Synthesis of Variable Speed Limit Signs

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16. Abstract
Variable speed limit (VSL) systems utilize information on traffic speed, occupancy, and volume detection, weather, and road surface conditions to determine the appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions. The use of VSL during less than ideal conditions, such as heavy traffic and adverse weather, can improve safety by decreasing the risks associated with traveling at speeds that are higher than appropriate for the conditions and by reducing speed variance in traffic. In addition, VSL can be used to dynamically manage speeds during planned (rush hour congestion) and unplanned (incidents) events. Used in conjunction with managed lanes and other active traffic management strategies, VSL can respond to downstream congestion to eliminate or delay bottlenecks and mitigate the possibility of crashes.
Based on a comprehensive literature review along with agency interviews to gather information on existing, deactivated and planned VSL systems, this synthesis provides a comprehensive review of current practices on VSL operations, particularly experiences from deployments in the United States, and to identify successful and best practices from the following perspectives: planning and policy, design, deployment, and standards, operations and maintenance, and outcomes.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
In.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in.^{2}	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1,000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in.^{2}	poundforce per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003).

SI* (MODERN METRIC) CONVERSION FACTORS (CONTINUED)

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	$in.^2$
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003).

Table of Contents

Table of Contents (Continued)

List of Figures

List of Tables

List of Acronyms

ATM	active traffic management
ATMS	active/advanced traffic management system
ATSMS	active traffic safety management system
CAV	connected automated vehicle
CMS	changeable message sign
CCTV	closed-circuit television
CV	connected vehicle
DOT	department of transportation
FHP	Florida Highway Patrol
ITS	intelligent transportation system
HOT	high occupancy toll
HOV	high occupancy vehicle
MOE	measures of effectiveness
MUTCD	*Manual on Uniform Traffic Control Devices*
RWIS	road weather information system
TMC	transportation management center
TMC PFS	Transportation Management Center Pooled Fund Study
VMS	variable message signs
VSL	variable speed limit

EXECUTIVE SUMMARY

Variable speed limit (VSL) systems utilize information on traffic speed, occupancy, volume detection, weather, and road surface conditions to determine the appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions. The use of VSL during less than ideal conditions, such as heavy traffic and adverse weather conditions, can improve safety by decreasing the risks associated with traveling at speeds that are higher than appropriate for the conditions and by reducing speed variance among vehicles. In addition, VSL can be used to dynamically manage speeds during planned (rush hour congestion) and unplanned (incidents) events. Used in conjunction with managed lanes and other active traffic management (ATM) strategies, VSL can respond to downstream congestion to eliminate or delay bottlenecks and mitigate the possibility of crashes.

VSL has been successfully implemented in Europe since the 1960s, with deployments in countries such as the Netherlands and Germany generating significant benefits. While the United States has deployed VSL systems for safety purposes over a few decades, during the past 15 years there has been a renewed interest in expanding VSL use among the States in order to achieve operational benefits.

PURPOSE OF REPORT

The purpose of this synthesis report is to provide a comprehensive review of current practice on VSL operations, particularly experiences from deployments in the United States, and to identify successful and best practices from the following perspectives:

- Planning and policy.
- Design, deployment, and standards.
- Operations and maintenance.
- Outcomes.

METHODOLOGY

The research team conducted a comprehensive literature review along with agency interviews to gather information on existing, deactivated and planned VSL systems. Literature reviewed included published research, policy, and operating documentation from departments of transportation (DOT) and cooperating law enforcement agencies, and public-facing outreach material, such as websites. Thirteen agencies were identified for interview; the research team established a list of questions and conducted the interviews via telephone.

KEY RESULTS

Several VSL systems have been implemented successfully in the United States for congestion-based active traffic management, work zones, and weather. The research team identified the current state of the practice, lessons learned, and best practices from implementations to date. Key findings:

- VSL planning processes should use the systems engineering process to clearly identify and communicate objectives, requirements, and anticipated costs/benefits.
- VSL infrastructure requirements generally include changeable speed limit signs, weather/environmental sensors, traffic speed/volume sensors, and communications equipment to transmit data. Infrastructure repair and replacement is a considerable cost that should be recognized early. Durable signing is especially important to maintaining a functional system.
- Selection of speed control algorithms greatly depends on the primary functional requirements. The success of VSL systems relies to a significant degree on driver compliance, and therefore it is essential that regulatory systems are consistently enforced. However, in real-world deployments, particularly those in the United States, many systems are still advisory or cannot be enforced as intended.
- Dynamic speed limit setting control algorithms can be difficult to calibrate due to data quality or delays and driver behavior. Agencies should anticipate the need for periodic adjustment and enhancement of algorithms over time based on observed roadway and driver characteristics.
- In most cases, VSL implementations can generate preferential system benefits in terms of traffic efficiency and safety. Because VSL systems have different deployment goals and corresponding system design, varying system benefits result. Speed homogenization projects usually use simple algorithms in response to real-time traffic, road, and other conditions (e.g., weather, work zone, incidents, visibility, etc.), and they usually focus more on safety. Multi-objective projects, mostly as a part of ATM systems, report positive effects on mobility, safety, and even environmental impacts.
- State and local statutes and agency policies should ensure that a VSL system is enforceable if a regulatory speed limit is desired. It is also beneficial to begin meeting with law enforcement partners early to discuss concerns and processes for enforcing the VSL system, if enforcement is required.
- When calculating the system's cost, maintenance, operations, staffing, evaluations, and end-of-life replacement costs must be considered.
- Future deployments of VSL/speed harmonization could incorporate emerging connected/automated vehicle technologies; real-time collection, storage, processing, and decision-making using emerging big data sources will be necessary for the next generation of VSL/speed harmonization systems.

CHAPTER 1. INTRODUCTION

SHORT DESCRIPTION

The advancement of technological solutions in surveillance and control systems for traffic operations has led to significant reductions in the cost of implementing actively managed components of transportation systems. The benefit of these systems, particularly on highway-grade facilities, can be substantial. A few deployments have demonstrated the success of active traffic management (ATM) strategies. Recent studies conducted in Europe found that ATM applications have resulted in up to 22 percent of capacity increases and 30 percent of incident reductions. The key component in many of these actively managed systems is the variable speed limit (VSL) system. While the United States has installed VSL systems as far back as the 1960s on systems such as the New Jersey Turnpike, there has been a renewed interest in expanding their use in the United States during the past 15 years in order to achieve both operational benefits as well as proven safety benefits. The level and amount of positive impacts, however, vary from site to site, and there is a great interest in understanding the actual benefits under different operational scenarios.

Variable speed limits are typically installed on interstate highways or high-speed arterials and are used for three primary functions that can improve safety and operations: reducing congestion, reducing speeds during inclement weather, and managing speeds during traffic events such as work zones and incidents. Depending on State statutes and policies, speed limits can be either regulatory or advisory. Agencies use various data to inform the appropriate speed limit for current conditions. Using VSL, agencies can take into account a variety of conditions such as traffic volume, operating speeds, weather information, sight distance, and roadway surface conditions when posting speed limits. This data is typically transmitted to a transportation management center (TMC) and analyzed automatically with an algorithm or reviewed by agency personnel who make decisions about the speed limit. Some agencies use systems that will automatically change the speed limit based on the data received and others use data monitoring by personnel to change the speed limit manually. A majority of agencies use a hybrid approach with the VSL updating automatically supplemented with oversight by agency staff that have the option of overriding the automated system to manually change the speed limit when warranted.

VSL provides many benefits for improving roadway safety and operations. The use of VSL systems to manage speed during inclement weather or other challenging driving conditions can improve safety by decreasing the risks associated with traffic moving at speeds that are higher than appropriate for the conditions. In addition, VSL can dynamically manage speeds during planned (rush hour congestion) and unplanned (incidents) circumstances. Used in conjunction with managed lanes and other ATM strategies, VSL can help eliminate or delay bottlenecks and mitigate the possibility of rear-end, sideswipe, and other collisions generally associated with slowed traffic on high-speed roadways.

HISTORY AND PREVIOUS RESEARCH

VSL has been successfully implemented in European countries for several decades, and deployments in countries such as the Netherlands and Germany have shown significant benefits. In Germany, VSL (i.e., speed harmonization) systems have been deployed since the 1960s, with installations on about 124 miles of highway. Germany's experiences show that VSL has the potential to decrease crash rates and increase road capacity by five to 10 percent. The Netherlands has implemented VSL since the 1970s in order to manage traffic speed, mitigate effects of extreme weather, and improve safety. The United Kingdom has implemented VSL and hard shoulder running on the M-42 motorway. An evaluation over a 12-month period showed the application of VSL and hard shoulder running resulted in seven percent increase in capacity, a 4 to 10 percent decrease in pollutants, and a 4 percent drop in fuel consumption.

In the United States, Michigan and New Jersey were the first two States to implement VSL. Speed limits at these two pioneer VSL sites were adjusted manually according to traffic conditions observed by traffic operations staff. Since 1990, VSL use in the United States has increased dramatically, with a renewed interest in expanding functionality to achieve operational benefits. VSL system complexity, in terms of infrastructure, signing, real-time detection and control algorithms, has significantly increased.

Over the years, agencies and researchers have published reports evaluating the effectiveness of VSL systems. Lu et al. (2014) and Ma et al. (2016) are two examples of comprehensive reviews of VSL speed control algorithms and resulting benefits from deployed systems. Generally, these systems have been proven effective in one or multiple performance measures on traffic efficiency, safety, and environmental impacts, depending on project characteristics such as deployment goals and speed control algorithms. These reviews, however, rely only on published reports and focus heavily on academic research. Many important issues such as VSL planning, policy, standards, design, and maintenance are not addressed systematically in these or other existing literature on VSL or ATM. This synthesis has been developed to provide a more comprehensive review of VSL by using agency interviews and additional internal agency documents to complement material from published reports.

CHAPTER 2. RESEARCH METHODOLOGY

The research team used two methods to collect information for analysis on existing policies, procedures, and practices by highway transportation agencies on variable speed limit (VSL) systems. A literature review compiled information from resources such as published research, dissertations, presentations, guidelines, and other relevant publications. To supplement the literature review, agencies operating VSL were interviewed to gather descriptions of their systems and background information on lessons learned. This report reviews all VSL systems but uses those that have been investigated through both a literature review and agency interviews as examples when discussing different VSL system components.

LITERATURE REVIEW

The research team conducted a comprehensive literature review using a variety of resources. This literature review included published research related to VSL planning, policy, and operations; resources obtained from operating agencies, policy manuals, operating documentation from operating and law enforcement agencies, and documentation directly related to VSL-instigated legislative action on speed limits; and additional public information campaign materials, such as web sites, that are used to interact with the public. The team reviewed VSL sites in the United States and other countries. A list of most relevant references is shown in Appendix A.

AGENCY OUTREACH

In addition to the literature review, the research team selected representative VSL systems that are currently active and collected VSL data from corresponding agencies directly. The team documented how agencies are operating their respective VSL systems and their experiences using this particular traffic management strategy by interviewing agency representatives and reviewing various documents provided by highway transportation agencies. During the process of contacting agencies, the team identified some States that are considering VSL systems as well as those that have deactivated their VSL systems. Information collected from these agencies was documented as well.

The data collection methods included phone interviews with agency staff and a review of various VSL documents and materials (e.g., video clips, reports, presentations, operations documents, etc.) provided by the agencies. The research team used the following resources to identify agencies using VSL systems:

- Results of the literature review.
- Historical information from Guidelines for the Use of Variable Speed Limit Systems in Wet Weather.
- Members of the Transportation Management Center Pooled Fund Study (TMC PFS).
- Personal knowledge of the research team.

The research team interviewed 13 agencies about their VSL systems, 9 of which currently have active VSL systems. In addition to the phone interviews, the team also obtained VSL documents from nine agencies. These documents include VSL activation procedures, operations manuals, equipment/software specifications, signing protocols, algorithms, checklists, and internal/external educational materials. Table 1 summarizes the data sources.

Table 1. Summary of variable speed limit data sources.

Agency	Conducted Phone Interview	Provided Documents Used in Synthesis
Arizona Department of Transportation (DOT)	Yes	N/A
Florida DOT	Yes	Yes
Georgia DOT	Yes	Yes
Minnesota DOT	Yes	Yes
Missouri DOT	Yes	N/A
Nevada DOT	Yes	Yes
New Jersey Turnpike Authority	Yes	Yes
Oregon DOT	Yes	Yes
Pennsylvania Turnpike	Yes	N/A
Tennessee DOT	Yes	Yes
Virginia DOT	Yes	Yes
Washington State DOT	Yes	Yes
Wisconsin DOT	Yes	N/A

N/A = not applicable (no variable speed limit systems).

The research team requested information in the following categories to gain a comprehensive description of each agency's VSL system:

- Planning and policies.
- Design, deployment, and standards.
- System operations and control.
- Maintenance and lifecycle costs.
- Costs and benefits.
- Liability issues.
- Enforcement issues.

To perform the interviews, the research team developed a list of questions and classified each as key or auxiliary. In consideration of agency staff time, interviews were scheduled to last 30 minutes. During that time, the key questions were discussed first with the intention of collecting information on the auxiliary questions from agency-provided documents. Time permitting, some auxiliary questions were discussed during the calls as well. On some occasions, agencies provided feedback to the full set of questions and/or emailed supporting documents prior to a phone interview. These instances provided the team with an opportunity to become familiar with the agency's VSL system to better tailor the phone discussion. The interview questions were not generally provided to an agency, but the interviews were completed by project team members using a form and gathering as much information possible during each interview. A summary of each interview is included in Appendix B. Agency Interview Summary.

SYNTHESIS AND ANALYSIS

Both during and following each interview, all State representative responses were compiled and recorded in an Excel spreadsheet, which served as the research team's main database. This database allowed the team to organize all responses into categories (e.g., general VSL information, setting speed limits, equipment and costs, enforcement, VSL signs, etc.). After all responses were appropriately categorized, the information was synthesized and incorporated in the appropriate sections of the final report. Additional documents provided by various agencies were also utilized to better understand and describe VSL systems located throughout the United States.

CHAPTER 3. VARIABLE SPEED LIMIT STATE OF THE PRACTICE

REPRESENTATIVE VARIABLE SPEED LIMIT SYSTEMS IN THE UNITED STATES

Variable speed limit (VSL) systems have been widely used in many of the States for various functional purposes. Table 2 briefly summarizes each focused VSL system that is investigated thoroughly through the literature review and agency interview. Note that planned and removed systems are not included in this table, although they are discussed throughout the report.[1] The "Primary Functions" column may include any of the following descriptions:

- Congestion: includes speed/incident management-related issues.
- Weather: includes visibility/pavement condition-related issues.
- Work zones.

Note that some systems may include only VSL while others may include additional traffic management techniques (e.g. variable message signs (VMS), dynamic shoulder lanes, ramp metering, etc.).

Table 2. Description of the variable speed limit systems considered in the report.

State	Location	Length of System (miles)	Status	Authority	Operation Type	Primary Functions
Florida	I-4	10.5	Active	Regulatory	Hybrid	Congestion
	US 27	3	Active	Regulatory	Automated	Congestion
Georgia	I-285	36	Active	Regulatory	Hybrid	Congestion, Work Zones
Minnesota	I-35W	18	Temporarily Deactivated	Advisory	Automated	Congestion
	I-94	10	Temporarily Deactivated	Advisory	Automated	Congestion
Nevada	US 395 Alternate	5	Active	Regulatory	Automated	Weather (wind)
New Jersey	NJ Turnpike	148	Active	Regulatory	Manual	Congestion, Weather

1 The VSL systems included in this synthesis are a snapshot in time as of January 2016. A more comprehensive listing of all known planned and existing VSL systems is available at the Federal Highway Administration's Active Transportation Demand Management Program website at http://www.ops.fhwa.dot.gov/atdm/approaches/adm_table/index.htm.

Table 2. Description of the variable speed limit systems considered in the report. (Continued)

State	Location	Length of System (miles)	Status	Authority	Operation Type	Primary Functions
Oregon	OR 213	Single intersection	Active	Regulatory	Hybrid	Congestion
	OR 217	7	Active	Advisory	Automated	Congestion, Weather
Tennessee	I-75	9	Active	Regulatory	Hybrid	Weather (fog)
Virginia	I-66	13	Active	Advisory	Automated	Congestion, Work Zones
	I-95 Express Lanes	~10	Active	Regulatory	Manual	Congestion
Washington	I-90 (near Snoqualmie Pass)	25	Active	Regulatory	Hybrid	Weather
	US 2	23	Active	Regulatory	Hybrid	Weather
	I-5	8	Active	Regulatory	Automated	Congestion
	I-90 (Bellevue to Seattle)	10	Active	Regulatory	Automated	Congestion
	SR 520	8	Active	Regulatory	Automated	Congestion

VARIABLE SPEED LIMIT SYSTEMS USED FOR CONGESTION-BASED ACTIVE TRAFFIC MANAGEMENT

VSL systems used for congestion-based active traffic management (ATM) are sometimes referred to as “speed harmonization systems.” The purpose of speed harmonization is to dynamically and automatically reduce speed limits in or before areas of congestion, accidents, or special events to maintain flow and reduce the risk of collisions due to speed differentials. They are usually used in conjunction with other ATM strategies such as queue warning and hard shoulder running. Note that the speed limits for VSL systems used for congestion are generally updated every 30 seconds to 15 minutes. An interval of 1 to 5 minutes was found to be the most common practice.

