SYNTHESIS OF VARIABLE SPEED LIMIT SYSTEMS

Research Project Briefing

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• Success of Active Traffic Management (ATM)
• Renewed interest in expanding their use in the United States during the past 15 years for operational and safety benefits
• Three primary functions to improve safety and operations:
  • Reducing congestion
  • Reducing speeds during inclement weather
  • Managing speeds during traffic events such as work zones and incidents
• Regulatory v.s. advisory
Document the VSL state of practice in the U.S. and identify trends, successful strategies, benefits, and challenges from the following perspectives:

• Planning and Policy
• Design, Deployment, and Standards
• Operations and Maintenance
• Outcomes
The Research Team used two methods to collect information for analysis.

1. Literature Review
2. Agency Interviews
Literature review sources included:

- Published Research

- Agency Documents
  - Policy manuals
  - Operations manuals
  - Enforcement documentation
  - Legislation
  - Public information campaign materials
**METHODOLOGY: DATA COLLECTION**

Information was collected from 13 agencies.

<table>
<thead>
<tr>
<th>Participating Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona DOT</td>
</tr>
<tr>
<td>Florida DOT</td>
</tr>
<tr>
<td>Georgia DOT</td>
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<tr>
<td>Minnesota DOT</td>
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<tr>
<td>Missouri DOT</td>
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<tr>
<td>Nevada DOT</td>
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<tr>
<td>New Jersey Turnpike Authority</td>
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<tr>
<td>Oregon DOT</td>
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<tr>
<td>Pennsylvania Turnpike</td>
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<tr>
<td>Tennessee DOT</td>
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<tr>
<td>Virginia DOT</td>
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<tr>
<td>Washington State DOT</td>
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<tr>
<td>Wisconsin DOT</td>
</tr>
</tbody>
</table>
All collected information was organized in an Excel spreadsheet with categories such as:

- General VSL information (e.g., location, length of corridor, etc.)
- Setting speed limits
- Equipment and costs
- Enforcement
- Signage
## METHODOLOGY: SYNTHESIS AND ANALYSIS

<table>
<thead>
<tr>
<th>State</th>
<th>Location</th>
<th>Length of System</th>
<th>Status</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>I-4</td>
<td>10.5 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td></td>
<td>US 27</td>
<td>3 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td>Georgia</td>
<td>I-285</td>
<td>36 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td>Minnesota</td>
<td>I-35W</td>
<td>18 mi</td>
<td>Temporarily Deactivated</td>
<td>Advisory</td>
</tr>
<tr>
<td></td>
<td>I-94</td>
<td>10 mi</td>
<td>Temporarily Deactivated</td>
<td>Advisory</td>
</tr>
<tr>
<td>Nevada</td>
<td>US 395 Alternate</td>
<td>5 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td>New Jersey</td>
<td>NJ Turnpike</td>
<td>148 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td>Oregon</td>
<td>OR 213</td>
<td>Single intersection</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td></td>
<td>OR 217</td>
<td>7 mi</td>
<td>Active</td>
<td>Advisory</td>
</tr>
<tr>
<td>Tennessee</td>
<td>I-75</td>
<td>9 mi</td>
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<td>Regulatory</td>
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<td>Virginia</td>
<td>I-66</td>
<td>13 mi</td>
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<tr>
<td></td>
<td>I-95 Express Lanes</td>
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<td>Washington</td>
<td>I-90 (near Snoqualmie Pass)</td>
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<tr>
<td></td>
<td>US 2</td>
<td>23 mi</td>
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<td>Regulatory</td>
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<tr>
<td></td>
<td>I-5</td>
<td>8 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td></td>
<td>I-90 (Bellevue to Seattle)</td>
<td>10 mi</td>
<td>Active</td>
<td>Regulatory</td>
</tr>
<tr>
<td></td>
<td>SR 520</td>
<td>8 mi</td>
<td>Active</td>
<td>Regulatory</td>
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## State of Practice

<table>
<thead>
<tr>
<th>Primary Function(s)</th>
<th>Operation Type(s)</th>
<th>Data Used to Inform VSL</th>
<th>Authority</th>
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</thead>
<tbody>
<tr>
<td>Congestion-based ATM</td>
<td>Weather</td>
<td>Work Zones</td>
<td>Manual</td>
</tr>
<tr>
<td>Florida</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Georgia</td>
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<td>✓</td>
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<td>Minnesota</td>
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<td>Virginia</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Washington</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
STATE OF PRACTICE:
CONGESTION-BASED ATM

• I-4 in Florida
  • Installed to efficiently manage large volumes of traffic and improve speed harmonization.
  • VMS used in conjunction with VSL to display relevant information to drivers.
  • VSL system uses traffic data to recommend an appropriate speed limit, which the operator may accept or alter.

