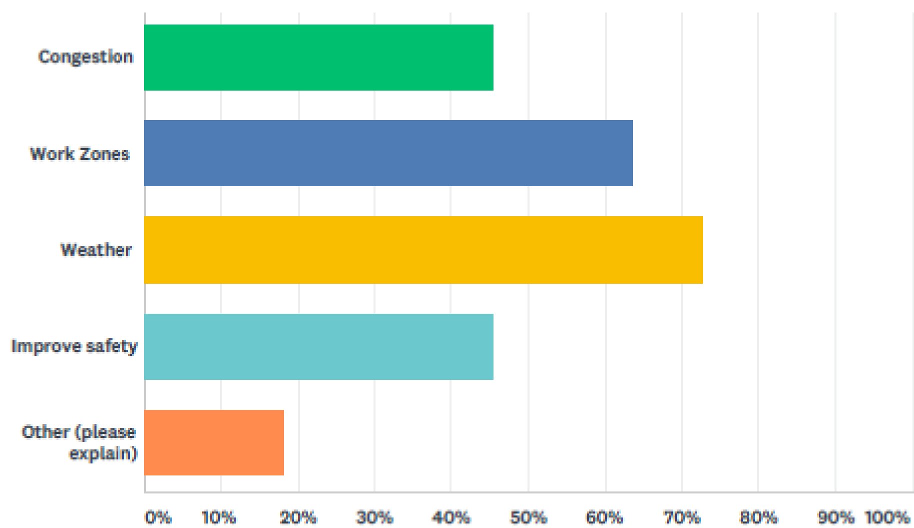


Figure 6. How NMDOT personnel would use VSL if implemented.

CONCLUSIONS AND RECOMMENDATIONS

This research effort has provided a lot of valuable information for NMDOT to consider. They now know that a VSL had previously existed in the urban Albuquerque area – one of the early deployments in the United States. The Literature Review provided other insights as NMDOT moves towards deploying VSL during inclement weather conditions, a DMS to provide motorists with recommendations to slow down during inclement weather or pilots a DSFS on an interstate with FHWA approval. This research effort also identified some valuable recommendations provided by peer DOTs as NMDOT works to address concerns with excessive driver speed and safety at the Top of the World using ITS. Finally, the surveys of NMDOT suggest that additional outreach to maintenance sheds, law enforcement, and the public are needed prior to implementing an ITS system (see above examples) in order to plan for success of the system. This section concludes with recommended steps for Phase II of *Using Real-Time Data from Road Weather Information Systems (RWISs) to Affect Driver Behavior During Inclement Weather*.

VSLs can be a cost-effective technology that can be used to improve safety, reduce speeds, and reduce crash rates in hot spots or corridors with high crash rates. From the literature review the following relevant information was identified:

- RWIS data needs for use in the VSL system
    - VSL implementations have been developed to utilize all available data from RWISs. The key for New Mexico will be identifying the key parameters (recommendations for which were identified by Katz et al., 2017) to use for VSL calculations or triggering the system, and ensuring data from more than one RWIS station is available to create a more robust system. In some cases, states found that the RWIS data was not reliable and made use of additional data sources. NMDOT should investigate these accuracy of RWIS data.
- Infrastructure and hardware architecture needs for a VSL system
    - Communication problems were identified with VSL (see MnDOT and Nevada DOT interviews). However, many of these seem to be overcome with fiber optic cable. Therefore, there is a need to understand the relationship between the target segment to address issues near Top of the World and communication options. ITD also reported the need to ensure that if LED bulbs are used, there is sufficient contrast on the sign, as the information can be "washed out."
- Information on advisory versus enforced VSL
    - In general, published work and feedback from the interviews recommends using enforceable speed limits to ensure the success of the implemented VSL system. Limited research into the effectiveness of advisory VSL has found it to be successful at reducing driver speeds and improving safety, but the degree of improvement compared to enforced VSL is unknown at this time.
- Signage and recommended sign locations
    - Signage typically used for VSL systems includes the VSL sign(s), often in concern with a DMS (see MnDOT interview). In some instances, only a DMS board is used and the advisory or regulatory speed is posted on it, although these tend to be larger over-the-highway DMS (i.e. Washington, Wyoming).
- Recommended speeds for various conditions

