Evaluation of Integrated Platoon-Priority and Advance Warning Flasher System at High Speed Intersections

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Decision/Dilemma Zones

- Decision Zones arise due to variation in drivers’ behavior
- Some researchers (Bonneson et al., 1994; Zegeer, 1977) have defined the decision zones as that area of the approach between a point where 90 percent of the drivers will stop on yellow and a point where 90 percent of the drivers will go.
Dilemma Zone Protection

• Two common methods of providing dilemma/decision zone protection
  – Dilemma zone detectors
    • Multiple detectors are placed on the intersection approach such that the signals are able to extend the green and prevent the onset of yellow while the vehicles are in their dilemma zone.
  – Advance warning flashers (AWF)
    • AWF, located upstream of intersection, start flashing prior to the signal turning yellow. This additional information provided to the drivers reduces the variability in their behavior.
Dilemma-zone Protection

Source: MnDOT MUTCD
Drawback of Current Signal Control of High Speed Intersections

- Current signal system setup lacks the ability to provide platoon progression at isolated intersections having major and minor streets
Current MnDOT Advance Warning Flasher (AWF) System

- Actuated Portion
- Trailing Overlap
- Arterial Signal Indication
- AWFlasher

Gap Out

Fixed Overlap Portion (7 ~ 8 sec)

Warning Beacons Flashing

~ 850 ft.
Research Questions to Be Answered

• How can we provide signal priority to a vehicle platoon so that we can improve the operational efficiency?

• How can we operate the advance warning flasher intelligently so that it can provide advance warning when necessary at the same time minimize the delay on the minor approach?
Typical Layout for High Speed Rural Intersections with 65mph Speed Limit
Integrated Platoon-Priority and AWF System
Objectives

• Provide platoon detection and progression
• Reduce stops, delay and fuel consumption
• Provide advance warning of end of green phase
• Enhance dilemma-zone protection
• Improve operational efficiency and intersection safety
Proposed System Layout (65 mph)

Dilemma Zone Detectors

Advance Detectors
≈ 1000 ft. -1500 ft.

315 ft.
625 ft.
850 ft.
315 ft.
Platoon-Priority System (Chaudhary et al., 2003)

- Platoon Identification Stage

  - In real-time, the algorithm keeps track of the last group of ‘n’ consecutive vehicles that passed through advance detectors
    - Speed
    - Departure time at advance detector
    - Estimated arrival time at stop bar

  - If the estimated cumulative headway of the detected platoon at the stop bar is less than the user specified threshold, algorithm schedules a low-priority preemption.

  - Algorithm switches to *Platoon Extension Mode*. 
Platoon-Priority System (Cont’d)

• Platoon Extension Stage

  • Now the algorithm evaluates each additional detected vehicle to determine if it is a part of the previously detected platoon

  • If the detected vehicle’s estimated headway at stop bar is less than the user specified threshold, algorithm extends the preemption termination by an appropriate amount of time
Advance Warning Flasher System
(Messer et al., 2003)

- Uses advance detectors to acquire future information about approaching vehicles
- Uses current signal controller status information and the future vehicle arrival information to predict end of green in advance (≈ 3 to 8 seconds, depending on advance detector location)
- Once the system predicts the end-of-green, it turns on Advance Warning Flashers
- If there are going to be any vehicles in dilemma zone during the predicted end-of-green time, the system places a hold for an appropriate amount of time to allow the vehicles to clear their respective dilemma zones
- AWF watch dog task monitors gap-out timers of detectors and max-out timers to prevent any unexpected gap outs
System Hardware

Industrial PC → NIDAQ I/O Card

Detector and Signal Status

Controller Over-ride Inputs

Detector Inputs, Controller Over-ride Inputs

Signal Status

Traffic Controller

Cabinet

Detector and Signal Status

Detector Status

Signal and AWF Status
Cabinet-in-the-Loop Architecture

Vissim Traffic Simulation Software

Industrial PC

NIDAQ I/O Card

Detector and Signal Status

Controller Over-ride Inputs

Detector Inputs

Traffic Controller

NIDAQ I/O Card

Detector Status

Signal and AWF Status

Cabinet
Key Concepts

Controller Status Data Acquirer

- Gets the current signal and detector status from the controller via cabinet back panel
- Uses digital data acquisition card to facilitate communication between computer and cabinet back panel
- The signal status information is deduced from Phase Green On and Ring Status Bit pin terminals in the cabinet

Advance Detection Data Acquirer

- Acquires vehicle detection time and speed from advance detectors
- Predicts vehicle type based on length
Key Concepts

• Controller Manipulation

  • Early Green
    • The system issues a TSP call for an early green
    • TSP settings are set such that the priority phases get green immediately (subject to minimum green constraint)
    • Immediately after getting an early green, TSP call is removed, and a phase hold is applied for the remaining scheduled time

• Green Extension

  • Phase hold is used

• Constraints

  • Phase hold is not placed beyond Max timer expiration
  • Once an early green is granted, the system is locked from issuing another until all the non-priority phases are served once
Key Concepts

Equivalent Time-based Dilemma Zones

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Car (sec.)</th>
<th>Truck (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>45</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>50</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>55</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>60</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>65</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>70</td>
<td>2.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>

- A research study conducted by Zimmerman (2007) concluded that trucks get benefited by an additional 1.5 seconds dilemma-zone protection over cars as they require longer stopping distance.
Scenario where Platoon Priority and AWF system is used

