Optimal Implementation of Red Light Extension Using Hardware-in-the-Loop Simulation for

Kittelson and Associate, Inc.
- Pat Marnell (Presenter)
- Shaun Quayle, PE

Oregon State University
- David Hurwitz, PhD
- Masoud Ghodrat Abadi
- Sarah McCrea

Western ITE -- July 2016
Outline

- Red Light Extension Background
- Field Study
- Simulation Study
- Findings and Future Work
**Red Extension Basics**

What is a red extension?
- Additional time is added to the all-red (also called red clearance) period between signal phases

Why extend the all-red
- Provide additional time for vehicles to clear the intersection and avoid crash likely situations
Red Extension Basics

➤ When to use a red extension?
   ✶ Ideally use only when a vehicle is likely to run a red-light

➤ Where to use a red extension?
   ✶ Locations with high rates of red-light running
   ✶ High speed locations
   ✶ Record of right angle crashes
   ✶ With good detection, almost any intersection
Optional: The duration of a red clearance interval may be extended from its predetermined value for a given cycle based upon the detection of a vehicle that is predicted to violate the red signal indication.
clearance intervals as shown in Exhibit 6-3. (The width of the intersection is measured from the stop bar to the extension of the cross-street curb line or the outside edge of the farthest cross-street travel lane.) Some modern controllers can be configured to implement a red clearance extension when a vehicle is detected to be in an undesirable position at the onset of a conflicting green. This application is consistent with MUTCD guidance that allows lengthening of the red clearance interval.

<table>
<thead>
<tr>
<th>Approach Speed (MPH)</th>
<th>Red Clearance¹ (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width of Intersection (Feet)</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>25</td>
<td>0.4</td>
</tr>
<tr>
<td>30</td>
<td>0.1</td>
</tr>
<tr>
<td>35</td>
<td>0.0</td>
</tr>
<tr>
<td>40</td>
<td>0.0</td>
</tr>
<tr>
<td>45</td>
<td>0.0</td>
</tr>
<tr>
<td>50</td>
<td>0.0</td>
</tr>
<tr>
<td>55</td>
<td>0.0</td>
</tr>
<tr>
<td>60</td>
<td>0.0</td>
</tr>
</tbody>
</table>

¹Based on recent research conducted as part of NCHRP 731 (6), the calculated red clearance values have been reduced by 1 second.
Study Methodology

Field Study
- Select viable location for HIL simulation experiment
- Empirical observation of RLR vehicle characteristics
- Empirical observation of minor street TTC

Simulation Study
- Use approach speeds, volumes, signal timings, detector placement and function to calibrate an HIL model.
- Evaluate the performance of alternative RLE system designs
Field Study
CountCam Duo 40

- 2 bullet cameras capturing different views
- 60-ft aluminum extension pole
- Mounted to on-site infrastructure
- CountCam system recording camera feeds
Typical Video Equipment Placement
Data Transcription Process

Video Collection

Distance Overlay Creation in Paint.NET

Raw Video Feed

Distance Overlay

Video Displayed in Virtual Dub with Distance Overlay
Video Database - Summary

- 252 hrs (collected)
- 234 hrs (usable)
- 149 hrs (transcribed)
- Major approach = 6,155 vehicles
- Minor approach = 7,456 vehicles
- RLR vehicles = 36
- Right Angle Crash = 1 near miss
Stop/Go Frequency at Onset of CY

OR 99E – Broadway (Salem)
Stop/Go Frequency at Onset of CR

US 30 – Cornelius Pass
## Consideration of RLR Vehicles

<table>
<thead>
<tr>
<th>Location</th>
<th>Count</th>
<th>RLR rate/ hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR-99W – Circle Blvd</td>
<td>6 (17%)</td>
<td>0.128</td>
</tr>
<tr>
<td>OR-99E – Broadway</td>
<td>0 (0%)</td>
<td>0.000</td>
</tr>
<tr>
<td>OR-99E – Mt. Hood</td>
<td>1 (3%)</td>
<td>0.028</td>
</tr>
<tr>
<td>UW26WB – 185th</td>
<td>5 (14%)</td>
<td>0.208</td>
</tr>
<tr>
<td>US30 - Cornelius Pass</td>
<td>24 (67%)</td>
<td>1.263</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>36</strong></td>
<td><strong>0.242</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>M</th>
<th>PC</th>
<th>LT</th>
<th>B</th>
<th>T</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>0 (0%)</td>
<td>19 (53%)</td>
<td>12 (33%)</td>
<td>0 (0%)</td>
<td>1 (3%)</td>
<td>4 (11%)</td>
</tr>
</tbody>
</table>
# Consideration of RLR Vehicles