    - For those who mentioned it in their reports, 85^{th} percentile was used to calculate the VSL. Recommended speeds are based on key parameters identified from each site. In the case of New Mexico DOT, RWIS data will be used in addition to other identified key parameters.
- Urban versus Rural VSL implementation
    - The literature review and interviews showed that most urban VSLs monitor incidents and speeds, whereas rural systems monitor visibility, weather, and pavement conditions (with road geometry being considered more recently). However, it seems that there is likely some value in monitoring speeds of rural systems; therefore, the researchers recommended including and evaluating the effectiveness of monitoring speed in a rural environment in conjunction with VSL.
- The role of law enforcement in the successful implementation of VSL.
    - Many states have had success with their VSL systems because of their relationship with law enforcement. Regulatory VSL is not required in all cases for law enforcement to effectively support posted VSL. In the case of New Mexico DOT, where a modification of the state statute to allow for regulatory VSL is not likely, working with law enforcement to discuss the reasoning behind VSL implementation, where and how it will be implemented, and how they can work within the law to help support the posted VSL, could be invaluable in the success of the VSL system. It will help to avoid experiences like those reported by Nevada DOT.

The lessons learned sections of each interview provide a wealth of knowledge from experience. Some DOTs have established VSL systems (e.g., Washington State DOT), and other states are currently in the process of establishing VSL systems (e.g., Nevada and Arizona DOT). The constructive feedback received from the interviews and NMDOT survey will likely prove to be invaluable as New Mexico moves forward with consideration of VSL.

The interviews conducted for this project highlighted the importance of:

- Educating the public,
- Establishing an effective communication team with a point person at the DOT,
- Creating a stakeholder group early on in the process that engages all potential users, owners, and law enforcement. Specifically, Washington State noted that they rely “heavily” on the on-site feedback of both maintenance and law enforcement. Wyoming DOT also implied by their protocol that they rely on both law enforcement and maintenance assessment of conditions.
- Vendor Bankruptcy
    - As NMDOT considers what vendor to employ to put up their eventual system, they should consider how the contract is written. Both MnDOT and Nevada DOT noted that they were left with a system that was not operating well because the vendor in each case (it is unclear if it is one in the same) folded. NMDOT should consider how to incorporate performance when evaluating vendors of VSL, if they move forward with VSL.
- Value of Accurate ITS

- MnDOT noted that VSL were ignored if they were significantly different than free-flow speed. The New Jersey Turnpike Authority also noted that if the signs did not reflect conditions, they were ignored. While urban, both of these examples highlight the important of accurate messaging, whether through VSL or DMS. Washington State, who has a rural VSL application, noted that the condition should exist within 1 to 2 miles of the conditions.
- Communication with the Devices
  - Nevada DOT reported that they are investigating whether cable/fiber optic is present in an urban corridor where they are planning to implement VSL. The New Jersey Turnpike Authority indicated that they planned for power loss. For the rural application that NMDOT is considering, is power loss a possibility? Washington State's Snoqualmie Pass's VSL, a rural application, even noted that they connected into existing power and communication.
- Use Enforceable VSL
  - Similar to the findings from the literature review, the majority of interviewees commented that enforced VSL is preferred (Arizona DOT, Nevada DOT, New Jersey Turnpike Authority, and Wyoming). In fact, Wyoming DOT indicated that they had changed the state statute that would have limited them from enforcing VSL.
- Rural Pass Boundaries
  - Washington State has one of the oldest weather-related VSLs. They designed their system so that it extends to 10 miles on either side of the pass. How does the grade on either approach to the pass compare to that of Top of the World? Is this a rule of thumb, or should this knowledge be used in conjunction with crash data?

