TSPCV Experiment at the Virginia Tech Smart Road

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Introduction

• Transit Signal Priority (TSP) has been proposed and studied as an efficient way of improving transit operations.

• Evaluation of theoretical benefits:
  • Simulation-based evaluations ➔ Many
  • Field tests ➔ Few

• Limited number of field tests under CV environment
  • Multi-Modal Intelligent Traffic Signal System (MMITSS) project and some others almost in parallel with this study.
Objectives

• To implement TSPCV in real world on the Virginia Smart Road
  • The 1st TSPCV field experiment on the Smart Road of the Virginia Tech Transportation Institute (VTTI)

• To confirm software and hardware compatibility

• To illuminate TSPCV performance and reveal Global Positioning System (GPS) requirements (regular and differential)
Methodology

- Bus arrival time components:
  - Roadway geometry
  - Roadway speed limit
  - Speed of other vehicles

- TSPCV components:
  - Bus detection
  - TSP timing plan and bus speed calculation
  - Logic assessment and implementation
Experiment

Site

• Virginia Tech Smart Road
  • A test-bed research facility managed by VTTI
  • Owned and maintained by the Virginia Department of Transportation (VDOT)
  • Length: 2.2 miles (3.5 km)
  • 2 paved lanes
  • 7 roadside equipment units that facilitate CV communications + 2 mobile roadside equipment sites
  • A signalized intersection with complete signal phase and timing (SPaT) using remote controls
  • A connected-vehicle-compatible intersection controller model

Source: http://www.vtti.vt.edu/facilities/virginia-smart-road.html
Experiment

**Vehicle & Devices**

- **Vehicle**: Nissan Infiniti FX35 (2005) enabled with CV features:
  - **GPS devices**:
    - Regular GPS (GPS from NextGEN Head Unit)
    - Differential GPS (Novatel Flexpak6 located in vehicle trunk)
  - **OBE**: Savari OBE S100 located in trunk
  - **DAS**: Nextgen DAS located in trunk for data collection:
    - GPS position, GPS speed, etc.
  - **TSPCV algorithm**: on a Dell laptop
  - **User interface**: display screen (HDMI Feelworld 5” HD TFT LCD Monitor

- **RSE**: Savari StreetWave

- **Traffic signal controller**: Custom proprietary interface with D4 Controller connected to Control Room
Distance \((0.5 + d)\) 0.5 miles
# Experiment

## Experimental Scenarios

- **Signal Phasing**
  - Cycle length = **90** seconds

- **Arrival types**
  - Beginning of Red phase
  - Middle of Red phase
  - End of Red phase

- **GPS Type**
  - Regular
  - Differential

## TSPCV Experiment Scenarios

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>Regular GPS</th>
<th>Differential GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 mph</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle length Start Time</th>
<th>Regular GPS</th>
<th>Differential GPS</th>
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</thead>
<tbody>
<tr>
<td>40 sec. X 10 trials</td>
<td></td>
<td>40 sec. X 3 trials</td>
</tr>
<tr>
<td>50 sec. X 3 trials</td>
<td></td>
<td>50 sec. X 2 trials</td>
</tr>
<tr>
<td>60 sec. X 3 trials</td>
<td></td>
<td>60 sec. X 3 trials</td>
</tr>
<tr>
<td>70 sec. X 3 trials</td>
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<td>70 sec. X 3 trials</td>
</tr>
<tr>
<td>80 sec. X 3 trials</td>
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<td>80 sec. X 3 trials</td>
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</table>

<table>
<thead>
<tr>
<th>Subtotal</th>
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<tbody>
<tr>
<td>22 trials</td>
<td>14 trials</td>
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</table>

<table>
<thead>
<tr>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>36 trials</strong></td>
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</tbody>
</table>
Prior to the experiment:

- The study team visually confirmed the compatibility of the algorithm and the equipment (OBE and RSE) at the VTTI.
- Data flow was checked and tested.
Experiment

Data Collection

• From the beginning of each trial ➔ the end:
  
  • Time
  
  • Coordinated Universal Time (UTC) Time
  
  • Original Timing Plan
  
  • TSPCV Timing Plan (actually was activated after the bus passed 0.5 miles point)
  
  • Bus speed
  
  • Bus location
  
  • Distance to intersection
  
  • Traffic light status at intersection
Experiment

Data Analysis

- Delay computation
  - Predicted arrival time without TSPCV
    - Predicted Relative Cycle length Arrival Time without TSPCV at 0.5 miles
  - Predicted arrival time
  - Actual arrival time
  - Delay $\text{w/o TSPCV}$
  - Delay $\text{TSPCV}$
  - Reduced Delay (sec. & %)
## Evaluation