<table>
<thead>
<tr>
<th>Location</th>
<th>Count</th>
<th>RLR rate/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR-99W – Circle Blvd</td>
<td>6 (17%)</td>
<td>0.128</td>
</tr>
<tr>
<td>OR-99E – Broadway</td>
<td>0 (0%)</td>
<td>0.000</td>
</tr>
<tr>
<td>OR-99E – Mt. Hood</td>
<td>1 (3%)</td>
<td>0.028</td>
</tr>
<tr>
<td>UW26WB – 185th</td>
<td>5 (14%)</td>
<td>0.208</td>
</tr>
<tr>
<td>US30 - Cornelius Pass</td>
<td>24 (67%)</td>
<td>1.263</td>
</tr>
</tbody>
</table>

**Total**

| Count | 36 | 0.242 |

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>M</th>
<th>PC</th>
<th>LT</th>
<th>B</th>
<th>T</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>0 (0%)</td>
<td>19 (53%)</td>
<td>12 (33%)</td>
<td>0 (0%)</td>
<td>1 (3%)</td>
<td>4 (11%)</td>
</tr>
</tbody>
</table>
## Time Frequency of RLR Vehicles (US30 – Cornelius Pass)

<table>
<thead>
<tr>
<th>Time Period</th>
<th># Cycles</th>
<th># Leading Vehicles Recorded</th>
<th># RLR</th>
<th>Frequency of RLR / Cycle</th>
<th>Frequency of RLR / # of Leading Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>7–8 AM</td>
<td>118</td>
<td>122</td>
<td>2</td>
<td>0.017</td>
<td>0.016</td>
</tr>
<tr>
<td>8–9 AM</td>
<td>134</td>
<td>75</td>
<td>3</td>
<td>0.022</td>
<td>0.040</td>
</tr>
<tr>
<td>9–10 AM</td>
<td>147</td>
<td>93</td>
<td>2</td>
<td>0.014</td>
<td>0.022</td>
</tr>
<tr>
<td>10–11 AM</td>
<td>136</td>
<td>104</td>
<td>2</td>
<td>0.015</td>
<td>0.019</td>
</tr>
<tr>
<td>11 AM–12 PM</td>
<td>158</td>
<td>87</td>
<td>3</td>
<td>0.019</td>
<td>0.034</td>
</tr>
<tr>
<td>12–1 PM</td>
<td>161</td>
<td>90</td>
<td>0</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1–2 PM</td>
<td>150</td>
<td>74</td>
<td>2</td>
<td>0.013</td>
<td>0.027</td>
</tr>
<tr>
<td>2–3 PM</td>
<td>144</td>
<td>75</td>
<td>3</td>
<td>0.021</td>
<td>0.040</td>
</tr>
<tr>
<td>3–4 PM</td>
<td>139</td>
<td>64</td>
<td>3</td>
<td>0.022</td>
<td>0.047</td>
</tr>
<tr>
<td>4–5 PM</td>
<td>131</td>
<td>55</td>
<td>1</td>
<td>0.008</td>
<td>0.018</td>
</tr>
<tr>
<td>5–6 PM</td>
<td>132</td>
<td>70</td>
<td>1</td>
<td>0.008</td>
<td>0.014</td>
</tr>
<tr>
<td>6–7 PM</td>
<td>150</td>
<td>65</td>
<td>2</td>
<td>0.013</td>
<td>0.031</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td>1700</td>
<td>974</td>
<td>24</td>
<td>0.014</td>
<td>0.025</td>
</tr>
</tbody>
</table>

RLR Mean Speed = 58 mph (SD = 10.4 mph)  RLR Mean Latency = 0.8 s (SD = 0.8 s)
Minor Approach Conflict Zone Measurements
Time to Collision for C1 by Intersection Approach

Mean TTC = 4.1s to 5.9s

5th % TTC = 2.0s to 4.0s
Simulation Study
US 30 and Cornelius Pass Road
Existing Detector Placement – Past Stop Bar
Hardware-In-The-Loop Simulation

- Econolite ATC 2070
- McCain-NIATT Controller Interface Device (CID II)
Controller Software

- NW Signals Voyage
- Red Extension Feature
  - Set Phase, Detector, and Duration
  - If detector is active during the 2\textsuperscript{nd} half of yellow or the all-red an extension is triggered

<table>
<thead>
<tr>
<th>Phase</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Clear Extension Detector</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Red Clear Extension Red Time</td>
<td>0.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Controller Software

- NW Signals Voyage
- Red Extension Feature
  - Set Phase, Detector, and Duration
  - If detector is active during the 2\textsuperscript{nd} half of yellow or the all-red an extension is triggered
Experimental Scenarios

★ Downstream Detection (DD)
  δ Red extension triggered using existing Voyage feature
  δ DD (existing condition)
Downstream Detection (DD)
- Red extension triggered using existing Voyage feature
- DD (existing condition)
Experimental Scenarios