All of these concepts were echoed by New Mexico DOT personnel in the survey. For example, one NMDOT survey respondent echoed the need for accurate messages by ITS. Additional information gained from the interviews includes the potential to use/review existing or in-development design plans and algorithms for VSL systems in state such as Nevada, Arizona, or Washington State.

Work to consider prior to implementation includes:

- As recommended by a peer DOT, an investigation into speed compliance along I-40 at the Top of the World of the existing static posted speed limit signs.
- Establishment of a stakeholder group that engages all potential users, owners, law enforcement. This will help to address questions like, how will law enforcement be made aware of any changes to advisory speeds made by any ITS system.
- Identification of current infrastructure and hardware, as well as connectivity, to determine if additional resources are needed prior to installation of a VSL system (e.g., installation of fiber optic cables, presence of CCTV, speed collection devices, etc.).
- Investigate potential messaging for DMS if used in conjunction with VSL (see New Jersey Turnpike Authority and Washington State interviews).
- What about the current conditions and road geometry impact crashes occurring near Top of the World? Is it the road surface (i.e. reduced friction) or does reduced visibility during inclement weather contribute?

While some states use advisory VSL, overall, the Literature Review and interviewed DOTs recommended a regulatory implementation of VSL as compared with advisory. It is recommended that the DOT further pursue changes to state legislation, particularly as other locations in New Mexico might be a good fit for VSL (see NMDOT survey feedback regarding VSL for dust), as reported by several other states to enable VSL to be used in a regulatory fashion.

Survey respondents identified other issues to consider early on to allow for smoother implementation. These include who will:

- Own the VSL equipment?
- Maintain the equipment?
- Conduct ground truthing or real-time feedback on accuracy of the VSL speeds?
- Be responsible for the associated upfront and longer term maintenance costs?
- What is the protocol for law enforcement, maintenance sheds, or any other entity given permission to request a reduction in speeds of VSL?

Many respondents were concerned that the cost and maintenance of the VSL equipment might fall on the local jurisdiction.

Many of the issues identified in the survey could be easily addressed in an education campaign regarding the effectiveness of VSL, the ownership of VSL, and the enforcement (or advisory nature) of VSL. Long et al. (*25*) addressed the importance of public outreach and education with the implementation of VSL; they described a VSL deployment in Missouri, in which the Missouri DOT used Twitter, the Missouri DOT website, email, and a YouTube video to educate the public on VSL systems.

Based on the findings of this report, the proposed methodology by New Mexico DOT of using RWIS data to feed into or trigger a VSL system on I-40 near the Top of the World (mm 50), in conjunction with a radar based speed sensor providing driver feedback near where the VSL is reporting advisory speed, appears to be implementable. The research team recommends moving forward with the development of a Concept of Operations to further assess feasibility.

The research team recommends moving forward with *Using Real-Time Data from Road Weather Information Systems (RWISs) to Affect Driver Behavior During Inclement Weather, Phase II*. Recommendations include:

1) analyze crash data to provide recommended bounds of the application area,

2) obtain access to and analyze the usability of RWIS data for ITS alternatives, including determining how many RWIS may be used in the identified corridor,

3) perform outreach to law enforcement and the maintenance shed responsible for the identified road segment to discuss potential roles and responsibilities of alternative ITS options,

4) work with NMDOT to determine the extent of fiber optic cable, as highlighted in numerous other DOT interviews as imperative to communication,

5) determine placement, if applicable, of closed-circuit televisions (CCTV) in the area,

6) investigate horizontal and vertical curvature of the segment which may influence the recommended ITS solution, and

7) review and map locations of existing speed limit and advisory signs within the identified segment.

Any implemented system would be one of the first of its kind on a rural interstate in New Mexico; as there are also limited rural applications of VSL in the U.S. in general, the researchers recommend that NMDOT consider evaluating any implemented system. There are other potential ITS applications (i.e. dust storms in southern New Mexico) that could learn from any ITS implementation at Top of the World.