**Scenario**

- Isolated signal control,
- High speed approaches,
- Experience significant number of platoons from upstream intersection
Vissim Model

Advance Detectors

Local Detectors

AWFs
Speed Data Statistics

Trunk Highway 55 (Speed Limit: 65mph)

<table>
<thead>
<tr>
<th># of Obs.</th>
<th>Mean (mph)</th>
<th>St. Dev. (mph)</th>
<th>Min. (mph)</th>
<th>Max. (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>138</td>
<td>61</td>
<td>3.84</td>
<td>50</td>
<td>72</td>
</tr>
</tbody>
</table>

Cumulative Distribution Plot

Histogram Plot
Speed Data Statistics

Argenta Trail (Speed Limit: 45 mph)

<table>
<thead>
<tr>
<th># of Obs.</th>
<th>Mean (mph)</th>
<th>St. Dev.</th>
<th>Min. (mph)</th>
<th>Max. (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>40</td>
<td>4.04</td>
<td>26</td>
<td>52</td>
</tr>
</tbody>
</table>
Volume Data – PM Peak Hour

Peak Hour Data

Peak Hour Begins at 10:30
Cars & Trucks

Priority Phase

Concurrent Priority Phase

Non-priority Phases

<table>
<thead>
<tr>
<th>Volme Data – PM Peak Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priority Phase</td>
</tr>
<tr>
<td>Concurrent Priority Phase</td>
</tr>
<tr>
<td>Non-priority Phases</td>
</tr>
</tbody>
</table>
Cabinet-in-the-Loop Hardware
## Results

### Platoon-Priority System Performance

<table>
<thead>
<tr>
<th>Phase</th>
<th>Normal</th>
<th>Advance Detector Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delay</td>
<td>1000 ft.</td>
</tr>
<tr>
<td></td>
<td>Stops</td>
<td></td>
</tr>
<tr>
<td>Priority</td>
<td>23.2</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>53.7</td>
<td>21.9</td>
</tr>
<tr>
<td>Concurrent</td>
<td>9.9</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>27.8</td>
<td>32.0</td>
</tr>
<tr>
<td>Non-Priority</td>
<td>32.1</td>
<td>33.3</td>
</tr>
<tr>
<td></td>
<td>82.4</td>
<td>83.7</td>
</tr>
<tr>
<td>Total</td>
<td>24.6</td>
<td>21.1</td>
</tr>
<tr>
<td></td>
<td>61.3</td>
<td>50.4</td>
</tr>
</tbody>
</table>

Delay (s/veh)  Stops (%)
## Results

### Advance Warning Flasher System Performance

<table>
<thead>
<tr>
<th>Phase</th>
<th>Normal (Delay/Stop)</th>
<th>Trailing (Delay/Stop)</th>
<th>Advance Detector Locations (1000 ft/1250 ft/1500 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Delay/Stop</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1000 ft.</td>
</tr>
<tr>
<td>Priority</td>
<td>23.2/53.7</td>
<td>23.8/50.7</td>
<td>21.9/48.9</td>
</tr>
<tr>
<td>Concurrent</td>
<td>9.9/27.8</td>
<td>11.3/31.0</td>
<td>9.6/27.9</td>
</tr>
<tr>
<td>Non-Priority</td>
<td>32.1/82.4</td>
<td>35.7/87.3</td>
<td>33.4/83.0</td>
</tr>
<tr>
<td>Total</td>
<td>24.6/61.3</td>
<td>26.6/62.8</td>
<td>24.8/60.2</td>
</tr>
</tbody>
</table>
## Results

### Integrated System Performance

<table>
<thead>
<tr>
<th>Phase</th>
<th>Trailing</th>
<th></th>
<th>Advance Detector Locations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overlap</td>
<td>1000 ft.</td>
<td>1250 ft.</td>
<td>1500 ft.</td>
<td>Overlap</td>
</tr>
<tr>
<td></td>
<td>Delay</td>
<td>Stops</td>
<td>Delay</td>
<td>Stops</td>
<td>Delay</td>
</tr>
<tr>
<td>Priority</td>
<td>23.8</td>
<td>50.7</td>
<td>12.4</td>
<td>23.8</td>
<td>11.7</td>
</tr>
<tr>
<td>Concurrent</td>
<td>11.3</td>
<td>31.0</td>
<td>9.6</td>
<td>27.0</td>
<td>9.9</td>
</tr>
<tr>
<td>Non-Priority</td>
<td>35.7</td>
<td>87.3</td>
<td>35.3</td>
<td>85.2</td>
<td>35.3</td>
</tr>
<tr>
<td>Total</td>
<td>26.6</td>
<td>62.8</td>
<td>21.8</td>
<td>50.8</td>
<td>21.6</td>
</tr>
</tbody>
</table>

*Delay (s/veh)  Stops (%)*
Results

Advance Warning Time Histograms (Integrated System)
Conclusions

• Platoon-priority signal control strategy provided system optimal performance at intersections with batch arrivals
• For the 65 mph approach speed, advance detection at 1250 feet provided optimal performance
• For the 65 mph approach speed and advance detection at 1250 ft., the system provided $\approx 7$ seconds advance warning time at the end of green
• For the priority approach, 50 percent reduction in delays and stops were observed
• Overall intersection delay and stops were reduced by 20 percent
Thank You

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