• US-27 in Florida
  • Installed to improve safety by lowering speeds in a school zone on a high speed roadway.
STATE OF PRACTICE: CONGESTION-BASED ATM

• **I-285 in Atlanta, GA**
  - Volume and speed data are used to calculate appropriate speed limits based on current traffic conditions.
  - Fully automated, but a manual override may occasionally be necessary to properly handle more complex situations (e.g. work zones).

• **OR 217 in Oregon (Advisory)**
  - Corridor is divided into subzones where real time speed data is collected and speeds are displayed as the lowest of the 85th percentile speed or based on speed of downstream traffic
- **I-66 in Northern Virginia (Advisory)**
  - Speed limits are determined by a smoothing speed algorithm, which identifies the current lowest speeds along the roadway and appropriately slows upstream traffic.

- **New Jersey Turnpike**
  - Speed limits are manually reduced to 45 mph in response to a downstream incident, except when poor weather conditions are a factor. VMS is used in conjunction with the VSL to notify drivers about the cause of the speed reduction.
STATE OF PRACTICE: CONGESTION-BASED ATM

- Seattle, Washington
  - I-5, I-90 (Bellevue to Seattle), and SR 520
  - 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.
  - VMS is used in conjunction with VSL within all three systems.
• Weather
  • US 395 in Reno, NV – VSL is used as part of a larger wind-warning system
  • New Jersey Turnpike has a specific weather algorithm based on visibility
  • I-75 near Chattanooga, TN is a fog based system activated using weather sensors
  • OR 217 uses weather-related algorithms to calculate speed limits based on surface friction and weather sensors
  • “Guidelines for the Use of Variable Speed Limit Systems in Wet Weather” FHWA-SA-12-022
DEACTIVATED SYSTEMS

**I-35W and I-94 in Minneapolis/St. Paul, MN**
- The delay in real-time data was an issue.
- Poor driver compliance caused by lengthy sight distance.

**I-270 in St. Louis, MO**
- In response to law enforcement concerns, the regulatory system was changed to advisory.
- System ultimately deactivated due to poor driver compliance once the system became advisory.

**Woodrow Wilson Bridge Project on I-95**
VSL removed once construction was complete.
**Rationale** - Safety is a significant motive for implementing VSL.

**State Examples**
- Oregon and Virginia use VSL to combat crash rates in specific locations.
- Florida uses VSL to control high vehicular speeds around a school zone.
Overarching Design and Operations Considerations – A majority of VSL systems are automated, however there are some agencies operating their system manually.

State Example for Manual Operation

- The New Jersey Turnpike Authority previously operated automatically, but it was converted to the current manual system due to the level of maintenance the copper inductive loops required.
Public Outreach - Operating agencies use videos, websites, and other outreach materials to provide information about VSL systems. They also provide public feedback mechanisms.

State Example

• Georgia DOT developed an educational video about why the VSL system was installed, what it is, how it works, and the benefits drivers can expect to address negative public perceptions.
**Liability** – *It is best practice to consult with the operating agency’s attorney when designing a VSL system.*

**State Examples**
- 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.
- The VSL system on I-526 in South Carolina was created due to a court order that the I-526 Cooper River Bridge construction project must include a low visibility warning system, which included VSL.
Infrastructure Requirements

- This table shows the fundamental VSL elements for a system operating to manage speeds during congestion, weather, and work zones.

<table>
<thead>
<tr>
<th>Variable Speed Limit Infrastructure Component</th>
<th>Variable Speed Limit Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congestion</td>
</tr>
<tr>
<td>Changeable Speed Limit Signs</td>
<td>✓</td>
</tr>
<tr>
<td>Weather/Environmental Sensors</td>
<td></td>
</tr>
<tr>
<td>Traffic Speed/Volume Sensors</td>
<td>✓</td>
</tr>
<tr>
<td>Communications Equipment to Transmit Data</td>
<td>✓</td>
</tr>
</tbody>
</table>
Signage Type and Placement – Signage type, spacing, and installation locations differ from system to system.

State Examples

• Florida has ~20 VSL signs along the I-4 corridor, with at least one per mile.