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APPENDICES

APPENDIX A – LIST OF INTERVIEW CONTACTS

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Kansas DOT Shari Hilliard Shari.Hillard@ks.gov (785) 296-6356	Minnesota DOT John McClellan john.mcclellan@state.mn.us (651) 234-7025
Nevada DOT Alex Wolfson awolfson@dot.state.nv.us (775) 834-8365	New Jersey Turnpike Henry "Chip" Eibel eibel@turnpike.state.nj.us (732) 442-8600 ext.8555
Washington State DOT Vinh Dang dangv@wsdot.wa.gov (206) 410-0003	Wyoming DOT Darin Kaufman darin.kaufman@wyo.gov (307) 352-3034

*Please note that while Wyoming DOT, Kansas DOT, and New Jersey Turnpike were contacted, they were not pursued for follow-up interviews because they provided additional information via email that was deemed sufficient. A synopsis of the additional information gained is provided in each summary.

APPENDIX B - SURVEY QUESTIONNAIRE

New Mexico DOT Variable Speed Limit (VSL) Survey

Use of Variable Speed Limits (VSL) in New Mexico

Use of Variable Speed Limits (VSL) is being considered to increase safety by better harmonizing speeds in New Mexico by providing an advisory speed limit to drivers based on weather impacts.

We are seeking feedback from New Mexico DOT personnel on the potential use of VSL. Your participation in this survey is voluntary and you may stop the survey at any time.

1. What is your overall impression of variable speed limits (VSL) use?

Will not even consider	Not positive	Positive	Somewhat positive	Very positive
☆	☆	☆	☆	☆

2. What is your general impression of VSL? Particularly, maintenance needs or requirements.

3. What do you think would be the main **challenges** with setting up and maintaining VSL in New Mexico?

4. What institutional and policy hurdles could you envision encountering if implementing VSL?

5. If VSL is implemented, would you use it for;

- ☐ Congestion
- ☐ Work Zones
- ☐ Weather
- ☐ Improve safety
- ☐ Other (please explain)

Thank you for participating in this survey!

APPENDIX C - LIST OF ACRONYMS

AASHTO – American Association of State Highway and Transportation Officials
ATDM – Active Traffic and Demand Management
ATIS – Advanced Traveler Information System
AZDOT – Arizona DOT
CCTV – Closed-Circuit Television
CFM – Crash Modification Factor
CMS – Changeable Message Sign
DMS – Dynamic Message Sign
DOT – Department of Transportation
DPS – Department of Public Safety
DSFS – Dynamic Speed Feedback Sign
DUST – Dual Use Safety Technology
FHWA – Federal Highway Administration
HOT – High Occupancy Toll
HOV – High Occupancy Vehicle
ITD – Idaho Transportation Department
ITS – Intelligent Transportation System
KDOT – Kansas DOT
LED – Light Emitting Diode
MnDOT – Minnesota DOT
MOR – Meteorological Optical Range
MP – mile post
MPH – Mile Per Hour
NCHRP – National Cooperative Highway Research Program
NJTA – New Jersey Turnpike Authority
NRITS – National Rural Intelligent Transportation System Conference
PA – Project Assessment
PBPN – Prairie Band Potawatomie Nation
PDMS – Portable Dynamic Message Sign
RWIS – Road Weather Information System
SHRP – Strategic Highway Research Program
TMC – Traffic Management Center
TOC – Traffic Operation Center
TRB – Transportation Research Board
TRIS – Transportation Research Information Services
TRT – Transportation Research Thesaurus
TTI – Texas Transportation Institute
UPA – Urban Planning Agreement
UTC – University Transportation Center
VMS – Variable Message Sign
VSL – Variable Speed Limit
WHP – Wyoming Highway Patrol
WSDOT – Washington State DOT
WTI – Western Transportation Institute
YDS - Yards

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