A regulatory, hybrid VSL system was installed along I-4 in Florida in order to efficiently manage the large volumes of traffic that regularly utilize this corridor. The system is 10.5 miles long, and there is currently no plan to change the length. This system was not built to manage traffic based on weather conditions, rather the main focus of the VSL system is to improve speed harmonization. VMS are used in conjunction with VSL to display relevant information to drivers along the roadway. Loop detectors and side-fire radar are used to collect various traffic data. The VSL system then uses this data to recommend an appropriate speed limit which can be based on the current speeds, volume, capacity, roadway geometry, etc. The operator may then accept or alter the system’s recommended speed limit.

The VSL system along US 27 in Florida is 3 miles long, regulatory, and automated. Much like the VSL system located on I-4 in Florida, the US 27 VSL system uses loop detectors and side-fire radar to determine appropriate speed limits; however, no VMS is used along the corridor. The US 27 system was installed to improve safety by lowering vehicular speeds surrounding a school zone, thereby, reducing collisions and associated congestion levels. Note that there is presently no plan to alter the length of the VSL system on US 27.

A VSL system was also installed on I-285 in Georgia, where sensors capture volume and speed information to calculate appropriate speed limits based on current traffic conditions. Although the 36 mile, regulatory VSL system is fully automated, manual override may occasionally be necessary to properly handle more complex situations (e.g. work zones, etc.), which is discussed in the "Variable Speed Limit Systems Used for Work Zones" section below. Note that weather conditions are not included in the VSL algorithm.

The first deployment of VSL in Oregon was for a single intersection along Oregon Route (OR) 213, west of downtown Portland. This regulatory, hybrid system is still active due to its success, and it aims to regulate traffic and reduce congestion levels at the intersection. Note that this VSL system utilizes a single, side-mounted sign.

The advisory system along OR 217 utilizes current traffic and existing weather conditions to automatically calculate and display variable speed limits, warn of queues ahead, and estimate travel times. The final displayed speed limit depends on which piece reports the most needed condition change (weather vs. congestion). OR 217 is divided into various subzones where radar and dual loops are utilized to capture real-time speed data. The displayed speed in each subzone is calculated as the lower of these two values: 1) 85th percentile speed, or 2) speed of downstream traffic +5-10 mi/h (Mitchell, 2016). In addition to the VSL system on OR 217, the Oregon Department of Transportation (DOT) has installed active, weather- and speed-based curve warning systems at both ends of the corridor. Note that the weather-related algorithm for OR 217 is discussed in the "Variable Speed Limit Systems Used for Weather" section below**.**

The 13-mile, automated, advisory VSL system along I-66 in Virginia was installed to manage the high volumes of traffic and related congestion issues existing along the corridor. Note that the system is also capable of regulating traffic surrounding work zones, which is discussed in the "Variable Speed Limit Systems Used for Work Zones" section below**.** The speed limits are determined by a smoothing speed algorithm, which establishes the current lowest speeds along the roadway and appropriately slows upstream traffic. In addition to the VSL signs, VMS are used to display vital information to drivers (e.g., "Congestion ahead," etc.). Lane availability is also displayed along I-66 to designate which lanes are open and which lanes are closed to traffic. There is no plan to extend the current VSL system along I-66 mostly because there are already significant proposed geometric changes along the roadway. The Virginia DOT does not want to invest in more traffic flow technology until those changes are known.

The VSL system on the I-95 Express Lanes was operational in December 2014. The manual, regulatory VSL system is approximately 10 miles long. The purpose of the VSL system along the I-95 Express Lanes is to control congestion. The I-95 Express Lanes also include high occupancy toll (HOT) lanes and lane management functionality (Earnest, 2015).

The statewide, 148-mile, regulatory VSL system along the New Jersey Turnpike used to be automatic but is currently manual due to the level of sensor maintenance required after repaving. The system is used to relieve congestion and also accounts for weather conditions. Note that the weather-related portion is discussed in the "Variable Speed Limit Systems Used for Weather" section below**.** In general, the speed limit is manually reduced to 45 mi/h in response to a downstream incident, except when poor weather conditions are a factor. VMS are posted next to the VSL to explain the reasoning behind the speed alteration.

The automated, regulatory VSL systems along I-5, I-90 (Bellevue to Seattle), and SR 520 in Washington uses the same method to alter speeds. Downstream conditions are assessed, and the speed limits are updated every minute based on the results of the traffic evaluations. The posted speed limits may vary across lanes and throughout the corridor, although currently the system only allows differences between the HOV lane and General Purpose lanes and not between individual General Purpose lanes. In addition, VMS are used in conjunction with VSL within all three systems. Currently, there is no plan to expand or decrease the length of any of the VSL systems in Washington (I-5, I-90 (Bellevue to Seattle), and SR 520). If there are expansion or contraction plans in the future, the Washington State DOT will base that decision on engineering judgment rather than public opinion.

VARIABLE SPEED LIMIT SYSTEMS USED FOR WORK ZONES

The VSL system on I-66 in Virginia is used not only to relieve congestion, but also to regulate traffic surrounding work zones. Relevant information and warnings related to work zones are displayed on VMS message boards along the corridor. In addition, overhead lane-use-control signs are used to denote lane availability (a green arrow is displayed when the lane is open to all traffic, and a red "X" is displayed when the lane is closed to all traffic), which is especially useful for traffic surrounding work zones.

The VSL system located along I-285 in Georgia also accounts for work zones. Roadway construction is typically performed at night when traffic is lighter which consequently results in faster speeds. Georgia DOT will manually adjust the VSL when needed to reduce speeds in work zone areas.

Note that a temporary VSL system was installed along the Woodrow Wilson Bridge, but the Virginia DOT removed the system once all construction tasks were complete. This system is also discussed in the "Deactivated Variable Speed Limit Systems in the United States" section below.

VARIABLE SPEED LIMIT SYSTEMS USED FOR WEATHER

The Nevada DOT selected US 395 in Reno for the State's first VSL implementation. The highway parallels I-580 and functions as an alternate route when the interstate is closed for high winds. The VSL system is approximately 5 miles long, automated, regulatory, and activates based on wind speeds. The system has experienced some hardware/software issues related to signing such as blank signs and inconsistent posted speed limits. Therefore, the Nevada DOT is considering a temporary deactivation of the system in order to improve overall functionality.

The manual VSL system located on the New Jersey Turnpike accounts for both congestion and weather conditions. The weather-related algorithm primarily focuses on visibility. Operator guidelines are provided to determine the appropriate speed limit based on the number of visible mile markers from a stationary location (e.g., 35 mi/h is used when three mile markers are visible, etc.).

The OR 217 advisory, automated VSL System not only accounts for congestion levels, but it also accounts for current weather conditions. As mentioned previously, the final displayed speed limit depends on which piece reports the most needed condition change (weather vs. congestion). The weather-related algorithm calculates appropriate speed limits based on data collected from friction factor sensors. The weather-responsive system considers many variables (e.g. visibility, grip factor, surface condition, etc.) to determine the warning message displayed to drivers.

The Tennessee DOT installed a regulatory, hybrid, weather-responsive VSL system along I-75 in Chattanooga, Tennessee. The system is approximately 9 miles long, and the Tennessee DOT does not currently plan to alter the length of the VSL corridor. Speeds are calculated based on current visibility due to fog conditions. This system reliably and instantly provides speed reduction to drivers along I-75 using environmental sensors which monitor current weather conditions. A single speed is set for the entire corridor, and a single display is used for all lanes at a particular location.

The Virginia DOT is currently designing a regulatory, weather-responsive VSL system to regulate traffic along I-77. The proposed system will be 15 miles long, and there is no current strategy to alter the length of the planned VSL system along I-77. The system will be located in the Fancy Gap Area, which is rural and has low traffic volumes. Speed limits will be determined based on available visibility levels captured by very reliable sensors. The majority of the signing will be VMS, which will post messages related to speed limits and/or traffic management.

There are two active, hybrid, and regulatory VSL systems used for weather-related issues in Washington State: I-90 (near Snoqualmie Pass) and US 2, which are 25 and 23 miles long, respectively. Currently, there is no plan to expand or decrease the length of either weather management system in Washington. A look-up table is used for both systems to manually determine the appropriate speed, which accounts for current pavement conditions, visibility, weather (i.e. rain, snow), and incidents. The VSL system also utilizes reliable sensors to calculate travel times based on speed converted from occupancy measurements. Signing is located on the roadside and/or overhead along I-90 (near Snoqualmie Pass). In contrast, all VSL signing is located on the right side of the highway along US 2.

DEACTIVATED VARIABLE SPEED LIMIT SYSTEMS IN THE UNITED STATES

The Missouri DOT installed a regulatory VSL system on I-270 in St. Louis. Law enforcement reported that they were uncertain of current speed limits and consequently reluctant to enforce the VSL. In response, the system was changed to advisory, but driver compliance became an issue so the system was ultimately deactivated.

A hybrid VSL system was installed on the Woodrow Wilson Bridge along I-95 to regulate traffic during construction operations. However, the system was removed once construction was complete and the work zone was no longer necessary.

Minnesota DOT has temporarily turned off the VSL systems installed on I-35W and I-94 in the Minneapolis/St. Paul area. Both systems were advisory and operated automatically, but the lag in real-time data was an issue. Speed limits were determined using the average of data sent from single loops every 30 seconds. The time to do the math to get the average speed slowed down a change in speed limits based on current conditions. If the VSL systems are reactivated, Minnesota DOT will most likely decrease the length of the corridors. Due to maintenance issues with the signs, Minnesota DOT is considering either replacing them in kind or installing a single overhead sign as opposed to lane-by-lane signage. This would reduce the cost of installation as well as maintenance and operations costs.

LESSONS LEARNED

Agency staff offered insights into important lessons their organizations learned from their experience with VSL systems (Table 3). Advice was related to overall design, algorithm, and infrastructure.

Table 3. Lessons learned by State agencies from variable speed limit implementations.

Washington State Department of Transportation (DOT) emphasized the importance of following the systems engineering process when designing variable speed limit (VSL) systems; let the corridor goals drive the operation needs, let the operation needs drive the system requirements, and let the system requirements drive the specifications. In addition, it is vital that all speed reductions be warranted and never without reason.
Florida DOT mentioned a few lessons they have learned from the VSL system along I-4: 1) improved signing is necessary for comprehension and compliance, 2) overhead signs are ideal, and 3) involving law enforcement officials is key to observe compliance. The Florida DOT also stressed the importance of investing in durable signing that will not fade due to sunlight exposure and will remain comprehensible to drivers.
The Nevada DOT suggests "starting small" when implementing VSL for the first time. The VSL corridor along US 395 in Reno was selected since it is a smaller urban area (as compared to Las Vegas, for example), experiences lower traffic volume, has less exposure to public and media attention, and the VSL could be incorporated with a larger wind-warning system operated by the State DOT. Starting small has helped the agency learn the ins and outs of operating a VSL without encountering significant consequences (such as negative media coverage) that could impact future implementation.
The Oregon DOT noted that developing a VSL algorithm is incredibly challenging. The hardest aspect is generating a system that alters speed in a way that feels natural to drivers. Speed recovery from a reduced speed is one of the most difficult situations to code, and multiple iterations are necessary to develop a system that can be modeled to closely replicate human behavior while also incorporating the impacts of horizontal and vertical curvature, pavement conditions, weather, and other factors. The Oregon DOT also mentioned that they are willing to share their algorithm with other States upon request.

Table 3. Lessons learned by State agencies from variable speed limit implementations. (Continued)

The Oregon DOT also stated that a successful VSL deployment in any State will require a qualified professional who understands the algorithm and who is available on a regular basis for the first 6 months to 1 year of deployment for algorithm enhancement. Necessary algorithm alterations will largely depend on the characteristics of the surrounding area and types of drivers utilizing the VSL.
The Virginia DOT highlighted one particularly difficult challenge when developing a speed setting algorithm: there are competing constraints between the assigned "safe speed" and actual driver behavior since many drivers travel much faster than the posted speed limit. When calculating a suitable VSL, the goal is to display a speed that is safe for travelers but also will not create increased variance.
Depending on how the VSL system is designed to operate, a single overhead sign, as opposed to lane-by-lane signage, can reduce installation, maintenance, and operations costs.
To encourage enforcement, discuss citation options with law enforcement. Instead of tying citations to a specific speed limit, law enforcement may be able to use other types of citations such as driving too fast for conditions.
Include additional information to help motorists understand the reason for the speed change. For example, use a changeable message sign to display messages such as SLOW TRAFFIC AHEAD.

CHAPTER 4. FINDINGS

As a component of active traffic management (ATM), variable speed limit (VSL) systems are subject to a systems engineering process[2] and are generally operated under a set of rules from a concept of operations document. In addition to planning the technical components of the system, VSL operators must also consider policy implications related to administrative law, case, and law enforcement priorities and policies. The system management includes operations, maintenance, performance monitoring, and coordination with partners, including law enforcement, private roadside assistance services, and external partners who may request VSL implementations for special events. There are several considerations related to systems management that have been learned from past implementations.

PLANNING AND POLICY

Rationale

States have various reasons for implementing traffic control systems (e.g. managing traffic in congested areas and following roadway incidents, altering speeds due to current weather and/or visibility conditions, controlling traffic surrounding work zones, modifying speeds based on pavement conditions, etc.). A few examples of varying rationales are discussed below.

The Oregon Department of Transportation (DOT) chose to implement VSL along OR 217 due to large crash rates on the roadway (more than 230 crashes/year). Half of the crashes occurred in peak traffic hours, and rear-end collisions accounted for 70 percent of the crashes (Mitchell, 2016).

The VSL system along US 27, a two-lane, divided, rural roadway in Florida, was installed to control high vehicular speeds surrounding a school zone. The goal of the VSL system was to increase safety by better controlling the traffic surrounding the school in both directions.

The Virginia DOT considered utilizing ATM, including VSL, along I-66 to increase safety, decrease congestion, and improve environmental sustainability along the corridor. With these overall objectives in mind, various stakeholders brainstormed specific goals for the system, which included reducing the quantity and severity of collisions, decreasing travel times, increasing system reliability, improving safety surrounding construction zones, enhancing communication tactics to provide vital information to drivers, and lowering vehicle emissions and fuel consumption. (Iteris, Inc., 2011).

2 The International Council on Systems Engineering defines systems engineering as an interdisciplinary approach that focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. For more information on systems engineering and the Federal Rule for intelligent transportation system projects, visit http://ops.fhwa.dot.gov/int_its_deployment/sys_eng.htm.

The Virginia DOT is currently designing an active traffic safety management system (ATSMS) for I-77 due to two major incidents that occurred because of heavy fog conditions along the corridor. In 2005, 26 people were injured and 1 person was killed when approximately 50 vehicles collided due to extreme fog conditions. In 2010, another incident involving 70 vehicles occurred due to intense fog, where 16 people were injured and 2 people were killed. In addition, the crash in 2010 negatively impacted the economy, costing about $8 million. Following these crash events, the Virginia DOT decided to implement various traffic control methods to improve safety along the roadway by decreasing the magnitude and severity of collisions due to weather conditions (URS, 2012).

While it has not employed VSL systems, the Arizona DOT is currently in the process of designing a VSL system to counteract the State's problem with dust storms. This issue occurs at a specific location in Arizona that is heavily impacted by such storms due to the area's terrain and surrounding land uses. Arizona DOT is hopeful that the VSL system will increase safety along the roadway. If successful, Arizona DOT would consider implementing other VSL systems in more northern areas of the State which are negatively impacted by snow. Further information regarding Arizona's future VSL plans may be found in Appendix B.

Nevada DOT installed a VSL system on US-395 to reduce speeds during high wind events. The VSL is part of a larger wind-warning system and is tied to two road weather information systems (RWIS). One RWIS is located on the northern end of the valley and the other is located on the southern end. High wind speeds have a history of blowing over high profile vehicles on I-580. Therefore, once the wind is high enough, I-580 is closed and vehicles are redirected onto US-395. However, the wind can also affect vehicles on the alternate route, so a VSL system was installed to reduce speeds when warranted by conditions. Typical speed limits on US-395 are either 55 mi/h or 50 mi/h. When one of the RWIS measures a 30 mi/h wind gust, the VSL is activated and all speeds are lowered to 45 mi/h. At least 30 minutes must pass without a 30+ mi/h wind gust measurement from either RWIS before the speed limits can return to 55 mi/h or 50 mi/h.

Initiation Process

One of the first steps in the planning process for the I-66 ATM system was to identify user needs. In order to determine these needs, the Virginia DOT held multiple meetings and forums with various stakeholders to gain their input regarding system design and then summarized these conversations in a Technical Consensus Memorandum. The identified needs were then transformed into overall project goals and objectives that would shape the final design of the system (Iteris, Inc., 2011).