### Success Rate

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cycle Length</th>
<th>Start Time</th>
<th># TSP Green Provided</th>
<th>%</th>
<th># TSP Green with Shorter Delay</th>
<th>%</th>
<th># TSP Green with Shorter Delay without Green Extension</th>
<th>%</th>
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<tbody>
<tr>
<td>Regular GPS</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td>100%</td>
<td>10</td>
<td>100%</td>
<td>4</td>
<td>40%</td>
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<tr>
<td></td>
<td>50</td>
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<td>3</td>
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<td>3</td>
<td>100%</td>
<td>2</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>3</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>100%</td>
<td>1</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>3</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>100%</td>
<td>1</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>3</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>100%</td>
<td>2</td>
<td>67%</td>
</tr>
<tr>
<td></td>
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<td>22</td>
<td>22</td>
<td>100%</td>
<td>22</td>
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<td>10</td>
<td>45%</td>
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<td>100%</td>
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<tr>
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<td>100%</td>
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<td>100%</td>
</tr>
<tr>
<td></td>
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<td>100%</td>
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<td>100%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>3</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>3</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>100%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
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<td>100%</td>
<td>14</td>
<td>100%</td>
<td>7</td>
<td>50%</td>
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</table>
Evaluation

Delay Reduction and Original Red Light Arrival Time

Combined GPS Devices

Predicted Relative Original Red Light Arrival Time w/o TSP (Sec.)

Reduced Delay with TSP (Sec.)
Evaluation

Delay Reduction and Original Red Light Arrival Time (Cont.)

Predicted Relative Original Red Light Arrival Time w/o TSP (Sec.)

Combined GPS Devices

Reduced Delay with TSP (%)
Evaluation

**GPS Type Effect**

![Graph showing the comparison between Regular GPS and Differential GPS in terms of Reduced Delay with TSP and Predicted Relative Original Red Light Arrival Time without TSP. The graph illustrates the effect of GPS type on reduced delay and arrival time, with Differential GPS generally showing improved performance compared to Regular GPS.](image-url)
Evaluation

**GPS Type Effect (Cont.)**

![Graph showing the comparison between Regular GPS and Differential GPS in terms of Reduced Delay with TSP (%). The x-axis represents the Predicted Relative Original Red Light Arrival Time w/o TSP (Sec.), ranging from 0.0 to 50.0. The y-axis represents the Reduced Delay with TSP (%), ranging from 0% to 80%. The graph shows that Differential GPS generally outperforms Regular GPS in reducing delay, especially in the lower predicted arrival time ranges.](image-url)
## Evaluation

### GPS Type Effect (Cont.)

<table>
<thead>
<tr>
<th></th>
<th>Actual Overall Time</th>
<th>Reduced Delay (Sec.)</th>
<th>Reduced Delay (%)</th>
<th>Green Extension</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>R-GPS</td>
<td>D-GPS</td>
<td>R-GPS</td>
<td>D-GPS</td>
</tr>
<tr>
<td>Mean</td>
<td>59.14</td>
<td>57.43</td>
<td>26.36</td>
<td>26.86</td>
</tr>
<tr>
<td>Variance</td>
<td>48.13</td>
<td>16.11</td>
<td>156.86</td>
<td>168.75</td>
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<tr>
<td>Observations</td>
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<tr>
<td>Pearson Correlation</td>
<td>0.75</td>
<td>0.98</td>
<td>0.87</td>
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<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>df</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>t Stat</td>
<td>1.36</td>
<td>-0.65</td>
<td>-0.41</td>
<td>-0.12</td>
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<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.099</td>
<td>0.26</td>
<td>0.35</td>
<td>0.45</td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.77</td>
<td>1.77</td>
<td>1.77</td>
<td>1.77</td>
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<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.20</td>
<td>0.53</td>
<td>0.69</td>
<td>0.90</td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.16</td>
<td>2.16</td>
<td>2.16</td>
<td>2.16</td>
</tr>
</tbody>
</table>
Conclusions

• TSPCV algorithm implementation program, data packets, and communications devices worked properly in a CV environment.

• The implementation of the TSPCV algorithm was successful
  • reduce an average of 57% of bus delay or an average of 26.9 seconds

• TSPCV algorithm provided the bus green time at a 100% success rate (50% with “Green Extension”) & delay reduction (32%-75%)

• The difference in performance of regular and differential GPS devices was not statistically significant.
Future Work

• TSPCV worked properly at a controlled environment but future research at real world with general traffic is necessary.

  • It is likely that the 100% TSP success rate would not be always possible if queues and unexpected delays happen at the intersections.

• Test was conducted under a suburban environment (0.5 miles intersection spacing), it was because the controller that was developed had the limitation.

  • Since experiment, the research team has enhanced the controller for more urban and tight spacing, future work could consider extending evaluation to urban environment.
More Information

• Report:

Next Generation Transit Signal Priority with Connected Vehicle Technology (Chapter 4)

https://vtechworks.lib.vt.edu/handle/10919/72257

• ASCE Journal of Transportation Engineering

Transit Signal Priority Experiment in a Connected Vehicle Technology Environment

In Press
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