• Minnesota 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.
  • Due to maintenance issues, the agency is considering either replacing the signs or using a single message sign as opposed to lane-by-lane signing.
Signage Type and Placement (continued)

- Oregon, Virginia, and the New Jersey Turnpike post VMS adjacent to VSL signs to describe the reason for the speed change.
- Tennessee uses a FOG SPEED LIMIT word message on the changeable speed limit sign mounted on the shoulder.
- The signs along I-5, I-90 (Bellevue to Seattle), and SR 520 in Washington are full color and full matrix.
Integration with Active Traffic Management and/or RWIS

- VSL systems in Virginia, Nevada, Utah, and on the Pennsylvania Turnpike 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.
Control Algorithms

- Speed control algorithms can be categorized into two types:
  1. Speed homogenization projects that focus on improving safety, and
  2. Multi-objective projects whose goal is to improve mobility and/or reduce environmental impacts in addition to speed homogenization.

- Algorithms for congestion-focused systems are often more complex because they must consider overall corridor effects rather than simply reducing speed and speed variance for safety.

- Congestion-focused projects may also be weather responsive if adverse weather conditions exist.
The VSL on the New Jersey Turnpike were previously automatically calculated and posted according to average travel speeds collected by copper loop detectors located in the pavement.

- The algorithm was designed to reduce the speed limit in 5 mi/h increments with a minimum speed limit setting of 30 mi/h.

Loop detectors and side-fire radar, which detect volume, speed, and occupancy, determine speed limits on I-4 in Florida.

- When an issue is detected, the VSL system alerts the traffic management staff and recommends an appropriate speed.
• Nevada’s wind-warning VSL system lowers speeds from 50 or 55 mi/h to 45 mi/h when gusts of 30 mi/h are detected.

• Tennessee VSL system on I-75 is weather-responsive with speeds changed based on visibility during fog conditions
  • 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.
Manual vs. Automatic Operations

• Most VSL systems operate in a hybrid fashion using a combination of automated and manual speed changes.

• Delaware and New Jersey Turnpike use manual systems.

• Nevada’s wind-warning system is fully automated.

• In Georgia, Florida, and Washington operators may override the system to set speeds manually.
Advisory vs. Regulatory Operations (Enforcement)

• Many systems are still advisory or cannot be enforced as intended due to State laws.

• VSL systems require enforcement to gain driver compliance.
  • Lack of enforcement caused the VSL system in Missouri to fail and be deactivated.

• Where enforceable, lack of access to speed limit information by police is a significant challenge.
  • Georgia DOT provided the Highway Patrol with a direct data feed so they can see the signs at all times.
FINDINGS: OPERATIONS

• Problems with the system have caused law enforcement to lose confidence in VSL and become reluctant to enforce the VSL-set limits (e.g., Nevada)

• Regulatory speeds can be difficult to enforce when exceeding them can be dangerous to law enforcement, such as during severe weather conditions.
Performance Measurement

- Traffic efficiency:
  - Average speed and travel time, travel time reliability, traffic throughput, driver journey times, traffic flow stability, number of significant shockwaves.

- Safety:
  - General crash rates by crash severity and by crash types
  - Crash rates during certain seasons (e.g., during winter if a VSL is deployed for severe winter weather conditions).

- Other:
  - Driver subjective ratings, compliance rates, emissions measured by environmental sensors.
Compliance

• Compliance rates depend on many factors, including:
  • Regulatory vs. advisory systems
  • Enforcement strategies
  • Public education/outreach
  • Others

• European sites typically report higher compliance rate and larger benefits due to automated enforcement.
FINDINGS: OUTCOMES

• Despite extensive outreach, compliance on I-4 in Florida remains minimal due to lack of enforcement; compliance is high, however, on US 27, where the VSL is regulatory and thus enforced.

• Despite limited compliance with Oregon’s advisory system, it has resulted in substantial reductions in speed differentials, improved harmonization, increased roadway capacity, and reduced crashes.
<table>
<thead>
<tr>
<th>Location, Time</th>
<th>Variable Speed Limit (VSL) Summary</th>
<th>Evaluation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Homogenization Projects</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 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 |
| 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. |
• Cost of deployment a VSL system along a route varies from less than $10 million to almost $40 million

• Dependent on the existence of current intelligent transportation system facilities, such as traffic detectors, VMS, and gantries
SUMMARY: VSL BENEFITS

• Smoother traffic flow and less delay.
• Safer speeds in work zones.
• Ability to tie to RWIS data to reduce speeds during inclement weather.
SUMMARY: VSL CHALLENGES

- Enforcement
- Driver compliance
- Hardware/software failures
- Lag in data
- Returning the VSL back to the normal operating speed
- Lack of cost/benefit information to support rationale for a VSL system
• Collecting and Processing Big Data

• Consideration of Driver Compliance

• Variable Speed Limit Systems with Connected/ and Automated Vehicles