At the beginning of the planning process for the system along I-77, the Virginia DOT identified eighteen specific stakeholders and summarized the roles and responsibilities of each once the system is activated. The roles and responsibilities were categorized as (URS, 2012):

- Responsible (those that work with intelligent transportation system (ITS) devices themselves).
- Accountable (those that can allow or reject operational decisions).
- Consulted (those that provide insight to others in the Responsible/Accountable groups).
- Informed (those that should always be updated and notified of system functionality).

The Virginia DOT outlined the I-77 project goals based on former traffic incidents and previously completed safety studies, which focused on quantifying and categorizing collisions that occurred along the I-77 corridor. Stakeholders and countermeasures were discussed in these past studies; therefore, the Virginia DOT could apply any relevant findings/conclusions from these studies to the I-77 design plan. In addition to defining stakeholders, project goals and objectives were developed, and Measures of Effectiveness were outlined based on the project objectives. A list of potential countermeasures was also developed based on past research studies along I-77. The final, selected countermeasures were determined following various consultations with stakeholders/Virginia DOT employees and further study of the I-77 corridor (URS, 2012).

Overarching Design and Operations Considerations

Currently, the VSL system along the NJ Turnpike is manually operated; however, the system used to be automatic. The automatic system relied on copper inductive loops located in the pavement to gather current traffic data, such as vehicle speed and volume. The automatic VSL system successfully and efficiently managed traffic conditions along the New Jersey Turnpike. However, the automatic system was switched to the current manual system due to the level of maintenance the copper inductive loops required. Any time the roadway was repaved, the inductive loops were damaged and needed to be repaired. Therefore, the system became manual and more reliable sensors (from Sensys) were installed along the roadway. The New Jersey Turnpike Authority noted that the Sensys sensors are very reliable, but they are spaced farther apart than the inductive loops, which creates a slight lag in responsiveness. In addition, sensor reinstallation is still included in all paving contracts to ensure proper sensor functionality. The New Jersey Turnpike Authority is currently working to restore the system's former automatic capabilities in order to increase throughput and efficiency.

Public Outreach

Georgia's first VSL system was activated in September 2014 as a speed management strategy on I-285. Much of the public's reaction was negative, with many believing it to be a new mechanism for generating cash for the State. To help educate the public, the Georgia DOT adopted the slogan of "Slow Down to Get There Faster." They developed an educational video to explain why the VSL system is being implemented, what it is, how it works, and the benefits drivers can expect. The video is posted on a dedicated VSL webpage (Georgia Department of Transportation, 2015) along with other educational information and materials, such as a fact sheet. In addition to the webpage, the Georgia DOT established an email address (VSL@dot.ga.gov) where the public can send their comments.

Minnesota implemented VSL systems on I-35W and I-94, but both are currently turned off. The systems were slow to respond to real-time conditions, which ultimately caused the public to lose trust in the speed limits. Consequently, the systems were turned off and the Minnesota DOT is reevaluating them to make improvements. The Minnesota DOT received very few comments from the public when the VSL were activated. Most questions asked about the meaning of the messages. For example, drivers expressed confusion about whether the displayed speed indicated the speeds ahead or the recommended speed. Of interest, the Minnesota DOT only received two inquiries after the VSL were turned off; both were to ask why the system was off.

Nevada did not use an aggressive public relations campaign before activating the VSL, but a press release was issued. This was due in part to the nature of US 395 serving as an alternate route in a smaller community. Public reaction to the VSL on US 395 has been mixed with positive and negative feedback. The negative responses have primarily been from homeowners because they most often see when issues occur with the signing. For example, hardware problems have caused the signs to go blank. In response to a request by the Highway Patrol, Nevada DOT installed beacons on the VSL signs that flash when the speed changes. Homeowners have complained that the beacons are too bright. To address this issue, the DOT has temporarily disabled the beacons but plans to try a dimmer in the future as a more permanent solution.

When the VSL system was first implemented along OR 217, the Oregon DOT received some feedback indicating driver confusion about speed limit reduction. However, after improving the speed algorithm, public feedback has been positive. The Oregon DOT stressed the importance of public notification about the purpose of the VSL system and why the speed is being reduced.

The Washington State DOT reported that the VSL systems along I-90 (near Snoqualmie Pass) and along US 2 were well-received by the public. However, the public had reservations regarding the VSL systems along I-5, I-90 (Bellevue to Seattle), and SR 520 during the first few months of deployment. But, after refining the algorithm and lowering the speed threshold, the public is now in favor. The Washington State DOT found that during periods of extreme congestion, such as stop-and-go traffic, the public feedback was negative regarding the concept of displaying a system floor threshold speed such as 30 mi/h.

The University of Florida evaluated the VSL system along I-4. Part of their evaluation included a survey that captured driver's opinions of the VSL system. Participant responses indicated that many drivers will not reduce their speed until other drivers begin to slow down as well. Participants also stated that overhead gantries and signing above each lane would be helpful. In addition, survey results showed support for side-mounted VSL signing (Elefteriadou, Washburn, Yin, Modi, & Letter, 2012).

Liability

To date, the team has not identified an agency experiencing issues with liability. Agency processes do include archiving all speed data which can be provided as documentation or evidence of the posted speed limit at any specific time.

Only two VSL systems reviewed noted experience or recommendations for liability issues. Nevada DOT recommended that lawyers should be involved early on in future deployments to evaluate possible tort liability after the VSL implementation on I-80 (Robinson et al. 2002). With respect to the VSL system on I-526 in South Carolina, the system was created due to a court order. A Federal judge ruled that the I-526 Cooper River Bridge construction project must include a low visibility warning system, which included VSL (Goodwin 2003).

DESIGN, DEPLOYMENT AND STANDARDS

Infrastructure Requirements

Agencies report a variety of infrastructure used to operate their VSL systems. These components may differ based on the function of the VSL. Table 4 shows the fundamental VSL elements for a system operating to manage speeds during congestion, weather, and work zones.

Table 4. Fundamental variable speed limit infrastructure requirements.

	Variable Speed Limit Function		
Variable Speed Limit Infrastructure Component	**Congestion**	**Weather**	**Work Zones**
Changeable Speed Limit Signs	✓	✓	✓
Weather/Environmental Sensors		✓	
Traffic Speed/Volume Sensors	✓		✓
Communications Equipment to Transmit Data	✓	✓	✓

Signage Type and Placement

The Florida DOT reported approximately 20 VSL signs along the I-4 corridor. At least one sign is posted every mile, and some signs are located in medians while others are side-mounted along the roadway. I-4 also displays various word messages (VMS) in conjunction with their VSL system. Some VSL signs along US 27 are posted in medians while others are side-mounted. No VMS signs are used along US 27.

Georgia's VSL system includes 176 electronic speed limit signs for an interstate corridor that is 36 miles long (inclusive of both directions). Signs are mounted on both sides of the highway in 88 locations and are spaced every ½-mile to 1 ½-mile.

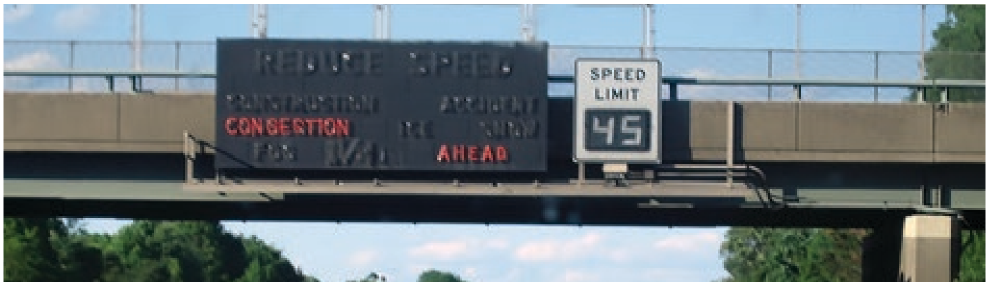
The Minnesota DOT installed 155 signs on I-35W, which is 18 miles long, and 101 signs on I-94, which is 10 miles long. When activated, the State used lane-by-lane overhead signs. Although displays were by lane, each showed the same speed at the same location. The signs are full matrix color CMS that measure 4 feet tall and 5 feet wide. HOT lane signs displayed a white diamond with no speed message. This was enacted to address concerns about displaying different speeds over different lanes, but at the same time not wanting to artificially slow down the speed in the HOT lane. Note that Minnesota did not use word messages in conjunction with the VSL signs.

Due to maintenance issues with the signs, the Minnesota DOT is considering either replacing them or using a single message sign as opposed to lane-by-lane signing. The latter alternative will reduce installation, maintenance, and operations costs. In addition, the Minnesota DOT is evaluating whether a VSL or a simple word message of SLOW TRAFFIC AHEAD is more successful for queue warning in a particular high crash area. It is possible that Minnesota could use the system for spot locations rather than implementing it throughout an entire corridor.

The Nevada DOT system used to lower the speed for trucks so that a long, elevated structure over a canyon can remain open in high winds. Nevada DOT determined the locations of the US 395 VSL signing installations based on locations of intersecting roadways; this permitted trucks to turn off the roadway if extreme winds were encountered, but the bridge remained open to automobile traffic. Signs use embedded LED and are mounted on the right side of the highway.

In addition to the VSL system, VMS are also installed along the New Jersey Turnpike. All VSL signs are posted adjacent to VMS that describe the reason for the speed change, as shown in Figure 1. The following word messages are used to warn drivers of conditions ahead:

- ACCIDENT AHEAD BE PREPARED TO STOP.
- DEBRIS AHEAD DRIVE WITH CAUTION.
- DELAYS AHEAD BE PREPARED TO STOP.
- MOWING OPERATION AHEAD (with tractor image).
- REDUCE SPEED CONGESTION AHEAD.



Source: ToXcel

Figure 1. Photo. New Jersey Turnpike variable speed limit and variable message signing.

Note that VMS along the New Jersey Turnpike are also used to notify drivers when the far right lane can be used as a shoulder (red “X”) and when it is a travel lane (green arrow) during peak travel periods. VSL and VMS are only displayed on message boards that are within 2 miles of the traffic issue (e.g., lane closing, construction site, congestion, etc.). The New Jersey Turnpike Authority noted that the warning messages and altered speed limits remain relevant to drivers when they are not posted too far in advance.

OR 217 in Oregon has a set of VSL signs for each segment. All signs are displayed overhead above each lane with additional VMS for traffic-related messages. The Oregon DOT estimates 40 to 50 signs on the main line plus 30 to 40 VMS signs that display travel time messages prior to entering OR 217. All of the VMS are full matrix and display messages such as CONGESTION AHEAD at a certain distance upstream of the congestion or information related to current weather conditions.

In the Chattanooga, Tennessee area along I-75, there are 10 signs that are right-shoulder mounted with embedded white LEDs for an interstate corridor that is 9 miles long (inclusive of both directions). There is one display for all lanes and signs are located in relation to interstate entrance ramps and *Manual on Uniform Traffic Control Devices* (MUTCD) guidelines. The Tennessee DOT uses a FOG SPEED LIMIT word message on the changeable speed limit sign, which is mounted on the shoulder. In addition, the following word messages are activated on VMS in conjunction with the VSL.

- FOG AHEAD TUNE TO 1620.
- REDUCE SPEED TURN ON LOW BEAMS.
- CAUTION FOG AHEAD.
- FOG AHEAD SPEED LIMIT 50 MPH.
- FOG AHEAD SPEED LIMIT 35 MPH.

Along I-90 (near Snoqualmie Pass) in Washington, VSL sign locations vary depending on the roadway geometry at any given point. Some areas have overhead signing while others have side-mounted signs on both sides of the roadway for each direction. US 2 is an undivided highway, and all VSL signs are located on the right-hand side of the roadway. All of the VSL signs on I-90 (near Snoqualmie Pass) and along US 2 are hybrid cut-out LED speed limit signs. VMS are not utilized in either location.

The signs along I-5, I-90 (Bellevue to Seattle), and SR 520 in Washington are full color and full matrix, and the spacing between gantries is approximately 0.5 miles. The speed limits along these three routes are displayed using specialized graphics files for each message; those files reside locally in the sign controllers and have been created to be identical to the FHWA Standard Highway Signs catalog so that the signs use the FHWA Standard Alphabet in their depictions. This method of providing the sign displays moves beyond text-based displays from typical changeable message sign controller units and into the realm of specialized graphics displays, which could include warning signs and MUTCD-approved symbols in the future. These three locations also utilize word messages in conjunction with VSL.

There are 21 overhead gantries along I-66 per direction, and each gantry holds 3 to 5 signs. VMS are used along I-66 to display messages to drivers in addition to the VSL (e.g. CONGESTION AHEAD, etc.). In addition to the VMS and VSL signing, other devices are also provided along I-66, including closed circuit television (CCTV) cameras, ramp metering, lane management devices, etc. (Earnest, 2015).

There will be 44 side-mounted signs along the VSL corridor on I-77 in Virginia. Thirty-six of these signs will be full matrix, VMS that can post speed limit messages and traffic management messages (e.g. FOG AHEAD, etc.). Eight of the signs will be typical variable speed limit signs where the display speed can dynamically change. Additional devices will include CCTV cameras, visibility sensors, etc.

To control everyday traffic along the corridor, I-66 uses signing to indicate lane availability, especially within and surrounding work zones. VMS are used to display information regarding work zones, and green arrows/red “X” symbols over each lane are used to indicate current lane availability. Work zones are not expected to be an issue along I-77 since it is a rural, low-volume roadway.

Integration with Active Traffic Management and/or Road Weather Information Systems

Several VSL systems were either planned as part of a larger ATM system or integrated with existing ATM or RWIS as a source of data or as a shared backbone for hardware and/or software systems.

The VSL system along I-66 in Virginia is part of a larger ATM that also includes VMS that can display other traffic management messages (e.g., CONGESTION AHEAD). The VSL system on the Pennsylvania Turnpike built off an existing ATM system to consolidate operations and reduce cost. The system used a series of RWIS stations to determine fog conditions. Nevada DOT's VSL relies on data from two separate RWIS stations. Once an RWIS measures a 30 mi/h wind gust, the VSL on US-395 is activated to reduce speeds. The VSL signs do not display normal operating speeds until neither RWIS measures a wind gust of 30 mi/h or more for 30 minutes. On the I-215 VSL in Utah, the DOT cited the lack of integration with the existing ATM as a serious obstacle during implementation.

OPERATIONS AND MAINTENANCE

Control Algorithms

VSL system speed control algorithms have been widely studied in both academic papers and evaluation reports. Lu et al. (2014) and Ma et al. (2016) presented comprehensive reviews of advanced algorithms for VSL systems, particularly as components of ATM. While these algorithms have been shown to be effective in simulation studies, they are often too complex to be implemented in the field.

Generally, VSL systems are activated when certain conditions (e.g., volume, occupancy, road surface conditions, or weather conditions) are met; corresponding algorithms will generate new speed limits. Usually, decisions are supported by real-time sensors that can detect current roadway conditions (e.g., traffic, weather, visibility, pavement). The algorithms can differ from project to project. In many cases, the 85th percentile speeds of downstream congested traffic are used directly or indirectly as new speed limits. In other cases where there is no congestion but severe road conditions, such as low visibility, engineers use look-up tables to determine speed limits using pre-determined values based on condition thresholds. Some VSL systems are deployed during major construction projects to slow upstream vehicles for safety purposes; a single reduced speed limit may be set in this case.

Based on their objectives, speed control algorithms can be categorized into two types: 1) speed homogenization projects that focus on improving safety, and 2) multi-objective projects that may strive for improvement of mobility and/or reduction of environmental impacts in addition to speed homogenization. Most systems related to weather, visibility, and work zones fall under the category of speed homogenization, while systems that react to current traffic conditions belong to the category of multi-objective projects.

Two particular challenges of setting variable speed limits were identified during agency interviews. One difficulty was generating speed changes in a way that felt natural to drivers, both at the stage of speed reduction or speed recovery from reduced speed. Oregon DOT advised that it takes multiple iterations to develop a system that reacts naturally enough to reduce negative feedback and to increase compliance. The other challenge was determining how to manage competing interests between the assigned “safe speed” and actual driver behavior, since many drivers travel much faster than the posted speed limit. When calculating a suitable speed limit, the goal should be to display a speed that is safe for travelers but also will not create increased variance. This balance can be very difficult to achieve.

In practice, algorithms differ depending on project objectives, purposes, weather conditions, and the surrounding environment. Algorithms for congestion-focused VSL systems are typically more complex because they need to consider overall effects on corridor traffic conditions instead of simply reducing speed and speed variance for safety. Congestion-focused projects may also be weather responsive if adverse weather conditions exist. Key questions related to dynamic speed limit setting issues include:

- What are the factors to consider, such as volume threshold, occupancy threshold, surface conditions, and 85th percentile speeds? How are they considered?
- Are there any safety issues to slow down traffic if the average speed is considerably higher than posted speed?
- How should maximum and minimum posted speed limits be determined?
- What is the period over which speed statistics are calculated?
- When should speed limits be adjusted and by what increment?
- How often can the speed limits be changed?

