Variable Speed Limits: An Overview of Safety and Operational Impacts

ITS Technology Workshop

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Outline

- What is Variable Speed Limit (VSL)?
- How VSL Works?
- VSL to improve Safety
- VSL to improve Travel Time
- METANET Model for Pro Active Trigger
Constructing new highways and adding lanes are not always the best option:

- Through proper management of existing transportation system, traffic condition can be improved
  - Ramp Metering
  - Variable speed limit design, etc.

- Every expressways and urban traffic have unique characteristics of traffic movement
  - Traffic management for one expressway can never be applied to other expressways

<table>
<thead>
<tr>
<th>Category of Area</th>
<th>4 Lanes Highway</th>
<th>6 Lanes Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural &amp; Suburban Area</td>
<td>$4-$6 million per mile</td>
<td>$8-$10 million per mile</td>
</tr>
<tr>
<td>Urban Area</td>
<td>~$7 million per mile</td>
<td>~$11 million per mile</td>
</tr>
</tbody>
</table>

Variable Speed Limit is an ITS solution that enables dynamic changing of speed limit in response to prevailing traffic, weather and incident situation.
Variable Speed Limit

- **Benefits:**
  - Resolving traffic breakdown
  - Safety improvements
  - Environmental benefits

- **Two types:**
  - Reactive: Based on current traffic measurements
  - Proactive: Predict future state of traffic
Congestion happens when:

Inflow > Outflow

Fig 7. Active Bottleneck which causes congestion if Inflow > Outflow
Real-time Crash Prediction model

- Crash Precursors
  - Standard deviation of speed
  - Average density
  - Average speed difference between adjacent lanes
  - Average congestion (ration of real travel time to free-flow travel time)
Variable Speed Limit to improve Safety

Fig 1. Comparison of fixed intervention speed limit strategies (Lee et al., 2004)
Variable Speed Limit to improve Safety

Fig 2. Comparison of fixed intervention speed limit strategies (Lee et al., 2004)
Variable Speed Limit to improve Safety

Fig 3. Speed profile immediately upstream of on-ramp (Lee et al., 2004)
Variable Speed Limit to improve Safety

Fig 4. Effect of speed limit on crash potential and travel time (Lee et al., 2004)
Variable Speed Limit to improve Safety

Safety-Integrated VSL system

Database
- Historical Crash data
- Weather data
- Traffic data

Crash Prediction module

Traffic Estimation module

Impact of traffic control on demand

VSL Optimization module

Historical Crash data
Weather data
Traffic data

Impact of traffic control on demand

VSL Optimization module
Greenshield’s theory
Basic Theoretical Model

Newell's Triangular Model
Generalized Model

Fig 5. Fundamental Diagrams of Greenshield Traffic Flow Mode (Greenshield et al., 1933)
Deerfoot Data

- **Freeway section** of the Queen Elizabeth II Highway (Highway 2) in Calgary, Alberta, Canada

Image Source: http://www.cyclecolor.com/ID47.HTM

Detectors for RTMS Data

Image Source: Snapshot from Google Earth
Existence of Capacity Drop at Bottleneck Locations

**Flow-Density Diagram (07 08 2015, Detector 113)**

- **Uncongested**
- **Capacity Drop**
- **Critical Density**
- **Congested**

**Fig 6. Existence of Capacity Drop at Bottleneck Locations**
Congestion happens when:

**Inflow > Outflow**

*Fig 7. Active Bottleneck which causes congestion if Inflow > Outflow*
VIDEO:  https://www.youtube.com/watch?v=8G7ViTTuwno

Source: Doug MacDonald, Washington State Department of Transportation
If we reduce the speed of vehicles approaching bottleneck, inflow would decrease and congestion can be prevented.
**VISSIM Simulation**

- Calibration of VISSIM Deerfoot Model
- Testing of Different VSL algorithms
- Scenarios:

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Prediction Horizon</th>
<th>Objective Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No VSL</td>
<td>Distributing Vehicles (Density Uniformity)</td>
</tr>
<tr>
<td>2</td>
<td>Reactive (No Prediction)</td>
<td>Optimizing TTT and TTC</td>
</tr>
<tr>
<td>3</td>
<td>Reactive (No Prediction)</td>
<td>Optimizing TTT and TTC</td>
</tr>
<tr>
<td>4</td>
<td>Proactive (5 minutes Prediction)</td>
<td>Distributing Vehicles (Density Uniformity)</td>
</tr>
<tr>
<td>5</td>
<td>Proactive (5 minutes Prediction)</td>
<td>Optimizing TTT and TTC</td>
</tr>
</tbody>
</table>

*Fig 8. Snapshot from PTV VISSIM*
No Variable Speed Limit
Vs
Scenario 1
Reactive VSL aimed at Density Uniformity
(Most basic VSL technique)

VIDEO: https://www.youtube.com/watch?v=ebXAp9n-AUs
Fig 9. Results (1. Speed Vs Simulation Time, 2. Density Vs Simulation Time)
Results

Fig 9. Results (Flow Vs Density Comparison)

Flow Vs Density
(0 - 3800 Simulation Seconds)
### Results

#### Vehicle Network Performance

<table>
<thead>
<tr>
<th>TIME INTERVAL</th>
<th>AVERAGE DELAY</th>
<th>AVERAGE STOPS</th>
<th>AVERAGE SPEED</th>
<th>AVERAGE DELAY DUE TO STOPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO VSL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1800</td>
<td>53.43</td>
<td>1.14</td>
<td>66.37</td>
<td>13.29</td>
</tr>
<tr>
<td>1800-3600</td>
<td>85.45</td>
<td>2.12</td>
<td>60.02</td>
<td>18.41</td>
</tr>
<tr>
<td>3600-5400</td>
<td>107.41</td>
<td>3.16</td>
<td>55.51</td>
<td>19.62</td>
</tr>
<tr>
<td>5400-7200</td>
<td>166.88</td>
<td>6.27</td>
<td>45.49</td>
<td>33.17</td>
</tr>
<tr>
<td>VSL (Responsive Density Based)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1800</td>
<td>48.1</td>
<td>0.9</td>
<td>75.79</td>
<td>10.2</td>
</tr>
<tr>
<td>1800-3600</td>
<td>74.12</td>
<td>1.48</td>
<td>68.01</td>
<td>15.21</td>
</tr>
<tr>
<td>3600-5400</td>
<td>100.7</td>
<td>2.56</td>
<td>59.92</td>
<td>16.54</td>
</tr>
<tr>
<td>5400-7200</td>
<td>160.16</td>
<td>6.03</td>
<td>46.66</td>
<td>29.35</td>
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<tr>
<td>COMPARISON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1800</td>
<td>5.33</td>
<td>0.24</td>
<td>-9.42</td>
<td>3.09</td>
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<tr>
<td>1800-3600</td>
<td>11.33</td>
<td>0.64</td>
<td>-7.99</td>
<td>3.2</td>
</tr>
<tr>
<td>3600-5400</td>
<td>6.71</td>
<td>0.6</td>
<td>-4.41</td>
<td>3.08</td>
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<tr>
<td>5400-7200</td>
<td>6.72</td>
<td>0.24</td>
<td>-1.17</td>
<td>3.82</td>
</tr>
</tbody>
</table>

*Table: Vehicle Network Performance*
✓ High-level crash precursors generally contribute to higher crash rates

✓ Variable Speed Limit generally reduces crash potential

✓ Variable Speed Limit with crash reduction purpose might increase travel time

✓ By developing proper optimization algorithm VSL can improve travel time as well as safety

✓ Traffic condition can be made smoother
QUESTIONS ?