- Smart Upstream Speed-Conditional Detection (SUSCD)
  - Red extension trigger programmed in Voyage logic
  - Only call for red extension if above a speed threshold
  - SUSCD at 125 Ft
  - SUSCD at 215 Ft
  - SUSCD at 475 Ft

[Diagram image showing a truck labeled "Buy Ice Cream!!" between two detectors labeled "Leading Detector" and "Lagging Detector" with a stop line at "T1 T2" and a known distance indicated.]
Experimental Scenarios

Smart Upstream Speed-Conditional Detection (SUSCD)

- Red extension trigger programmed in Voyage logic
- Only call for red extension if above a speed threshold
- SUSCD at 125 Ft
- SUSCD at 215 Ft
- SUSCD at 475 Ft
Experimental Scenarios

Smart Upstream Speed-Conditional Detection (SUSCD)

- Red extension trigger programed in Voyage logic
- Only call for red extension if above a speed threshold
- SUSCD at 125 Ft
- SUSCD at 215 Ft
- SUSCD at 475 Ft
Experimental Scenarios

Smart Upstream Speed-Conditional Detection (SUSCD)

- Red extension trigger programmed in Voyage logic
- Only call for red extension if above a speed threshold
- SUSCD at 125 Ft
- SUSCD at 215 Ft
- SUSCD at 475 Ft

\[
\text{Time Difference} + \text{Known Distance} = \text{Point Speed Measurement}
\]
Controller Data

▶ Voyage BIN files
  ✰ Actual ODOT timings that currently run in the field

▶ Red Extension Logs
  ✰ Time (beginning and end) of red extensions
  ✰ 1 second resolution
VISSIM Data

- **FZP – Vehicle Record**
  - Position data (and so much more) for each vehicle in the network.
  - \( \frac{1}{10} \)th of a second resolution

- **LSA – Signal changes**
  - Chronologically sorted file of the signal changes
  - \( \frac{1}{10} \)th of a second resolution

- **TRJ – SSAM trajectories**
  - Used with the Surrogate Safety Assessment Model. (Not currently evaluated)
Enhanced Time Space Diagram

Run 17 - Phase 2

Intersection Boundary
Detection Area
Stop Line

Vehicle’s Front Bumper
Vehicle’s Rear Bumper
Half of Yellow
Red Extension

Duration = 4439.1 - 4492.9

Kittelson & Associates, Inc.
Transportation Engineering/Planning
Detected Vehicles with High Risk of Collision (VHRC)

(a) Late Runner – vehicle enters at end of yellow

(a) RLR – vehicle enters during red
Accuracy – Correct Detection

(a) Detected VHRC

(b) Undetected VHRC

(c) Disregarded VHRC
Accuracy – Correct Extension

(a) Correct Extension

(b) Incorrect Extension (Non VHRC)

(c) Incorrect Extension (Triggered by Another Vehicle)
# Accuracy – Measurements

<table>
<thead>
<tr>
<th>VHRC</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>A VHRC is detected and a RLE is triggered</td>
<td>A VHRC is not detected and a RLE is not triggered</td>
</tr>
<tr>
<td>No</td>
<td>A RLE is triggered by a non VHRC</td>
<td>A RLE is not triggered and there is no VHRC.</td>
</tr>
</tbody>
</table>
Efficiency

(a) Highly Effective

(b) Effective

(c) Less Effective
Findings and Future Work
Example of a Detected VHRC in the DD System
Example of a Detected VHRC in the SUSCD System
Consideration of Accuracy and Efficiency
Consideration of Operations

- Mean Vehicle Delay: 13.08, 13.31, 13.1, 13.75
- Mean Stop Delay: 5.35, 5.56, 5.37, 5.83
- Mean Extension Duration: 1.25, 3.35, 1.01, 3.34

Legend:
- DD
- SUSCD at 125
- SUSCD at 215
- SUSCD at 475
System Alternatives

- The DD alternative provided higher accuracy than the SUSDC systems
- The SUSCD systems provided higher efficiency than the DD system
- The average vehicle delay was relatively low for each alternative

While the SUSCD systems have a higher rate of false prediction, they introduced the potential for a more robust RLE
Opportunities for Future Work

- HIL simulations of additional RLE system designs
  - Alternative detection placement
  - Refine RLE prediction logic

- Field Evaluation of alternative vehicle detection strategies
  - Evaluate SUSCD system in the field
  - Evaluate RLE system leveraging wide area detection
Acknowledgments

Oregon State University Research Team
Masoud Ghodrat Abadi
Dr. David Hurwitz
Sarah McCrea

Special Thanks to Paul Zebell (PBOT)

ODOT Research
KAI Research Team
Shaun Quayle
Patrick Marnell
Questions

GO BEAVERS!