Various examples of speed control algorithms and the corresponding approaches to implementation issues are described below.

The VSL system along the New Jersey Turnpike was installed in the early 1960s and is still being used today. Although the VSL system is currently operated manually, it was automatic in the past. The VSL were automatically calculated and posted according to average travel speeds collected by copper loop detectors located in the pavement (United States Department of Transportation, 2002). In order to avoid creating a second area of congestion, the VSL signs upstream of the traffic issue were posted as 10 mi/h faster than the speed of the downstream traffic. For example, if the downstream traffic was traveling at 25 mi/h, the upstream VSL would be 35 mi/h. Supervisors only manually intervened when setting speeds for construction work zones or if travel lanes were shut down along the roadway. The algorithm for speed reduction was simple: the speed limit was reduced in 5 mi/h increments with a minimum speed limit setting of 30 mi/h. The VSL system not only displayed the reduced speed limit, but it also displayed a REDUCE SPEED AHEAD message on VMS as well as the rationale behind the speed reduction. When appropriate, the distance from the warning sign to the congestion, crash, construction, etc. was also displayed (United States Department of Transportation, 2002).

The current VSL system employs approximately 250 signs (both VSL and VMS) along the entire New Jersey Turnpike corridor and is manually operated. The maximum regulatory speed limit along the New Jersey Turnpike is 65 mi/h, and there are other areas with a regulatory speed limit of 55 mi/h. Most of the time when there is a downstream issue, supervisors manually reduce the speed to 45 mi/h (except during poor weather conditions). During poor visibility conditions, the speed is determined based on how many mile markers are visible from a stationary location along the corridor. If three mile markers are visible, then the speed limit is posted as 35 mi/h. If two mile markers are visible, then the speed limit is set as 30 mi/h and operators consider closing the roadway. Currently, the posted VSL apply to all lanes, though VSL may vary across lanes in the future.

The speed limits along I-4 in Florida are determined with loop detectors and side-fire radar, which detect volume, speed, and occupancy. Weather conditions are visible through CCTV, although the VSL system along I-4 was primarily built for speed harmonization due to large dynamic waves frequently observed along the roadway rather than to observe weather. The Florida DOT reported that the loop detectors provide extremely reliable data. The side-fire radar systems have improved over the years, but they are still not fully reliable today.

The displayed speed limits along I-4 in Florida are regulatory and are based on the 85th percentile speed in 5 mi/h increments. When an event occurs that requires a speed alteration, the VSL system informs the traffic management staff and then recommends an appropriate speed. The speed selection algorithm along I-4 accounts for the design speed of the roadway, which depends on roadway curvature, superelevation, sight distance, etc. The staff may then accept or alter the recommendation. Once a suitable speed has been accepted, the speed limit is posted according to the following rules (FDOT: Traffic Engineering and Operations Office, 2010):

1. The posted speed limit is reduced and the yellow warning light begins flashing.
2. The new traffic flow is monitored and it is ensured that the new speed limit is appropriate.
3. If necessary, the speed is reduced in 5 mi/h increments while never dropping the speed 20 mi/h or more under the normal roadway speed limit.
4. Once the event has cleared, the normally posted speed limit is displayed and the flashing yellow light is turned off.

Because of ongoing construction on the I-4 corridor in Florida, the Florida DOT completely turns off the VSL system to accommodate work zones in the vicinity. This obviates the need to move signs, maintain electrical and communications to signing systems, and ensure that adequate data collection is taking place, particularly in areas where the freeway surveillance systems are disrupted by the ground works associated with grading and pavement reconstruction.

US 27 in Florida also uses loop detectors to determine speed limits. The Florida DOT later added side-fire radar systems just to detect current speeds along US 27 and to check compliance rates. US 27 does not experience much construction; therefore, it is not necessary for the VSL to accommodate work zones.

Georgia uses various sensors placed 1/3 mile apart on I-285. Sensors transmit data every 20 seconds, including the total volume and average speed. Weather stations do not contribute to the VSL system, and the Georgia DOT does not use probe data—primarily because there is a lag in that data. VSL speeds are determined based on speeds downstream of the sensors, so the cause of a slowdown in traffic is not a determinant. The VSL system is fully automated, but there is the option to change the speed manually as well. The VSL is manually changed for situations like work zones. In Georgia, construction typically occurs at night when there is less traffic volume. However, motorists can drive much faster with less traffic, so the VSL is used to lower speeds in active work zones.

The Minnesota DOT set speeds using an algorithm developed by the University of Minnesota – Duluth. When activated, the VSL would display a speed 5 mi/h lower than the posted speed (which is 55 or 60 mi/h) with a minimum speed of 30 mi/h. The same speed did not have to be set for the entire corridor. Instead, when congestion was detected, as many as three sets of lane control signals could be activated prior to the congestion. Because the lane use control signals for the active traffic management system (ATMS) equipment also functioned as the display modules for the VSL, the activation of VSL in advance of the congestion was desirable for the purposes of step-down speed harmonization. With lane control structures located every ½ mile, the VSL could be activated as much as 1.5 miles upstream of the congestion. This allowed traffic management staff to reduce speeds gradually as the traffic approached congestion.

The Nevada VSL system is part of a larger wind-warning system. Wind-speed data is tied to two RWIS stations; one on the north end and one on the south end of the valley. For the VSL to be activated, one of the RWIS stations must record a wind gust of 30 mi/h or more. Once activated, the speed limit is lowered to 45 mi/h. It is not raised back to its operating speed (either 50 mi/h or 55 mi/h depending on the section) until neither RWIS station registers a wind gust ≥ 30 mi/h for 30 minutes. The system operates automatically, but there is some human interface from the traffic management center for confirmation.

The displayed speed limit along OR 217 is determined by in-road, radar-based, downstream sensors from Wavetronix that measure 85th percentile speed at a 1 minute interval. The displayed speed is calculated as the lower of the following values: 1) 85th percentile speed, or 2) Speed of downstream traffic + 5-10 mi/h. If the calculated speed is less than 30 mi/h, then the system displays SLOW (Mitchell, 2016). The Oregon DOT has found these sensors extremely reliable. There are at least seven to eight different segments throughout the entire VSL corridor, and each segment is evaluated separately and assigned an appropriate speed limit. The speed setting algorithm ensures that the changes in speed between different segments are no more than 10 mi/h. Although the current VSL system is advisory, the VSL algorithm can easily be converted from an advisory to a regulatory VSL system. Oregon statutes regarding basic speed establish strict criteria for the installation of non-advisory speed limits. In addition, case law has established precedent for drivers overturning citations for violating posted maximum speeds, which, in Oregon, are signed with SPEED LIMIT signs instead of the SPEED signs found on rural primary highways.

The OR 217 speed algorithm accounts for both weather conditions and congestion levels. The final displayed speed limit depends on which piece reports the most needed condition change (weather vs. congestion). There is a friction factor sensor at each speed sensor location which considers roadway condition during calibration. When the friction factor reaches a certain level, the displayed speed limit is calculated based on the current weather conditions instead of congestion levels. A summary of the weather responsive algorithm is shown in Figure 2 (Mitchell, 2016).The necessary speed alterations based on weather and/or traffic are automatically calculated and implemented within the VSL algorithm itself. The algorithm does not account for roadway curvature since OR 217 is a freeway-level facility. In addition, the Oregon DOT does not have much experience in accommodating work zones in the vicinity of VSL since the last major construction in the area was the installation of the VSL system itself.

Weather Responsive System

Condition Code	Visibility	Grip Factor	Surface Condition Classification	Condition Speed	Weather Message	Actual Sign Message
A	<Visibility Threshold	>= Grip Factor Threshold	Moist, Wet	Maximum Speed - 10 MPH	"LOW VISIBILITY	LOW VISIBILITY
B	<Visibility Threshold	< Grip Factor Threshold	Moist, Wet	Minimum Speed	Slippery when wet sign + "USE CAUTION"	USE CAUTION
C	>=Visibility Threshold	>= Grip Factor Threshold	Moist, Wet	Maximum Speed	None	
D	>=Visibility Threshold	< Grip Factor Threshold	Moist, Wet	Maximum Speed - 20 MPH	Slipper when wet sign + "USE CAUTION"	USE CAUTION
E	<Visibility Threshold	>= Grip Factor Threshold	Frosty, Snowy, Icy, Slushy	Maximum Speed - 10 MPH	"LOW VISIBILITY"	LOW VISIBILITY
F	<Visibility Threshold	< Grip Factor Threshold	Frosty, Snowy, Icy, Slushy	Minimum Speed	ICE sign + "USE CAUTION"	ICE USE CAUTION
G	>=Visibility Threshold	>= Grip Factor Threshold	Frosty, Snowy, Icy, Slushy	Maximum Speed	None	

(Source: Oregon Department of Transportation)

Figure 2. Chart. Weather responsive system for Oregon Route 217.

The Tennessee VSL system on I-75 is weather-responsive with speeds changed based on visibility during fog conditions. It functions in a hybrid fashion with speed changes occurring both automatically and manually. Speed limits are determined by a conditional visibility algorithm due to weather event(s) related to fog, traffic speed, and stopping distances. The same speed is set throughout the corridor using the following parameters:

- Speed = 70 mi/h when visibility is < 10 miles and ≥ 1,320 ft.
- Speed = 50 mi/h when visibility is < 1,320 ft. and ≥ 480 ft.
- Speed = 35 mi/h when visibility is < 480 ft. and ≥ 240 ft.

Environmental sensors are used with the I-75 system and are reported by the Tennessee DOT to be very reliable.

The VSL system along I-66 in Virginia has dynamic (instead of fixed) speed segments. Dynamic segments allow the speed limit to apply to different lengths of the roadway depending on existing needs. A smoothing speed algorithm is used to appropriately alter vehicle speed within each dynamic section to maintain suitable traffic flow. The smoothing algorithm determines the slowest speeds along the corridor, and then it transitions the oncoming traffic into that slower speed.

Note that the Virginia DOT is still improving the current I-66 speed setting algorithm. Weather, roadway curvature, sight distance, and pavement type/condition are not included in the speed limit calculations for I-66, although some of those variables may be included in future iterations. I-66 currently utilizes Wavetronix speed sensors, which have been extremely reliable in providing relevant traffic conditions.

Since the I-66 VSL system in Virginia has only been consistently active for approximately six months, the Virginia DOT is still evaluating the effectiveness of the VSL system for reducing speeds. The Virginia DOT stated that maybe the most important determinant of the effectiveness is if the algorithm is successfully transitioning drivers into both higher and lower speed zones.

In addition to the VSL system along I-66, the Virginia DOT is currently designing a VSL system on I-77, which will primarily be used for visibility purposes. The VSL will be determined based on the available visibility with the goal of reducing speed variance. Similar to I-66, I-77 will also have dynamic speed segments, but the length of these segments will change depending on visibility levels. The algorithm will determine the areas with the worst visibility and then set the appropriate speed limits around those areas. Sight distance is included in the speed setting algorithm since it is a visibility-based system. Wet conditions, roadway curvature, and pavement type/condition are not included in the speed limit calculations for I-77, although some of those variables may be included in future iterations. The planned I-77 VSL corridor will use Wavetronix sensors to capture data.

Two of Washington's VSL systems have similar methods of operation: I-90 (near Snoqualmie Pass) and US 2. Both systems are regulatory, operate in rural areas, and display speed based on an operator look-up table, which accounts for current pavement conditions, visibility, weather (i.e. rain, snow), and incidents, as shown in Table 5. Currently, the operator uses the table to determine the appropriate speed and then manually displays it. Roadway curvature, sight distance, and pavement type/condition are not considered in the speed setting algorithm. The displayed speed limits are not necessarily the same throughout the entire corridor, and there is lane discrimination (e.g., high occupancy vehicle (HOV) lanes might have a different speed limit than the general purpose lanes). The Washington State DOT reported that both VSL systems have been effective at reducing speeds, and speed variation is small. In addition, the Washington State DOT stated that their current sensors are very reliable, and they have extensive experience in calculating travel times based on speed converted from occupancy measurements.

Table 5. Washington State Department of Transportation speed limit reference.

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.

Table 5. Washington State Department of Transportation speed limit reference. (Continued)

Traction Requirements	Speed Limit	Pavement Conditions	Visibility	Weather	Blocking Incidents
Tractor Trailer Requirement / Vehicle Over 10,000 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 Vehicles 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 supervisor, when available. Poorest possible road conditions and human life endangered. Conditions should be well documented. Return to higher speed limit as soon as possible.			

Source: Washington State Department of Transportation.

The displayed speed limits along I-5, I-90 (Bellevue to Seattle), and SR 520 in Washington are computed using the same method. All three systems are regulatory and located in urban areas. The displayed speeds are determined and adjusted every minute by monitoring downstream conditions: 1) the 85^{th} percentile speed is calculated, 2) multiple speed values are compared in the corridor, 3) smoothing/transitional calculations are performed, and 4) the displayed speeds are updated as needed. Since the displayed speeds are calculated by using measured downstream conditions, there is no need to include wet conditions, roadway curvature, sight distance, nor pavement type/condition in the speed calculations. The displayed speed limits are not necessarily the same throughout the entire corridor, and there is lane discrimination (e.g. HOV lanes might have a different speed limit than the general purpose lanes). All three of these VSL systems have been effective at reducing speeds.

Manual versus Automatic Operations

Many VSL systems operate in a hybrid fashion using a combination of automated and manual speed changes. There are fewer instances of a system being fully manual or entirely automated, but there are examples of each.

Speed limits on I-495 in Delaware are manually determined by the chief traffic engineer of Delaware DOT, the traffic management center manager of the DOT, or by request of the Delaware State Police, according to weather and road conditions. Using expert opinion and on-the-ground input limits unexpected speed variation due to faulty sensors or poorly calibrated control algorithms.

Presently, the VSL system along the New Jersey Turnpike is manual; however, the system used to be automatic. The New Jersey Turnpike Authority is currently working with other entities, including IBM and Rutgers University, in order to restore the automatic capabilities of the VSL system. The NJ Turnpike Authority noted that automatic VSL systems allow more throughput; therefore, transitioning back to an automatic system is ideal. Alternatively, the Nevada DOT system is fully automated and speeds are changed using wind-speed data from RWIS stations. A threshold wind gust of 30 mi/h automatically activates the VSL system so that the changeable speed limit signs show a reduced speed limit.

When an agency uses a hybrid approach, they typically rely primarily on an algorithm to automatically change the speed limit and supplement with a human interface. This may involve looking at data or video feeds to confirm the VSL is appropriately set for current conditions or overriding the automated speed limit for an extenuating variable. For example, the Georgia DOT system on I-285 automatically adjusts the VSL using speed data transmitted from sensors. However, agency personnel can override the system to manually change the speed limit during nighttime construction to reduce speeds in work zone areas. In addition, the VSL system in Florida along I-4 recommends a certain speed limit based on field sensor output, and the operator must then approve or alter the proposed speed. On I-5 and I-90 in Washington, operators monitoring the system can override automatically adjusted VSL if necessary, though this is not desirable for typical operations.

Advisory versus Regulatory Operations (Enforcement)

The success of VSL systems is highly dependent on compliance, and therefore it is essential that regulatory systems are consistently enforced. However, in real-world deployments, particularly those in the United States, many systems are still advisory or cannot be enforced as intended.

In some cases, State laws prevent VSL systems from being enforced. In Minnesota, the VSL systems on I-35W and I-94 were advisory because regulatory systems would have required a legal change. Even so, stakeholders in Minnesota shared the same views as many other agencies: VSL systems require enforcement to gain driver compliance. If the VSL system not enforced, it is suggested that speeds need to match drivers' expectations of what is sensible.

OR 217, located in the Portland, Oregon area, is an advisory system due to limited shoulder space along the roadway and also due to State law. In order to implement a regulatory VSL system in Oregon, a long legal process would be necessary to change State law to accommodate VSL along interstates. Currently, State troopers and local police in Oregon "enforce" VSL by using a "basic rule" whereby law enforcement officers judge whether drivers are traveling safely and prudently rather than examining vehicle speed. Oregon DOT is planning to utilize VSL systems in other areas once the State law has been altered to allow VSL installation on interstates, including a 30 mile, weather-based VSL system.

In many other cases, VSL systems were intended to be regulatory, but actual enforcement was limited. One major obstacle is the lack of direct access to speed limit information by law enforcement. The former Missouri VSL system was located on I-270 in St. Louis. It commenced as regulatory, but law enforcement was reluctant to issue citations because they were unsure of the current speed limit. Consequently, the system was changed to advisory, but compliance became an issue. The system was therefore ultimately deactivated. Missouri has no other VSL systems as of May 2016.

