Using Variable Speed Limits to Improve Safety During Fog Events: A Case Study of I-77 in Virginia

Michael D. Fontaine, P.E., Ph.D.
Virginia Transportation Research Council

Daniela Gonzales and Katie McCann
University of Virginia
Site Description

- I-77 is a rural, 4 lane mountainous freeway in southwest Virginia
- 18,000 AADT with 27% trucks
- 65 mph base speed limit
Safety Issues on I-77

- Frequent, dense fog creates dangerous driving conditions for motorists on I-77
- Low visibility leads to chain-reaction rear-end crashes
  - 95 car crash event with 3 fatalities March 30, 2013
  - 28 car crash event on October 3, 2014
I-77 VSL System

• A $7.5 million VSL system was activated in October 2016
  – 13 DMSs
  – 36 full matrix VSL signs
  – 8 VSL cutout signs
  – 25 CCTV cameras
  – 22 Wavetronix sensors
  – 14 RWIS stations
• Enabling legislation
• Speeds archived at TOC
Research Objectives

- Determine driver behavior before system activation
- Define a control algorithm for the VSL system
- Assess effectiveness of the system post-activation
Characterizing Visibility

- Existing RWIS visibility sensors provided estimates of visibility in feet
- These could be used to find an estimated safe speed based on stopping sight distance

\[ SSD = 1.47 \times V \times 2.5 \, s + \frac{1.075 \times V^2}{11.2 \, ft/s^2} \]

<table>
<thead>
<tr>
<th>Visibility Range</th>
<th>Safe Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 645 feet</td>
<td>65 MPH</td>
</tr>
<tr>
<td>495 - 645 feet</td>
<td>55 MPH</td>
</tr>
<tr>
<td>360 - 495 feet</td>
<td>45 MPH</td>
</tr>
<tr>
<td>255 - 360 feet</td>
<td>35 MPH</td>
</tr>
<tr>
<td>155 - 250 feet</td>
<td>25 MPH</td>
</tr>
<tr>
<td>&lt; 155 feet</td>
<td>&lt; 25 MPH</td>
</tr>
</tbody>
</table>

LOW VISIBILITY

8/21/2017
Fog Distributions 2010-2015

The diagram illustrates the distribution of fog hours across different mile posts from 2010 to 2015. The y-axis represents the number of hours, while the x-axis shows the mile posts. Different colors and heights indicate the percentage of time during the year that fog occurred at each respective height range.
I-77 “Before” Crash Data

- 11% of crashes during fog
- 84% of fog crashes in SB (downhill) direction
- Crash rate more than double than during clear conditions
I-77 SB “Before” Speed vs. Visibility

\[ \text{speed} = 64.6 - \frac{4204}{\text{visibility}} + 1.2 \times \text{Night} + 6.1 \times 6.6SB - 2.7 \times 7.3SB \]
VSL Control Algorithm

• Before conditions show that drivers traveled significantly faster than SSD “safe” speed
• What will happen if we post SSD based safe speed?
• Solution: initially set speeds at level that “splits the difference” between safe speed and current behavior, then iterate if positive effects occur
**I-77 VSL Control Algorithm**

- Step function algorithm used to set seeds at “worst” location
- VDOT controls VSLs from TOC
- Speed limits are smoothed and grouped to transition into and out of fog
Fog Events After VSL Activation

- 58 VSL activations from Oct 2016 to May 2017
  - Median duration 4.9 hrs
  - Three events lasted 50+ hrs
“Before” vs “After” at MP 4.4

\[ \text{Speed} = 67.26 - \frac{4275.95}{\text{Vis}} - 2915.83 \times \frac{\text{VSL}}{\text{Vis}} \]
Before vs. After at MP 4.4

Statistically significant reductions of about 5-6 mph

<table>
<thead>
<tr>
<th>Visibility Bin (ft.)</th>
<th>SSD Safe Speed (mph)</th>
<th>Before</th>
<th></th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Intervals</td>
<td>Mean Speed (mph)</td>
<td>No. of Intervals</td>
<td>Mean Speed (mph)</td>
</tr>
<tr>
<td>495-645</td>
<td>55-65</td>
<td>513</td>
<td>59.9</td>
<td>451</td>
</tr>
<tr>
<td>360-495</td>
<td>45-55</td>
<td>524</td>
<td>56.6</td>
<td>543</td>
</tr>
<tr>
<td>250-360</td>
<td>35-45</td>
<td>297</td>
<td>52.4</td>
<td>74</td>
</tr>
<tr>
<td>155-250</td>
<td>25-35</td>
<td>22</td>
<td>49.8</td>
<td>0</td>
</tr>
<tr>
<td>&lt;155</td>
<td>&lt;25</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>
## Deviation from PSL and Location

Values are mean observed speed - posted speed

<table>
<thead>
<tr>
<th>Milepost</th>
<th>65</th>
<th>60</th>
<th>55</th>
<th>50</th>
<th>45</th>
<th>40</th>
<th>35</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.6</td>
<td>-0.3</td>
<td>2.6</td>
<td>1.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10.2</td>
<td>2.2</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9.5</td>
<td>2.6</td>
<td>4.5</td>
<td>3.7</td>
<td>-</td>
<td>4.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.1</td>
<td>0.3</td>
<td>1.7</td>
<td>5.3</td>
<td>4.9</td>
<td>11.1</td>
<td>10.2</td>
<td>-</td>
<td>12.1</td>
</tr>
<tr>
<td>7.2</td>
<td>3.8</td>
<td>7.2</td>
<td>9.7</td>
<td>12.5</td>
<td>13.3</td>
<td>17.0</td>
<td>22.4</td>
<td>22.7</td>
</tr>
<tr>
<td>5.6</td>
<td>0.5</td>
<td>5.5</td>
<td>5.1</td>
<td>10.2</td>
<td>10.7</td>
<td>14.5</td>
<td>15.6</td>
<td>20.8</td>
</tr>
<tr>
<td>4.5</td>
<td>-0.1</td>
<td>2.8</td>
<td>2.6</td>
<td>4.2</td>
<td>3.7</td>
<td>4.2</td>
<td>4.2</td>
<td>-</td>
</tr>
<tr>
<td>3.4</td>
<td>2.2</td>
<td>4.4</td>
<td>3.2</td>
<td>6.5</td>
<td>5.3</td>
<td>4.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.8</td>
<td>3.4</td>
<td>4.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Conclusions and Next Steps

• The VSL did successfully decrease mean speeds by about 5 to 6 mph

• During dense fog, there appears to be a lagged effect where drivers do not decelerate until they experience the event

• Future work:
  – Evaluate crash effects
  – Refine control algorithm
Questions?

Michael D. Fontaine, P.E., Ph.D.
Associate Director
Virginia Transportation Research Council
Michael.Fontaine@VDOT.Virginia.Gov