The Georgia Highway Patrol as well as law enforcement from 14 local jurisdictions can enforce speeds on I-285. Prior to activating the VSL system, the Georgia DOT met with the Highway Patrol to explain the system. As many others have experienced, the reaction from law enforcement was not positive with concerns centralized on the officers not knowing the current speed that should be enforced. To help address this issue, the Georgia DOT provided the Highway Patrol with a direct data feed so they can see the signs at all times. Additionally, the Highway Patrol is using a different citation tactic to work around needing to know the exact speed. Instead of focusing on speed as the offense, law enforcement issues citations for reckless driving or driving too fast for conditions. To further support law enforcement, the Georgia DOT archives all of their VSL data and can provide information to the Highway Patrol when needed to verify the set speed at a specific time.

The VSL in Nevada is also regulatory. Law enforcement response has not been positive, primarily because of the hardware and software problems that have caused issues with the VSL signs. For example, a 45 mi/h speed limit may be displayed in one direction, but the signs display a 55 mi/h speed limit in the opposite direction. This has caused law enforcement to lose confidence in VSL, and Nevada DOT is considering temporarily turning off the system to replace the hardware. Law enforcement is not directly notified when the VSL is activated, but they are aware by default because they are notified when the larger wind-warning system is closing routes; so the speed limit reduction is implied.

Finally, it can be difficult to enforce speed limits in conditions where it is unsafe for law enforcement to exceed the posted speed limit. For example, the VSL system on I-77 in Virginia is regulatory and enforceable, but speeds are most often decreased due to heavy fog. Heavy fog is not only a safety issue for drivers, but it is also a safety problem for law enforcement officials. Therefore, enforcement along I-77 is a complex issue that transportation officials in Virginia are still working through.

OUTCOMES

Performance Measurement

Depending on functional requirements and system goals, VSL systems have been evaluated with various performance measures or measures of effectiveness (MOEs) as follows:

- Traffic efficiency: average speed and travel time at a certain time interval (e.g., 1 minute or 5 minutes), travel time reliability, traffic throughput, driver journey times, traffic flow stability, number of significant shockwaves.
- Safety: general crash rates (categories by crash severity: fatal and injury, property damage only, and crash types: rear-end, sideswipe, and others), crash rates during certain seasons (e.g., winter crash rate if a VSL is deployed for winter severe weather conditions).
- Other: driver subjective ratings, compliance rates, emissions measured by environmental sensors.

Agencies either apply these general performance measures directly or adapt them on the basis of special requirements and goals of the deployment site. The Virginia DOT defined MOEs for the planned VSL system on I-77 to guide the evaluations of system effectiveness. The primary MOEs focus on reducing the quantity of various crash types (e.g. fatal, injury, property, weather-related, work zone-related, etc.) along the corridor. The crash reduction goals would be met if the number of collisions over a five-year period following VSL operation is less than the number of collisions in the 5 years just before system implementation. Crash severity reduction goals were also developed related to injury and property crashes. The crash severity goals would be accomplished if the severity of injury and property crashes decreased every year following system implementation. In addition, the speed compliance goal would be achieved if the rate of compliance improves for a period following the system introduction when compared to a period just before system implementation (URS, 2012).

Compliance

States have observed varying levels of driver compliance with VSL systems. Compliance rates depend on multiple factors (e.g., regulatory vs. advisory systems, enforcement strategies, public education/outreach, etc.). Also, some speed homogenization projects, such as on I-94 in Minnesota, reported high compliance rates, perhaps because drivers are aware of the risks of high speeds in bad weather or work zones. Some deployments (e.g., A99 in Munich, Germany, and many others in Europe) adopt automated enforcement, which is effective in improving compliance. The feasibility (i.e., adoption issues and public support) of automated enforcement in the United States should be studied in the future. In addition, European sites typically report higher compliance rate and larger benefits. Future research should consider if cultural differences between U.S. and European drivers affect system effectiveness. Various State experiences related to VSL compliance rates are discussed below.

The manual VSL system along the NJ Turnpike is regulatory; therefore, the speed limit is enforced by the State Police to ensure that drivers are abiding by the posted speed limits. In addition, any time there is a severe collision along the VSL route, the police will issue any necessary citations based on the VSL that was posted at the time of the incident (United States Department of Transportation, 2002).

An outreach program was implemented (e.g. brochures, radio announcements, websites, etc.) for the VSL System along I-4 in Florida to educate the public about the purposes of the VSL system; however, without proper enforcement, minimal compliance is still observed. In contrast, Florida is obtaining high compliance rates along US 27 – a two-lane, divided, rural, high-speed roadway. Here, the VSL are regulatory and are being enforced along this roadway by the Florida Highway Patrol, which is believed to be causing the higher compliance rates.

The VSL system was advisory in Minnesota because a regulatory system would have required a legal change. Minnesota shares similar views as many other agencies – VSL requires enforcement to gain driver compliance. If the VSL is not enforced, the speed needs to match drivers' expectations of what is sensible.

The VSL system on OR 217 is currently advisory due to limited space for enforcement and State law. Even though current compliance along OR 217 is not perfect, the VSL system is still considered successful. Oregon has observed a substantial reduction in speed differentials, improved harmonization, increased roadway capacity, and a reduction in crashes along OR 217. However, Oregon would expect to see higher compliance rates with a regulatory system versus their current advisory system.

As mentioned previously, the former Missouri VSL system on I-270 in St. Louis was ultimately deactivated due to compliance-related issues. As of May 2016, Missouri has no other VSL systems.

System Benefits

With the variety of objectives and implementation approaches across VSL systems, benefits vary from deployment to deployment. Table 6 shows results for a number of representative VSL projects from the United States and other parts of the world. Not every deployment in Table 6 has been evaluated in the literature. European sites have been included in the results to better illustrate how system benefits can vary from site to site due to various influencing factors.

Speed homogenization projects usually used simple algorithms in response to real-time traffic, road, and other conditions (e.g., weather, work zone, incidents, visibility, etc.). Many of these studies reported improvement in traffic safety via before-and-after analyses (with some exceptions such as the I-270/I-255 corridor in Missouri, likely because of low compliance rates). Many of the multi-objective projects reported that VSL had positive effects on mobility, safety, and the environment. There are some discrepancies, although it is difficult to generalize the reasons for these discrepancies due to many uncontrolled factors among different sites, such as different compliance rates, heterogeneous driver behaviors, and various road geometries.

Table 6. Variable speed limit system practices and field results.

Location, Time	Variable Speed Limit (VSL) Summary	Evaluation Results
Speed Homogenization Projects		
Germany, 1990	• Advisory VSL. • Only three speed limit options: 100, 80, or 60 km/h.	• 20-30% reduction in crash rates.
E18 in southern Finland, 1990	• A central control unit analyzed the data and selected one of three speed limits, 120 km/h, 100 km/h, or 80 km/h, to display, based on driving/road conditions; the system is advisory.	• 95% of drivers reported positive ratings of its effectiveness. • Compliance rates were as high as 76%. • Significant safety improvements attributable to the weather VSL implementation: accidents during the winter dropped by 13% and during the summer by 2%.

Table 6. Variable speed limit system practices and field results. (Continued)

Location, Time	Variable Speed Limit (VSL) Summary	Evaluation Results
Attiki Odos Toll Motorway, Greece, 2004	• Speed signs are to notify drivers when the advisory speed limit inside the tunnel is different from the other parts of the motorway. • The system provides advice to motorists approaching the tunnel regarding the safe speed limit inside the tunnel.	• Significant reduction in injury accidents by 10%.
I-494, Minnesota, 2006	• Reduce the speed of the vehicles approaching the work zone.	• 25-35% reduction in maximum 1-minute average speed and a 7% increase in throughput between 6 and 7 a.m., although no throughput increase between 7 and 8 a.m. • Even though the speed limit was advisory, motorist compliance was significant.
I-270/I-255 Corridor, Missouri, 2010	• The maximum and minimum speed limits on the corridor are 60 mi/h and 40 mi/h, in 5 mi/h increments. • Uses a 5 minute update interval (less in case of incidents). • The system is advisory.	• No mobility gains (in terms of throughput improvement or congestion reduction) were observed. • The evaluation did show a significant reduction in number and severity of crashes by 8%. • Speed limit compliance remained surprisingly low, even though the signs were mandatory.
Multi-Objective Projects		
E4, E22, Sweden, 2003	• Both advisory and regulatory. • Goal: increase throughput, reduce shockwave, improve safety.	• 5 to 15 km/h (≈ 3 to 9 mi/h) reduction in speeds across the study sites, high rates of speed compliance (in particular in severe weather conditions), fewer disturbances in traffic flow, and less severe shockwaves. • Reduce travel time by 5%. • Most effective when they combined with additional speed enforcement and better information.

Table 6. Variable speed limit system practices and field results. (Continued)

Location, Time	Variable Speed Limit (VSL) Summary	Evaluation Results
MD 100, Maryland, 2009	• Smooth the transition between free flow to congested state. • Algorithm consider driver response.	• Increase average speed and throughput, shorter travel time.
I-5, I-90, Washington, 2010	• Include a few preset speed thresholds. • When thresholds reached, adjust VSL in 5 mi/h increment, with a 35 mi/h lower bound. • Operator can overwrite automatic VSL manually.	• Reduced average speed, reduced flow, travel time reliability increased.
A7/E15 south of Lyon, France, 2011	• Objective: traffic throughput and safety improvement. • Triggered by pre-set traffic flow thresholds (3000 vehicles per hour) with maximum speed limit of 110 km/h (≈ 68 mi/h).	• Increased average speed by 4-10%, reduced the number of bottlenecks by 50%, reduced average travel time by 30 seconds, no change in lane capacity, reduced incidents by 17%. • Low compliance rate.
I-35W, Twin Cities, Minnesota, 2010	• VSL displayed 1.5 miles upstream gradually reducing the speed of incoming traffic. • Using constant deceleration rate to decide VSL at the end of queues. • Updated every 30 seconds.	• Reduced travel time, increased traffic volume, less deceleration rate.
I-4, Florida, 2014	• Objective: to improve traffic flow; to reduce rear-end and lane change crash risks. • FDOT conducted an engineering and traffic investigation that identified reasonable and safe speeds under different weather and traffic conditions; e.g., some section in congested period has VSL at 20-30 mi/h—lowering upstream speed limits by 5 mi/h and raising downstream speed limits by 5 mi/h.	• Not available at time of this synthesis.

Table 6. Variable speed limit system practices and field results. (Continued)

Location, Time	Variable Speed Limit (VSL) Summary	Evaluation Results
I-66, Virginia, 2016	• A component of active traffic management, to improve safety and operations on I-66 through better management of existing roadway capacity. • The ATM includes advisory variable speed limits, queue warning systems, lane use control signs, and hard shoulder running.	• No specific VSL effects were analyzed. • Active traffic management has limited operational and safety impacts during the weekday peak periods and some impacts during the midday and off-peak weekday periods (2% to 6% improvement).
New Jersey Turnpike[1]	• Deployment for both congestion and road weather management; operated manually; regulatory for all travelers.	• The speed control strategy effectively decreases traffic speeds in adverse conditions. Speed management and traveler information dissemination have improved safety by reducing the frequency and severity of weather-related crashes (improvement quantity is not available).

[1] Federal Highway Administration, "Best Practices for Road Weather Management," (n.d.). Available at: http://ops.fhwa.dot.gov/weather/Publications/Case%20Studies/14.pdf

Life-Cycle Costs

Limited information is available on the cost of VSL systems. Through interviews with operators, it was roughly estimated that the cost of deployment a VSL system along a route varies from less than $10 million to almost $40 million. This cost is highly dependent on the existence of current intelligent transportation system facilities, such as traffic detectors, VMS, and gantries.

It was even difficult for some agencies to estimate the cost of the VSL system(s) in their States. For example, many pieces of hardware, devices, and processes had already been implemented prior to VSL deployment in Washington; therefore, the actual cost of their VSL system, sensors, and maintenance is unclear. In addition, since the Georgia and Nevada systems are fairly new (both are less than 2 years old), neither agency has comprehensive data yet on lifecycle costs. Also, the Minnesota DOT is considering using one sign for all lanes (instead of lane-by-lane signs) to reduce their maintenance and operations costs.

The approximate cost to install the VSL systems on I-35W and I-94 in Minnesota was $16 million and $10 million, respectively. These costs do not include the sensors since they already existed, but they do include the lane control signals and structures.

The total cost of the I-66 VSL system in Virginia was $39 million. However, this cost estimate was unique to I-66 due to additional costs related to communication, cameras, infrastructure, gantry construction, etc. The gantries themselves cost approximately $24 million. The total cost of the planned I-77 VSL system in Virginia is $9.6 million (Earnest, 2015). This figure includes a fair amount of additional upgrades (e.g. power, etc.).

CHAPTER 5. CONCLUSION – BENEFITS AND CHALLENGES OF VARIABLE SPEED LIMIT SYSTEMS

KEY BENEFITS

In most cases, variable speed limit (VSL) deployments are capable of generating desired traffic efficiency and safety system benefits. Because VSL systems have varying deployment goals and corresponding system design, varying system benefits resulted. Speed homogenization projects usually use simple algorithms in response to real-time traffic, road, and other conditions (e.g., weather, work zone, incidents, visibility, etc.), and report safety improvements. Multi-objective projects, mostly as a part of active traffic management (ATM) systems, report positive effects on mobility, safety, and even the environment. System benefits vary from site to site and it is difficult to generalize the reasons for these discrepancies due to many uncontrolled factors among different sites, such as compliance rate, driver behavior, or road geometry. However, VSL systems generally result in the following benefits:

- **Smoother traffic flow and less delay.** As a component of ATM, VSL proactively manages speed to improve traffic flow and safety. Generally, some of the benefits of VSL include shortened queues, reduced congestion, quicker clearance during incidents, and fewer crashes. For example, Oregon has observed several of these benefits with a substantial reduction in speed differentials, improved harmonization, increased roadway capacity, and a reduction in crashes along Oregon Route (OR) 217.
- **Safer speeds in work zones.** While agencies have found that performing nighttime construction reduces congestion and shortens traffic queues (compared to daytime construction), the lower volume also allows for faster speeds creating dangerous conditions in work zones. A VSL system allows the speed limit to be reduced so that vehicles approach construction areas and pass through work zones at safer speeds.
- **Ability to tie to road weather information system (RWIS) data to reduce speeds during inclement weather.** When installing a VSL system for weather, many agencies can tie into existing RWIS stations to provide the data needed to determine when the speed limit should be reduced. Implementing VSL during adverse weather conditions can significantly improve safety and, in some cases, traffic efficiency.

KEY CHALLENGES

Implementing a VSL system also comes with challenges, including enforcement of speeds that change, driver comprehension, and setting thresholds for speed limit changes (e.g., how much precipitation triggers a change, how often the signs should be updated, etc.). Although many VSL systems have been implemented across the country (and around the world), each site is unique and each system has its own characteristics and capabilities. Virginia DOT's challenges have included acquiring staff with vast capabilities, maintaining reliable system-wide communication, developing methods of encouraging compliance, and generating public approval through outreach activities (Earnest, 2015). Following are some of the other key challenges agencies experience when developing and implementing VSL systems.

- **VSL enforcement.** Nearly every agency operating a regulatory VSL system reports challenges with speed enforcement. Law enforcement must know whenever the speed limit changes to be able to successfully enforce a VSL. In some instances, law enforcement may be hesitant to issue citations because they are unsure of the speed limit or fear a lack of supporting evidence for citations to be adjudicated.
- **Driver compliance.** While enforcement of a regulatory system can be challenging, some agencies operating advisory VSL systems report a lack of driver compliance. Some agencies operate an advisory system due to current State statutes and agency policies. Others initiated their systems as regulatory, but changed to advisory after unsuccessful enforcement.
- **Hardware/software failures.** Minnesota has experienced a shorter than expected life from their changeable speed limit signs while Nevada has seen their signs displaying different speeds when the VSL is activated and all displayed speed limits should be the same. Nevada has also had issues of their signs going blank and not displaying any speed limit. In addition, the New Jersey Turnpike Authority cited the constantly changing technology and necessary system upgrades as major challenges when maintaining a VSL system (United States Department of Transportation, 2002).
- **Lag in data.** Depending on the source of the data or the algorithm used to analyze data, there can be a delay which results in the signage not displaying the appropriate speed limit for conditions. The New Jersey Turnpike Authority stresses the importance of calculating/posting the appropriate speed and ensuring that all variable messages are displayed/removed in a timely manner.
- **Returning the VSL back to the normal operating speed.** One of the most challenging aspects operating a VSL is smoothly and efficiently returning the speed limit back to the regulatory speed limit following an issue along the roadway. The better the VSL system can transition drivers back to the regulatory speed limit, the better the system will be at preventing secondary crashes and keeping drivers safe in general.
- **Lack of cost/benefit information to support rationale for a VSL system.** As highway agencies receive less funding, it is imperative to determine if a system's benefit will equal or outweigh the cost. There is limited information on cost/benefit analyses that agencies can use to support new implementation or expand existing systems.

VARIABLE SPEED LIMIT KEY CONSIDERATIONS

This section provides a list of key factors that agencies should consider when implementing a VSL system. The report provides a more detailed discussion on the various items, but this list provides a summary for developing preliminary concepts for a VSL implementation.

General Considerations

- First, develop some overall goals of what the VSL system should accomplish. It is important to note that VSL is not appropriate in all situations. Perform an analysis of whether or not VSL will be able to meet the overall goals.
- The goals should include the desired situations in which speeds would be reduced (congestion, weather, work zone, etc.). The system design and further planning will depend on the overall situations in which the VSL system will be used.

Planning

- The planning process should include a detailed systems engineering process to clearly identify and communicate objectives, requirements, and anticipated costs/benefits are crucial to successful implementations.
- Based on VSL system goals and appropriate laws, carefully determine whether the system should be regulatory or advisory.

Design

- The infrastructure requirements will depend on the system purpose. VSL infrastructure requirements can include changeable Speed Limit Signs, weather/environmental sensors, traffic speed/volume sensors, and communications equipment to transmit data.
- Selection of control algorithms also varies based on system goals. Algorithms can be difficult to calibrate so ample time should be spent on fine tuning the algorithms, particularly when incorporating real-time decisions based on congestion.
- Systems can be set up to automatically display speeds or to provide recommendations for traffic management center staff for choosing to accept the recommendations. It is important to determine the method used for speed changes to occur.

Legal and Enforcement Considerations

- Review State and local statutes and agency policies to ensure that a VSL system is enforceable if a regulatory speed limit is desired.
- Begin meeting with law enforcement partners early in the process to discuss any concerns and processes for enforcing the VSL system, if enforcement is required.
- Ensure that law enforcement personnel can safely enforce speed limits with potential safe places to stop violators, if enforcement is required.

Cost Considerations

- When calculating the cost, be sure to account for items beyond the initial system cost, such as maintenance, operations, staffing, evaluations, and end-of-life replacement.

FUTURE OF VARIABLE SPEED LIMITS

Following the comprehensive literature review and agency interviews, the research team has identified the following needs for future developments of VSL systems.

Variable Speed Limit Systems with Connected and Automated Vehicles

Highway technologies on information sharing and vehicle automation have made encouraging successes in recent years. Connected vehicle technology allows infrastructure units and vehicles to share high-resolution information from not only aggregated traffic, but also individual vehicles with other vehicles on the road, roadside infrastructure, and traffic management centers. With such connectivity, traffic operators can transmit traffic control information to individual drivers through wireless communication and in-vehicle devices. In addition to connectivity, connected and autonomous vehicle (CAV) technology enables vehicles to be controlled by precise, fast-responding, error-free computers instead of error-prone, slowly responding human beings.

CAV can be expected to provide much richer real-time traffic information (e.g., high-resolution vehicle trajectories) than traditional traffic sensors. Such information can be used to better understand what is happening, and what is to happen, with highway traffic, which is a new information basis for real-time traffic control. Studies have found that only a small market penetration percentage of CAV can yield very high benefits. Automation provides a new dimension for implementing traffic management strategies by directly regulating each individual vehicle's motion with precise, quickly responding computer algorithms. This will make it possible to extend traditional aggregated infrastructure-based traffic control to a disaggregated individual-vehicle-based control. This will achieve higher traffic efficiency, better safety and more comfortable individual driving (or riding) experience.

VSL speed-control algorithms should be updated to take advantage of these new technologies. Practically speaking, there will be a long period during which human drivers share the right-of-way with CAVs. In such mixed traffic scenarios, how to properly understand interactions between CAVs and manual vehicles, and how to utilize their interacting behavior and patterns to improve the system performance, is a highly relevant implementation issue yet to be addressed.

It is expected that with wide deployment of CAV technologies, traditional VSL systems that use gantries and variable message signs will gradually phase out. VSL or speed harmonization based on CAV technology, however, will require high market penetration. This is particularly critical for safety purposes and all drivers are supposed to be informed of hazardous and dangerous traffic and weather conditions. In the near term, VSL will still play an important role in traffic management systems and it will not be replaced completely by CAV technologies unless high market penetration, in some cases 100 percent for safety, is achieved and it is estimated that high market penetration of CAV technologies cannot be realized until 2030 (Underwood, 2016).

Collecting and Processing Big Data

Traditional VSL techniques only use aggregated traffic data obtained from regular point detectors (e.g., loop detectors, traffic cameras). Nowadays, increasingly advanced traffic sensors, such as in-vehicle Global Positioning System devices or connected vehicle technologies, provide higher resolution data with a wider coverage area: primarily, a more accurate aggregated traffic state (e.g., density, speed), and more detailed individual vehicle data (e.g., vehicle trajectories). The data generated from connected vehicle technologies (when fully deployed) will be much greater in quantity and much more complex in structure than traditional point detector data. How to utilize these data in the future VSL or connected-vehicle-based control paradigms is an interesting question. Real-time collection, storage, processing and decision-making using emerging big data sources is a promising VSL development.

Consideration of Driver Compliance

Driver compliance or driver response is a critical factor for effectiveness of VSL systems. Driver compliance rates, however, can vary dramatically across different projects due to information communication mechanisms, regulation, education, culture, and many other factors. Traditional VSL broadcasts uniform speed limit information via roadside infrastructure, and emerging connected vehicle technologies can send customized messages to each individual vehicle. Hayat et al. (2015) selected a small number of representative drivers to conduct a field test to evaluate driver compliance with different advisory messages, including VSL, lane change advisory, and merge control. From a human factors perspective, it is critical to understand how to design ATM signs. The recent FHWA ATM signage study (Perez et al., 2010) developed and tested alternative signs for variable speed limit (VSL) signs and used the deployments in Minnesota and Washington as inputs to sign development. Laboratory and field studies determined both the comprehension of the ATM signs as well as their respective legibility distances. Another major issue is how to make drivers believe that they would be better off (e.g., save time or reducing crash risks) if they comply with VSL messages and travel at a slower speed than they intuitively desire.

Further, VSL speed control algorithms should explicitly consider potential driver response or compliance rate. Considering driver compliance inevitably increases the complexity of such algorithms, but real-world deployments of these algorithms should consider the added complexity. Without pre-validated evidence of compliance rates, field studies should be conducted before implementing and tuning these algorithms in the real world.

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APPENDIX B. AGENCY INTERVIEW SUMMARY

ARIZONA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Note that Arizona has not implemented a variable speed limit (VSL) system; however, three representatives from the Arizona Department of Transportation (DOT) were interviewed to discuss their opinions of VSL systems in general as well as the future of their VSL plans and to establish specific information regarding VSL systems that would assist the State in the future.

ARIZONA	
Interview Date: 9/9/2016 Name: Mark Poppe Agency: Arizona DOT Phone Number: 602-359-2277	
INTERVIEW QUESTIONS	
Based on what you have heard from other agencies, what is your impression of VSL?	VSL has promise and is capable of reducing the number of collisions along roadways.
Have you considered implementing VSL in Arizona?	Yes. We are considering one rural location that is prone to dust storms, which is similar to a fog problem.
What institutional and policy hurdles would you encounter if implementing VSL?	This is unknown at this time.
If Arizona implemented VSL, would you use it for congestion, work zones, weather, or other functions?	We would use it for weather. A safety study was completed at the potential site, and it suggested that VSL may be a good idea (although this is still being assessed).
What kind of information would you want to have in a VSL document to help with decisions?	A few topics would be helpful: other States' experiences, public acceptance, information about compliance/enforcement, etc. Speed limit compliance is always an issue with any type of system.

ARIZONA	
Interview Date:	9/20/2016
Name:	Scott Beck
Agency:	Arizona DOT
Email Address:	sbeck@azdot.gov
Phone Number:	602-712-6391
INTERVIEW QUESTIONS	
Based on what you have heard from other agencies, what is your impression of VSL?	The research we have found says that VSL is fairly effective on weather-related incidences. We know Colorado and Washington have implemented VSL systems for snow. We are now in the process of designing a VSL system to counteract our current dust problem. We have a specific location that is impacted by dust storms. As far as benefits from VSL systems to solve routine congestion issues, we are not sure if there is significant research showing the effectiveness.
Have you considered implementing VSL in Arizona?	Yes, in one specific area. We have one place we are currently designing a VSL system for, which is our most concentrated area because of the terrain and land uses surrounding it. There are some old farm fields that are no longer maintained surrounding the area, so there is layer of loose soil that gets picked up by the wind. If the feedback is successful, then we would look into implementing other VSL systems for some northern areas of the State which struggle with snow-related issues.
What institutional and policy hurdles would you encounter if implementing VSL?	Our State statutes allow VSL systems, so we don't have any issues from a legislative perspective. We are allowed to set speed limits and govern speed limits by time of day, vehicle type, weather conditions, etc. The only hurdle Arizona has now is how to coordinate with law enforcement. Our system is designed to be regulatory, so we need a plan for how law enforcement will actually enforce the speed limits.
If Arizona implemented VSL, would you use it for congestion, work zones, weather, or other functions?	Weather.

ARIZONA	
What kind of information would you want to have in a VSL document to help with decisions?	Short Answer: There is no authoritative document related to compliance. Arizona would like to see quantitative measures on voluntary compliance and whether the compliance rates have any safety benefit from those locations that have already implemented VSL. Long Answer: A lot of States have implemented VSL systems, but it doesn't seem like there is significant research on the actual compliance rates. VSL is still fairly new – If you looked for VSL systems 5 years ago, there weren't many, but now there are quite a few. There are a couple research papers that suggestively infer that VSL systems make roadways safer, but it's based on theory and some modeling. Arizona would like to see statistical data related to active VSL systems, particularly on the safety side. This is especially important when considering implementing VSL systems to reduce congestion. Arizona's downtown areas have higher crash rates, so they might consider implementing VSL systems to make those areas safer; but, just putting up a sign isn't going to slow people down.

ARIZONA	
Interview Date:	11/22/2016
Name:	Reza Karimvand
Agency:	Arizona DOT
Email Address:	RKarimvand@azdot.gov
Phone Number:	602-712-7640
INTERVIEW QUESTIONS	
Based on what you have heard from other agencies, what is your impression of VSL?	VSL is good for rural areas, but it is not good for urban areas. In urban areas, we don't need to add gantries to inform the public that they need to reduce their speeds; pretty soon we will have V2V, V2I, etc. and we will have all that information available on the dashboard. However, in rural areas, VSL would definitely be helpful.
Have you considered implementing VSL in Arizona?	We are currently designing a VSL system.
What institutional and policy hurdles would you encounter if implementing VSL?	We don't have any – our policies say we can specify the VSL.

ARIZONA	
If Arizona implemented VSL, would you use it for congestion, work zones, weather, or other functions?	Weather.
What kind of information would you want to have in a VSL document to help with decisions?	We already have everything.

FLORIDA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

FLORIDA	
Interview Date:	6/22/2016
Name:	Alan S. El-Urfali
Agency:	Florida DOT
Email Address:	alan.el-urfali@dot.state.fl.us
Phone Number:	805-410-5416
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Florida.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	1) I-4. 2) US 27 – West of Fort Lauderdale (two-lane, divided, rural, high speeds).
How long is the VSL system(s) (in miles)?	1) 10.5 miles. 2) 3 miles, both directions.
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	1) Mainly automated, but operator input is still used. 2) Automated.
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	Both are used for congestion.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	1) The algorithm uses 85th percentile for the speed limit with 5 mi/h increments.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	1) When we measure, conditions have to be dry.

FLORIDA	
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	1) Design speed is taken into consideration (American Association of State Highway and Transportation Officials criteria – curves, superelevation, sight distance, etc.). We measure prevailing speed.
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	1) This VSL system has not been very successful, but it is still in operation. There was a study conducted 3 years ago from University of Florida (before/after) that looked at the VSL algorithm and made recommendations for improvement, although Florida DOT has not implemented the changes yet. Overhead signs and more enforcement is needed. 2) The VSL system is effective now. We did not observe much compliance until enforcement was added.
What are the VSL system(s) pros and cons with respect to setting speed?	If you sign the VSL system well and have enforcement, you will have a successful operation; if not, then you have no compliance. The infrastructure used for the VSL system must have good quality and not fade in the sunlight.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	1) Loop detectors, side-fire radar (volume, speed, occupancy), closed-circuit television cameras (can see weather, but not really using the system for weather conditions). 2) Loop detectors, side-fire radar (added later to detect speed and check compliance rates).
How reliable are the sensors that are used?	The loop detectors are very reliable. The old side-fire radar systems had huge issues – the best you could get with side-fire radar systems is 92%.
Do you have any design drawings for your system layout? These drawings can be a typical layout or a site-specific layout.	Could get them, if necessary.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Both are regulatory.

FLORIDA	
What are you experiences with enforcement and the judicial process when it comes to VSL?	1) We did hold some meetings with the Highway Patrol to get their input and comments. When you have such a large volume of vehicles in the peak hours, it is very difficult to pull over one or two violators, especially without causing a secondary crash. So, the Highway Patrol stayed out of it completely. Florida DOT provided outreach materials (e.g. brochures, websites, announcements, radio ads, etc.), but the outreach was unsuccessful. Some of the lessons learned: we need better (possibly overhead) signs and enforcement partners should be involved to observe better compliance rates. 2) Once the Highway Patrol began issuing tickets, everyone complied.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	1) Approximately 20 – one sign or more per mile.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	Both systems have signage on the roadside and on medians.
Do you use any associated word messages (changeable message signs) in conjunction with VSL ("congestion ahead," "slow ahead," etc.)?	1) Yes. 2) No.
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	1) We completely turn off the system to accommodate work zones in the vicinity of the VSL system. The entire corridor is being reconstructed, so work zones are common. 2) There isn't much construction in this area, so work zones are not a problem.
To your knowledge, what is the public perception of the VSL system?	1) The University of Florida studied the VSL system and discussed outreach/public opinions of the system within the final report.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	No for both.
Do you have any additional information/comments that we should include in our report?	Read through the University of Florida study results for additional information.

GEORGIA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

GEORGIA	
Interview Date:	6/23/2016
Name:	Mark Demidovich
Agency:	Georgia DOT
Email Address:	mdemidovich@dot.ga.gov
Phone Number:	678-852-0852
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Georgia.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	I-285.
How long is the VSL system(s) (in miles)?	36 miles total (includes both directions).
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	Automated.
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	Congestion.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	The speed limit is determined by sensor-measured speed of traffic downstream. Various sensors are used and they are placed every 1/3 mile. Data is transmitted every 20 seconds and includes traffic volume and the average speed. Some video detection is used. Cameras are installed on 80’ poles, but they are fixed and do not pan. Video runs through a processor. Georgia DOT does not use probe data because there is a lag in that data. The system is automated with an option to change the speed manually for work zones. Construction is typically performed at night when traffic is lighter, which makes vehicle speeds faster.
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	The speed limit is applicable to all lanes.

GEORGIA	
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	The speed limit is applicable to all lanes.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	Weather stations have no input into the VSL system.
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	Georgia DOT is not seeing much improvement when analyzing basic elements (such as average speed). A possible reason is that the recession ended at the same time the VSL was activated so there are more vehicles on the road.
EQUIPMENT AND COSTS	
How reliable are the sensors that are used?	Georgia DOT reports that the sensors being used are reliable.
Do you have a cost/benefit analysis?	No.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Regulatory.
What are you experiences with enforcement and the judicial process when it comes to VSL?	The Georgia Highway Patrol (GHP) enforces the speed limit as well as local jurisdictions. (The VSL system crosses 14 different jurisdictions.) Georgia DOT met with GHP to explain the system and they were not excited. Georgia DOT archives data and can give it to GHP. Law enforcement does not focus on speed, but more on aggressiveness. They ticket for recklessness or driving too fast for conditions instead of ticketing for speeding. Georgia DOT has given GHP a data feed so they can see the VSL signs at all times, but not sure if it is being used.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	176.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	Signs are mounted on the right and left shoulders; VSL system signs are also posted on Georgia DOT's website so people can see the current speeds.
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	Ability to manually change the speed limit for work zones.
To your knowledge, what is the public perception of the VSL system?	Negative because the public thinks its purpose is for generating funds.

MINNESOTA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

MINNESOTA	
Interview Date:	7/1/16
Name:	John McClellan and Brian Kary
Agency:	Minnesota DOT (MnDOT)
Email Address:	john.mcclellan@state.mn.us, brian.kary@state.mn.us
Phone Number:	651-234-7025
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Minnesota.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	I-35W (18 miles; Burnsville to Minneapolis). I-94 (10 miles; Minneapolis to St. Paul).
How long is the VSL system(s) (in miles)?	
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	Both systems are currently deactivated.
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	Both systems used automated operations.
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	Congestion.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	Both used an algorithm developed by the University of Minnesota-Duluth.
Are the same speeds set throughout the corridor? Is there a minimum distance?	No; lane-by-lane signage is spaced every ½ mile along the corridor. When congestion is detected, up to three sets of lane control signals (1.5 miles) can be activated prior to the congestion and speeds are gradually stepped down as traffic approaches congestion.

MINNESOTA	
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	The displays are per lane, but the same speed is displayed on all at the same location. The high-occupancy toll (HOT) lane displays a white diamond with no speed message. This was done to mitigate concerns about displaying different speeds over different lanes, but MnDOT did not want to artificially slow down the HOT lane.
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	The displays are per lane, but the same speed is displayed on all at the same location. The high-occupancy toll (HOT) lane displays a white diamond with no speed message. This was done to mitigate concerns about displaying different speeds over different lanes, but MnDOT did not want to artificially slow down the HOT lane.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	The system could be turned off by operators, but this was never done in practice; the system was usually left on.
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	No.
Is pavement type/condition considered in the speed setting algorithm?	No.
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	A minor reduction was observed in one location, but overall, there has been little observed difference in speeds.
What are the VSL system(s) pros and cons with respect to setting speed?	VSL requires enforcement to gain compliance. If it is not enforced, then speeds need to match drivers' expectations of what is sensible to them. The system was slow at responding to real-time conditions which caused the public to lose trust. The system was turned off to allow MnDOT time to reevaluate the system and make improvements.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	Loops and microwave.

MINNESOTA	
How reliable are the sensors that are used?	Both are reliable. Data was transmitted every 30 seconds, but that was not fast enough to match conditions. Loop detector data was averaged which added to the slow response of the system.
Do you have any design drawings for your Can you share any cost information for your system(s) (cost of the system, cost of any sensors used, maintenance costs, etc.)?	I-35W: Approximate cost to install was $16M. This included the lane control signals and structures. The sensors already existed. I-94: Approximate cost to install was $10M. This included the lane control signals and structures. The sensors already existed.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Advisory; making the system regulatory would have required a legal change. Static speed limit signs are 55 to 60 mi/h. The VSL would start displaying at 5 mi/h below posed speed with a minimum speed limit of 30 mi/h.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	I-35W: 155 signs. I-94: 101 signs.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	Overhead.
What is the display technology used (R2-1 signage, embedded YLED, shared CMS, etc.)?	Full matrix color CMS; 4 feet tall by 5 feet wide.
What were your control specs for the actual VSL signs (Bid documents? Standards and specs book?)?	RFP for equipment which was then provided as State-furnished materials to the installer.
Do you use any associated word messages (changeable message signs) in conjunction with VSL ("congestion ahead," "slow ahead," etc.)?	No.
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	No changes.

MINNESOTA	
To your knowledge, what is the public perception of the VSL system?	MnDOT received very few comments when the VSL was first implemented. Most were questions about the meaning of the messages. Drivers were not sure if the displayed speed reflected speeds ahead or the recommended speed. After the system was deactivated, MnDOT only had two inquiries about why the system was turned off.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	MnDOT will most likely decrease the length of the corridor. There have been maintenance issues with the signs so they are considering either replacing them in kind or using a single message sign as opposed to lane-by-lane signage to reduce installation, maintenance, and operations costs. MnDOT is evaluating whether a VSL or a simple message of SLOW TRAFFIC AHEAD is better for queue warning in a particular high crash area. Depending on the outcome, MnDOT would consider using VSL for spot locations rather than a full corridor approach.
Do you have any additional information/comments that we should include in our report?	VSL worked well for recurring congestion, but did not work well for non-recurring congestion. One of the VSL roadways is a 5-lane freeway with good sight distance so drivers can see the slowed traffic 1 mile ahead. Roadway design is a factor in the effectiveness of VSL. If MnDOT were to do it again, they would focus VSL in places where sight distance is not good; they would use it in spot locations. Drivers would not decelerate from 70 mi/h to 45 mi/h because they would get run over; it was unsafe. VSL should include additional information to help motorists understand the reason for the speed change. For example, messages such as SLOW TRAFFIC AHEAD. MnDOT has not seen a reduction in crashes. MnDOT will be using a queue warning system on a construction project on I-94 that uses Doppler radar sensors and PCMSs every ½ mile. The system will display the actual speed downstream. So the signs will display XX MPH SPEED ½ MILE AHEAD. When the speed is <15 mi/h, the sign will display STOPPED TRAFFIC AHEAD. This system could be more of a replacement for VSL if it is effective. The construction project will be 2 years. The queue warning system will be activated in August 2016 for 3 months and will then be active all next construction season. UMN will do the evaluation after summer 2017.

MINNESOTA	
Do you have any additional information/comments that we should include in our report? (Continued)	MnDOT uses ramp metering for roads with closer interchanges and VSL for roads where interchanges are farther apart. What is the cost/benefit for each? MnDOT emphasizes that there is a difference between speed harmonization and queue warning. They consider queue warning in spot locations. If the system is being used primarily as a queue warning system, would a dynamic message sign (DMS) or even a static sign with remote flashers be just as effective at less cost? Is speed harmonization effective in urban areas or is it more suited for exurban areas with long distances between ramps? The entire VSL cost needs to be compared with DMS and ramp metering strategies. Full VSL costs must include operations, maintenance, utilities, and end-of-life replacement, all of which are more involved than other strategies. MnDOT has found ramp metering to be the more cost effective.

MISSOURI DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

MISSOURI	
Interview Date:	5/20/2016
Name:	Alex Wassman
Agency:	Missouri DOT
Email Address:	alex.wassman@modot.mo.gov
Phone Number:	573-526-0121
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Missouri.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	I-270 in St. Louis.
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	Deactivated.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	The system was implemented as regulatory, but law enforcement was not sure what the speed limit was and reluctant to enforce and give citations. The system was consequently changed to advisory, but driver compliance became an issue so the system was deactivated.

NEVADA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

NEVADA	
Interview Date:	6/24/2016
Name:	Alex Wolfson
Agency:	Nevada DOT (NDOT)
Email Address:	awolfson@dot.state.nv.us
Phone Number:	775-834-8365
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Nevada.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	US-395 in Reno.
How long is the VSL system(s) (in miles)?	~4 – 5 miles.
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	Active.
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	The system is all automated with no human interface from the traffic management center.
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	Weather.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	There are two different speed limits on US-395 (55 mi/h and 50 mi/h). When the VSL is activated, all speeds are lowered to 45 mi/h. The VSL system is tied to 2 RWIS stations. A 30 mi/h wind gust is the threshold for activating the VSL. At least 30 minutes must pass with no 30+ mi/h wind measured on either RWIS before the speed limit can return to 50/55 mi/h.
Are the same speeds set throughout the corridor? Is there a minimum distance?	Yes.

NEVADA	
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	The VSL applies to all lanes.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	N/A.
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	No.
Is pavement type/condition considered in the speed setting algorithm?	No.
What are the VSL system(s) pros and cons with respect to setting speed?	The system has been hit or miss; NDOT has experienced hardware problems with the signs.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	2 road weather information system (RWIS) stations; one on the northern end and one on the southern end of the valley.
Do you have a cost/benefit analysis?	No.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Regulatory.
What are you experiences with enforcement and the judicial process when it comes to VSL?	Law enforcement is not positive and their confidence is the system is shaky because of the hardware problems being experienced. (For example, 45 mi/h is displayed in one direction and 55 mi/h is displayed in the opposite direction.) Law enforcement is notified by phone by the District's Road Operations when the larger wind warning system closes routes so the speed limit reduction implemented by the VSL system is implied.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	7 using embedded LEDs.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	Right shoulder mounted using NDOT's methodology for sign placement (typically placed at cross streets with US-395).

NEVADA	
MISCELLANEOUS	
To your knowledge, what is the public perception of the VSL system?	Some positive and negative reactions. Homeowners have been negative because they see the problems with the signs (e.g., blank signs). At the request of law enforcement, beacons flash when the speed changes. These beacons are too bright for homeowners so NDOT has unplugged them for now and they will try a dimmer.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	The US-395 system may be deactivated due to the hardware problems and law enforcement's lack of confidence. Additional VSL systems are being planned in urban areas. Specifically, interstates in Las Vegas.
Do you have any additional information/comments that we should include in our report?	No liability issues to report. They were not aggressive with a public relations campaign initially. VSL was implemented on US-395 because it is a low-volume road and does not attract a lot of attention. A good lesson is to start small when implementing VSL.

NEW JERSEY DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

NEW JERSEY	
Interview Date:	6/27/2016
Name:	Henry "Chip" Eibel
Agency:	New Jersey Turnpike Authority
Email Address:	eibel@turnpike.state.nj.us
Phone Number:	732-442-8600 ext. 2901
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	New Jersey.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	Statewide.
How long is the VSL system(s) (in miles)?	~148 miles.
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	Active.

NEW JERSEY	
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	Manual (used to be automatic).
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	Congestion, Weather.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	We used to use California's algorithm back when it was still automated. Currently, there is no automation to the VSL right now, although we are working with IBM and Rutgers to come up with a plan to automate the system. The supervisors drop the speed according to a current downstream issue. Most of the time, 45 mi/h is posted, unless there are foggy conditions or bad operations. The system used to work by posting 10 mi/h more than the downstream traffic. For example, if the speed was 25 mi/h downstream, we would post 35 mi/h because we didn't want to create a second pocket of congestion due the change in speed.
Are the same speeds set throughout the corridor? Is there a minimum distance?	There are different sections, but right now, the maximum speed is 65 mi/h. There are areas that are 55 mi/h. The supervisors manually populate the VSL, and just post 45 mi/h, unless there are poor conditions (snow, fog, etc.).
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	All lanes are same, but we are looking to have different speeds across lanes in the future. We do have a shoulder we use during high peak periods with variable message signs (VMS) and green arrows/red X's.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	There are guidelines regarding fog, heavy rains, heavy snow, etc. For visibility issues, troopers call in with how many mile markers they can see. If they can see 3 mile markers, then the speed is set to 35 mi/h. If they can only see 2 mile markers, then the speed is set to 30 mi/h, and then they contemplate closing the road.
Is pavement type/condition considered in the speed setting algorithm?	Pavement conditions are account for. If the road is being treated, then we will drop the speed.

NEW JERSEY	
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	It used to be very effective when it was automated. Our VSL signs are adjacent to VMS, so the VMS message emphasizes the reason for the speed reduction. For example, the VMS would say "Accident Ahead, Be Prepared to Stop." There is always a VMS adjacent to the VSL that gives a reason for the speed.
What are the VSL system(s) pros and cons with respect to setting speed?	We have had the VSL system for over 40 years, maybe almost 50. It is enforceable (not advisory), and the State police do issue tickets accordingly. Courts have also held to the standard. Automatic systems would allow more throughput, so that's the next step. The old system was automatic, but we had to switch to manual due to maintenance on the copper inductive loops every time we repaved. Since the traffic volume has increased so much now, it makes it really hard to carve out time for maintenance. Now we have difference sensors up and down the roadway that are very reliable, but they are spaced farther apart than the conductive loops we used to use, so there is a little bit of lag in the system.
EQUIPMENT AND COSTS	
How reliable are the sensors that are used?	We get exact traffic counts now - no problems at all. Sensys is the name of the new sensors they use now. Caltrans uses them and they are also used on Golden Gate Bridge.
Can you share any cost information for your system(s) (cost of the system, cost of any sensors used, maintenance costs, etc.)?	I would have to look into it. Sensor reinstallation is always included in our paving contracts. So now when we repave, we have funding to replace the sensors in that repaving section to ensure functionality.
Do you have any design drawings for your system layout? These drawings can be a typical layout or a site-specific layout.	http://www.state.nj.us/turnpike/standard-drawings.html.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Regulatory.

NEW JERSEY	
What are you experiences with enforcement and the judicial process when it comes to VSL?	We have experiences with law enforcement all the time. Anytime there is a bad crash, especially secondary crashes, troopers will come back to us and ask what the VSL said at that time of the incident. Then, the troopers will issue a summons based on the speed that was posted.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	~250, including VMS and VSL signs.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	The Turnpike has overhead VSL signs over the right lane and full VMS signs as well. The speed limit and variable messages are all posted in the same sign.
Do you use any associated word messages (changeable message signs) in conjunction with VSL ("congestion ahead," "slow ahead," etc.)?	Yes: • ACCIDENT AHEAD BE PREPARED TO STOP. • DEBRIS AHEAD DRIVE WITH CAUTION. • DELAYS AHEAD BE PREPARED TO STOP. • MOWING OPERATION AHEAD. • REDUCE SPEED CONGESTION AHEAD.
MISCELLANEOUS	
To your knowledge, what is the public perception of the VSL system?	The tricky part is you have to post the appropriate speed. There is nothing worse than saying there is a downstream problem, and then the problem isn't there. This is why we want to make our system automated again. The main difficulty is returning the speed back to normal after the problem has cleared. The better you get at this, the better it is for drivers, and you can hopefully prevent secondary collisions.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	No. Our entire network has VSL signs on it now.
Do you have any additional information/comments that we should include in our report?	We only post VSL and VMS if it's within 2 miles of the lane closing due to construction, congestion, debris, etc. If we post signs further away, it's too far away and drivers tend to forget by the time they get there. For example, if there is a lane closing from mile marker 10 to mile marker 8, the VSL and VMS at mile marker 12 may say "Road Work Ahead, 2 miles." Then at mile 8, the VMS would say "roadwork continues" b/c you are now within the work zone.

OREGON DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

OREGON	
Interview Date:	6/24/2016
Name:	Mike Kimlinger
Agency:	Oregon DOT
Email Address:	Michael.J.Kimlinger@odot.state.or.us
Phone Number:	503-986-3557
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Oregon.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	1) Oregon Route (OR) 217 – Adjacent to I-5 in Portland area. 2) OR 213 – West of downtown Portland; single location sign at a single intersection, recreational traffic issues, 1st deployment of VSL in Oregon.
How long is the VSL system(s) (in miles)?	1) 7 miles. 2) 1 intersection.
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	Both are active.
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	1) Fully automated. 2) Semi-hybrid.
What is the primary function of the VSL system? **• Congestion** **• Weather** **• Work Zones**	1) Congestion, weather. 2) Congestion.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	1) In-road, downstream sensors are used that measure 85th percentile speeds at a 1 minute interval. We pair up the segments of the highway so that the decrease from one speed to the next is no more than 10 mi/h between segments. The current algorithm can be used for advisory and regulatory systems. 2) Single sign.
Are the same speeds set throughout the corridor? Is there a minimum distance?	1) No. There are 7-8 segments through the whole corridor, and each segment is evaluated separately.

OREGON	
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	1) There is a friction factor sensor at each sensor location. When the friction factor gets down to certain level, the weather piece of the algorithm takes over from the congestion piece of the algorithm. It just depends on which one reports the most needed condition change. Everything is automated.
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	1) No. OR 217 is a freeway-level facility with a regulatory speed of 55 mi/h, but vehicles can drive much faster than that (curvature piece is not an issue). We have 5 other systems in line to be installed in the next couple years, and none of them need to account for roadway curvature.
Is pavement type/condition considered in the speed setting algorithm?	1) Surface conditions are all weather related, so the pavement type/condition is included in the friction factor portion. The condition of the roadway is considered when calibrating the friction factor.
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	Yes for both systems.
What are the VSL system(s) pros and cons with respect to setting speed?	1) It is very difficult for any algorithm to react like a driver. Recovery from a reduced speed is very difficult, and it is hard to build a VSL algorithm to react like a human would. It takes a lot of tweaking to make it more naturalistic. Most of the public feedback has been along these lines, although we have not received much public feedback.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	1) Radar-based sensors from Wavetronix.
How reliable are the sensors that are used?	1) Very reliable.
Can you share any cost information for your system(s) (cost of the system, cost of any sensors used, maintenance costs, etc.)?	1) They could send us a PowerPoint presentation containing cost information.
Do you have any design drawings for your system layout? These drawings can be a typical layout or a site-specific layout.	1) They could send us a set of plans, if necessary.

OREGON	
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	1) Advisory. 2) Regulatory.
What are you experiences with enforcement and the judicial process when it comes to VSL?	1) One of the reasons we went to an advisory system on OR 217 was that there was not a lot of extra shoulder and the State troopers and local police were worried about being able to do any kind of enforcement since enforcement can cause more congestion. Currently, the system is enforced by "basic rule" rather than examining vehicle speed (Is the individual driving safely and prudently?). The same reasoning is being used for the other areas where VSL systems will be installed. We are planning to install a 30-mile, weather-based, regulatory VSL system because we hope that regulatory will mean better compliance. But first, we have to change State law to install a VSL system on the interstate. Currently, the State law discusses what the speed limit should be on each interstate, so our ability to change the speed requires us to go through a legal adoption process, which is very long and drawn out. In order to install the future regulatory system, we must have the laws in place. There is some compliance on OR 217, a substantial reduction in speed differentials, better harmonizing of speeds, increase in capacity, and a reduction in crashes. Since safety has improved, the system is considered effective.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	1) There are 7 or 8 segments and a set of signs for each segment. There is a sign over each lane at each location plus VMS sign that further discusses current conditions. There are about 40-50 signs on main line plus "travel time" messages at every intersection as you enter the OR 217 corridor, which accounts for another 30-40 VMS signs. All the signs are full matrix. We could change the system from advisory to regulatory, if needed, at any time. 2) Just one sign.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	1) Overhead. 2) Side-mounted.

OREGON	
Do you use any associated word messages (changeable message signs) in conjunction with VSL ("congestion ahead," "slow ahead," etc.)?	1) Yes – "Congestion Ahead" signage is used and an approximate distance is given. Weather conditions are also included in messages (e.g. wet, icy, etc.).
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	1) We do not have much experience with work zones on OR 217 yet. The last major construction in the area was the installation of the VSL system itself. This is an experience still to be learned.
To your knowledge, what is the public perception of the VSL system?	1) We have received bits and pieces of feedback. The feedback seems to be fairly positive, other than early in system deployment (the algorithm has been tweaked since). We have not received any bad press or public comments since the last set of tweaking.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	1) OR 217 is an isolated corridor, so the VSL system will not be extended. It is a heavily instrumented corridor – weather-based, speed-based active curve warning systems at either end also exist.
Do you have any additional information/comments that we should include in our report?	1) In order to achieve low bad press, public notification is important, including why and when the system will be installed, functioning, etc. Deployment of a VSL system anywhere requires someone who understands the system and can tweak the algorithm on a regular basis for the first 6 months to a year. The algorithm will need to be adjusted based on its location and the kinds of drivers that utilize the roadway. It is easier to switch a system from advisory to regulatory, but it is harder to do the reverse.

TENNESSEE DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

TENNESSEE	
Interview Date:	5/13/2016
Name:	Donald Gedge
Agency:	Tennessee DOT
Email Address:	donald.gedge@tn.gov
Phone Number:	615-253-0041
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Tennessee.

TENNESSEE	
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	I-75 in Chattanooga.
How long is the VSL system(s) (in miles)?	Total of 9.0 mi . NB = 3.4. SB = 5.6.
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	Active.
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	Hybrid.
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	Weather.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	Determined by conditional visibility algorithm due to weather event(s) related to fog, traffic speed, and stopping distances.
Are the same speeds set throughout the corridor? Is there a minimum distance?	Yes: 70 mi/h: visibility <10 mi / >1320 ft. 50 mi/h: visibility <1320 ft. / >480 ft. 35 mi/h: visibility <480 ft. / > 240 ft.
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	One display is used for all lanes.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	N/A.
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	Yes; sight distance relative to fog conditions. Signs are located in relation to entrance ramps and MUTCD guidelines.

TENNESSEE	
Is pavement type/condition considered in the speed setting algorithm?	N/A.
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	Yes. Speed data is available from the Roadway Traffic Monitoring System.
What are the VSL system(s) pros and cons with respect to setting speed?	Pros include real-time, instant speed reduction and functional reliability.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	Environmental sensors that are monitored 24/7; Preventive maintenance and calibration are performed quarterly.
How reliable are the sensors that are used?	The sensors are very reliable.
Can you share any cost information for your system(s) (cost of the system, cost of any sensors used, maintenance costs, etc.)?	The VSL system was installed as part of the Fog Warning System, so the costs are in the original construction contracts and past and current preventative maintenance contracts.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Regulatory.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	10.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	Right shoulder mounted.
What is the display technology used (R2-1 signage, embedded YLED, shared CMS, etc.)?	Embedded white LEDs.
What were your control specs for the actual VSL signs (Bid documents? Standards and specs book?)?	Manufacturer specification sheets.
Do you use any associated word messages (changeable message signs) in conjunction with VSL (“congestion ahead,” “slow ahead,” etc.)?	Yes.

TENNESSEE	
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	The VSL system is used to enhance work zone safety and driver awareness of work zones.
To your knowledge, what is the public perception of the VSL system?	It has been positive.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	No, not in this area.

VIRGINIA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

VIRGINIA	
Interview Date:	6/22/2016
Name:	Mike Fontaine
Agency:	Virginia DOT
Email Address:	Michael.Fontaine@VDOT.Virginia.gov
Phone Number:	434-293-1980
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Virginia.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	1) I-66 – US 50 to I-495. 2) I-77 – Fancy Gap Area. 3) I-95 Express Lanes.
How long is the VSL system(s) (in miles)?	1) 12.5 – 13 miles. 2) 15 miles.
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	1) Active (VSL was turned on, then back off after a week of operation. It took 3 months of turning the algorithm to turn it back on again, which was in the middle of January). 2) Planned (end of summer 2016). 3) Active.
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	1) Automated. 2) Hybrid. 3) Manual.

VIRGINIA	
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	1) Congestion, Work Zones. 2) Weather. 3) Congestion.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	1) The algorithm is still being iteratively tweaked. 2) The posted speed primarily depends on the available visibility. We do not want a lot of speed variance, so we are trying to "split the difference" between vehicle's current speeds and the desired speeds.
Are the same speeds set throughout the corridor? Is there a minimum distance?	Dynamic segments are calculated based on current traffic conditions. We look at the slowest speed and then slow down the oncoming traffic into that slower speed. 2) We use a smoothing and trooping algorithm. Dynamic segments exist on this corridor, much like on I-66. We determine where the worst visibility conditions exist, and the speed is set based on the worst case.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y," etc.)?	1) Rain is not used at all. 2) Rain is not used at all. We want to pursue this in the future, but it is not currently included in the algorithm.
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	1) Design speeds are much higher than the posted speed limits. Roadway curvature is not included in the algorithm because the roadway is designed for 70 mi/h or more. 2) Sight distance is included in the algorithm since it is a weather-based system.
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	1) We are still evaluating the effectiveness of the system. It is a congestion-based system, so vehicles can only go but so fast when there is congestion on the roadway. A more important question for evaluating system effectiveness may be "Are we more smoothly transitioning vehicles into different speeds?" 2) The system has not been turned on yet.

VIRGINIA	
What are the VSL system(s) pros and cons with respect to setting speed?	1) Compliance is always a question, especially without automated speed enforcement (Europe has this). We have to rely on traditional enforcement and make-do with what we have. 2) We have a challenge due to competing constraints: there is a "safe speed" and then there is actual driver behavior. Sometimes drivers are traveling 20 mi/h over the safe speed. When it comes time to set the speed limit, we don't want to create increased variance, but we also want drivers to travel at a safe speed. This balance can be very difficult.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	Wavetronix speed sensors are used on I-66 and I-77.
How reliable are the sensors that are used?	The sensors are extremely reliable on I-66 and I-77.
Can you share any cost information for your system(s) (cost of the system, cost of any sensors used, maintenance costs, etc.)?	1) The system was turned on in the middle of September 2015. The total cost was $39 million. This cost included a lot of additional costs for commutations, cameras, infrastructure, gantries, etc. The gantries themselves were probably about $24 million. 2) This system is going to cost about $7.5 million, which includes a fair amount of additional upgrades (power, etc.).
Do you have any design drawings for your system layout? These drawings can be a typical layout or a site-specific layout.	1) I-66 has a huge plan set, but it would be hard to track down and hard to interpret. 2) We could see if we can share.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	1) Advisory. 2) Regulatory. 3) Regulatory.

VIRGINIA	
What are you experiences with enforcement and the judicial process when it comes to VSL?	1) The system is advisory, so drivers cannot be cited for speeding. The system was implemented more for speed harmonization-related goals. We have different driver attitudes in the United States than in Europe. In the United States, drivers don't slow down unless they see a reason. 2) Enforcement is very challenging. This system drops the speed when there is fog, and we can't have an officer on the side of the roadway when there is heavy fog because it is a safety concern. We are still working through how to enforce the VSL system without endangering the officers. It is possible that enforcement would occur after-the-fact.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	1) 21 gantries in each direction and 3-5 signs per gantry. 2) 44 signs.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	1) Overhead. 2) Side-mounted.
What is the display technology used (R2-1 signage, embedded YLED, shared CMS, etc.)?	2) Typical speed limit signs are used, expect that the posted speed can be changed on the sign. There will be 8 of these VSL signs. There will also be 36 full matrix DMS signs where the speed limit and various messages may be posted.
Do you use any associated word messages (changeable message signs) in conjunction with VSL ("congestion ahead," "slow ahead," etc.)?	1) Yes. For example, "Congestion ahead." 2) Yes. For example, "Fog ahead."
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	1) Overhead lane use control signs are used (can either post VSL or green arrow/red "X" indicating lane availability). 2) VSL can be used by operators to reduce the speed limit; however, this is a rural, very low volume area, so work zones don't really cause traffic problems.
To your knowledge, what is the public perception of the VSL system?	1) The challenge in educating drivers with repeated explanations for speed limits and other outreach activities. VDOT employees in the northern region could provide additional insight. 2) We won't know until the system is activated.

VIRGINIA	
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	1) There are currently no plans to extend the current system. There may be significant geometric changes along I-66, so nobody wants to do anything until we know exactly what the roadway will look like. 2) There are no plans to extend the VSL system.
Do you have any additional information/comments that we should include in our report?	Note that the Concept of Operations document I sent you for I-66 was never updated.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

WASHINGTON STATE	
Interview Date:	6/3/2016
Name:	Vinh Q. Dang
Title:	Freeway Operation Engineer
Agency:	Washington State DOT
Email Address:	dangv@wsdot.wa.gov
Phone Number:	206-410-0003
GENERAL VSL INFORMATION	
What State is the VSL system(s) located in?	Washington.
What route(s) is the VSL system(s) located along and how would you describe that location (the entire State, only a certain area, along certain roadways, etc.)?	There are 2 functional groups: Group 1: Weather / road environmental condition responsive: • US-2 Vicinity Steven pass. • I-90 Vicinity Snoqualmie pass. Group 2: Congestion / Q-Warn / Speed Transition as part of the ATM corridors. • I-5 Tukwila to Seattle. • I-90 Bellevue to Seattle. • SR 520 Bellevue to Seattle.
How long is the VSL system(s) (in miles)?	The VSL system lengths are: • US-2 Vicinity Steven pass (23 mi over the pass). • I-90 Vicinity Snoqualmie pass (25 mi over the pass). • I-5 as part of ATM corridor (8 mi). • I-90 as part of ATM corridor (10 mi). • SR 520 as part of ATM corridor (8 mi).
What is the status of the VSL system(s) (Active, Removed, Under Construction, Planned, etc.)?	All systems are active.

WASHINGTON STATE	
What is the operation type of the VSL system(s) (Manual, Automated, or Hybrid))?	Group 1: Both systems are hybrid, semi-automatic. Group 2: For the ATM corridors, all 3 systems are fully automatic.
What is the primary function of the VSL system? • **Congestion** • **Weather** • **Work Zones**	1) Weather. 2) Congestion.
SETTING SPEED LIMITS	
Describe how the displayed speed limit is determined. If you use an algorithm, can you share it with us?	Group 1: The display speed is determined from a look-up table. Currently the operator looks-up the table and manually displays the speed. Group 2: The displayed speeds is determined and adjusted every minute by monitoring downstream conditions, calculating the 85th percentile speed, comparing multiple speed values in the corridor, performing smoothing/ transitioning calculations, and displaying speed updates on one or more gantries as needed.
Are the same speeds set throughout the corridor? Is there a minimum distance?	No. See above.
What lanes does your display(s) apply to (one display for all lanes, there are displays per lane but speeds are identical, HOV lane is a different speed, etc.)?	All GP lanes at the same station have the same speed. An HOV lane at a station might have different speed from the GP lanes.
How do wet conditions affect speed selection (rain intensity of "X" reduces the speed by "Y", etc.)?	Group 1 has wet pavement conditions as part of the look-up table. Speeds are displayed accordingly. Group 2 calculates speed based on actual measured downstream condition, hence no need for wet condition adjustment.
Does roadway curvature (horizontal or vertical) and sight distance get considered in your speed setting algorithm? Did you locate your VSL signage in its current spot because of sight distance or other issues?	No to both.
Is pavement type/condition considered in the speed setting algorithm?	No.

WASHINGTON STATE	
Has VSL been effective at reducing speeds? Is operating speed data available in the vicinity of your VSLs?	Yes to both.
What are the VSL system(s) pros and cons with respect to setting speed?	Group 1 is in rural setting. The spacing between signs are farther apart. Most of the time, the speed are set for longer segment of the corridor (if not for the entire length). The speed variation tends to be small. Group 2 is in urban setting and responsive to downstream congestion. Spacing between gantries is approximately ½ mi apart. Variation is tighter at 5 mi increment.
EQUIPMENT AND COSTS	
What sensors are used to determine speed limits (speed indicators, environmental sensors, etc.)?	The measured occupancy is converted to speed for calculations. At locations where we have speed trap, the measured speed is used.
How reliable are the sensors that are used?	Very reliable. We have extensive experience in calculating travel times based on speed converted from occupancy measures.
Can you share any cost information for your system(s) (cost of the system, cost of any sensors used, maintenance costs, etc.)?	The cost is not very clear because many hardware, devices, and processes have already been in place before VSL deployment.
Do you have any design drawings for your system layout? These drawings can be a typical layout or a site-specific layout.	Yes.
ENFORCEMENT	
How is your VSL system(s) enforced (regulatory, advisory, hybrid)?	Regulatory.
What are you experiences with enforcement and the judicial process when it comes to VSL?	We have not been challenged yet.
VSL SIGNS	
How many VSL signs are associated with your system(s)?	Few hundred for both Groups 1 and 2.
Where are the VSL signs located (right/left shoulder, overhead, median, side-mounted, etc.)?	Group 1: On US 2, undivided highway, VSL signs are on the right. On I-90, mixed. Some locations have over head, some have signs on both side of one direction. Varied by location's geometrics.

WASHINGTON STATE	
What is the display technology used (R2-1 signage, embedded YLED, shared CMS, etc.)?	Group 1: Hybrid cut-out LED speed. Group 2: Full color, full matrix. Speed limits are graphics resided locally in the sign controller.
What were your control specs for the actual VSL signs (Bid documents? Standards and specs book?)?	Design, bids, build.
Do you use any associated word messages (changeable message signs) in conjunction with VSL ("congestion ahead," "slow ahead," etc.)?	Group 1: No. Group 2: Yes.
MISCELLANEOUS	
How do you accommodate work zones in the vicinity of the VSL system(s)?	Display the reduced speed if needed.
To your knowledge, what is the public perception of the VSL system?	Group 1: Well received. Group 2: Initial reservation during the first few months of deployment. Well received by now after tweaking of algorithm and lower threshold.
Are you planning to expand or decrease the length of the VSL corridor (based on the public's response)?	No adjustment to the existing system limits. If there are any, it will be based on engineering judgment rather than public opinion process.
Do you have any additional information/comments that we should include in our report?	Always follow the system engineering process. Let the corridor goals drive the operation needs. Let the operation needs drive the system requirements. Let the system requirements drive the specifications. Do not deploy VSL just because it's "cool." Credibility is critical. Following a display of a reduced speed limit should be a real condition warranting a reduction of speed.

WISCONSIN DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

WISCONSIN	
Interview Date:	7/7/2016
Name:	Paul Keltner
Agency:	Wisconsin DOT (WisDOT)
Email Address:	paul.keltner@dot.wi.gov
Phone Number:	414-225-3727

INTERVIEW QUESTIONS	
Based on what you have heard from other agencies, what is your impression of VSL?	Some agencies are backing away from VSL because of unexpected consequences. Buy-in from law enforcement (after VSL is implemented) is an issue. The expected benefits have not proved out.
Have you considered implementing VSL in Wisconsin?	WisDOT has looked at the VSL systems in Minnesota and Seattle. Wisconsin wants to increase capacity; they want speed harmonization and less crashes to increase throughput.
What institutional and policy hurdles would you encounter if implementing VSL?	To implement VSL in Wisconsin there would need to be modifications to State statutes. VSL would also require a change in the process for setting speeds.
If Wisconsin implemented VSL, would you use it for congestion, work zones, weather, or other functions?	WisDOT would use VSL for ATM, managing congestion, and during winter weather events.

<table>
<tr><th colspan="2">WISCONSIN</th></tr>
<tr><td rowspan="10">What kind of information would you want to have in a VSL document to help with decisions?</td><td>Can you ever get compliance with an advisory system?</td></tr>
<tr><td>Cost/benefit information. They can estimate costs, but want to know what other agencies' actual costs have been. It is also hard to explain to the public the benefits based on the cost.</td></tr>
<tr><td>Information on safety benefits. What have other States seen in terms of safety?</td></tr>
<tr><td>The synthesis report should include best practices on collaboration, cooperation, communication, and outreach.</td></tr>
<tr><td>Information on signage; specifically spacing (how far apart to install the signs).</td></tr>
<tr><td>What threshold do other agencies use for activating weather-responsive VSL systems? Do they activate for mist, flurries, or 1' of snow?</td></tr>
<tr><td>How are messages activated?</td></tr>
<tr><td>What rate of change do agencies use? Do agencies step down speeds by 5 mi/h or something different?</td></tr>
<tr><td>Do agencies use lane-by-lane signage with different speeds or the same speed for all lanes?</td></tr>
<tr><td>Have any public surveys been done? Wisconsin will have a queue warning system this summer which will operate somewhat like an advisory VSL. They will have a survey as part of this project.</td></tr>
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Federal Highway Administration

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