Bus Signal Priority Based on GPS and Wireless Communications

Outlines

- Background
- Phase I - Simulation Study
- Phase II – Prototype system development
What is Transit Signal Priority (TSP)?

“Transit signal priority systems use sensors to detect approaching transit vehicles and modify signal timings to improve transit performance.”

“A tool to help make transit service more reliable, faster, and more cost effective. It has little impact on general traffic and is an inexpensive way to make transit more competitive with the automobile.”

- ITS America TSP planning and implementation handbook

Priority vs. Preemption

- Signal priority modifies normal signal operation process to accommodate transit vehicles
- Preemption interrupts the normal signal operation process for special events (railroad crossing, emergency vehicles)
Transit Signal Priority
Detection Technologies

Inductive loop-based detection

- **Advantage:**
  - β Compatible with commonly used loop detectors
  - β Relatively reliable
  - β Does not require line-of-sight or visibility

- **Disadvantage:**
  - β Require in-pavement loop detectors
  - β Prone to failure due to pavement flexing

- **Example:**
  - IDC LoopComm

- **Implementation:**
  - LA, Chicago

Light-based (Infrared) detection

- **Advantage:**
  - β Widely used in U.S. for EVP,
  - β Well tested for many years

- **Disadvantage:**
  - β Require Line-of-sight clearance between emitter and detector

- **Example:**
  - 3M Opticom, Optronix/Tomar Strobecom, Novax Bus Plus

- **Implementation:**
  - Oakland, Tacoma, Portland, Vancouver
Transit Signal Priority Detection Technologies

Sound-based detection

- **Advantage:**
  - ⬜ Emergency vehicle does not need additional equipment
  - ⬜ Facilitate inter-jurisdictional emergency response
  - ⬜ Does not require line-of-sight or visibility

- **Disadvantage:**
  - ⬜ Not practical for transit signal priority (need additional audible siren)
  - ⬜ False activation from building/car alarms

- **Example:**
  - ⬜ Sonic Sonem 2000, EPS II

Radio-based detection

- **Advantage:**
  - ⬜ Does not depend on line-of-sight or visibility

- **Disadvantage:**
  - ⬜ Require RD tag installation at upstream curbside
  - ⬜ None directional vehicle information (with no RF tag installation)

- **Example:**
  - ⬜ TOTE (RF Tag), Econolite (EMTRAC)

- **Implementation:**
  - ⬜ King County Seattle
Transit Signal Priority
Detection Technologies

Satellite (GPS)-based detection

- **Advantage:**
  - Does not depend on line-of-sight or visibility
  - Can easily notify controller when vehicle has cleared

- **Disadvantage:**
  - Slow AVL polling rate
  - Low/no GPS reception in urban canyon

- **Example:**
  - 3M GPS Opticom

- **Implementation:**
  - City of Edinburg, TX?

TSP Experiences in US

<table>
<thead>
<tr>
<th>City</th>
<th># of Buses</th>
<th># of Stopped Signal Phases</th>
<th>% of Traffic Phases</th>
<th># of Bus Stops</th>
<th>% of Bus Stops in Stopped Signal Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix</td>
<td>100</td>
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<td>10%</td>
<td>100</td>
<td>50%</td>
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<tr>
<td>Seattle</td>
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<td>250</td>
<td>15%</td>
<td>50</td>
<td>25%</td>
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<tr>
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<td>Houston</td>
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<td>10%</td>
<td>100</td>
<td>50%</td>
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</table>
Transit Signal Priority (TSP)
Background

- Bus signal priority has been implemented in several US cities (Seattle, Portland, LA, Chicago, St. Cloud, etc.)*
- Metro Transit performed tests on Lake Street using 3M Opticom technology (problem w/ nearside bus stops & trigger timing)
- Metro Transit contracted SEH Inc. to conduct TSP conceptual design along Northwest (Bottineau) corridor
- Most TSP deployments use sensors to detect buses at a fixed or preset distance.

* An Overview of Transit Signal Priority, ITS America 2002

Adaptive Bus Signal Priority
Objectives

- Provide efficient and reliable bus transit service to traveling public.
- Reduce transit operation cost.
- Use already installed GPS/AVL on bus & a wireless communication based adaptive signal priority system with minimum impact on other traffic.
- Conduct traffic modeling and simulation to analyze and evaluate the possible impact.
Bus Signal Priority
Our Approach

- Bus transmits signal priority request to traffic controller based on its \textit{readiness} not \textit{presence}.

Bus Signal Priority
Our Approach (continue)

- Adaptive bus signal priority strategy using GPS/AVL and wireless communication technology.
- Provide conditional signal priority based on bus’s schedule adherence, speed, location and estimated dwell time at bus stop.
- Transmit priority request wirelessly from bus to intersection signal controller.
- Evaluate benefits and impacts of signal priority from simulation model.
Key Features of Our Approach

- Non-proprietary wireless communication (802.11x protocol)
- Use existing GPS/AVL system on bus
- Incorporate passenger count and bus lateness to provide conditional priority
- Consider bus stop dwell time for signal priority request when it is ready (Intersection arrival time forecast)
- Include controller phasing and timing status in priority request, forecast and decision making

Study Site – Franklin Ave. Minneapolis

Dupont Ave. 3 miles, 22 signalized intersections 27th Ave

To I-94 & I-394

I-35W

I-94

Hiawatha LRT
Simulation Model Development

- Intersection Capacity Analysis (Synchro)
- Data Collection
  - Signal timing plan (from Minneapolis)
  - Volume and turning movements (Use Jamar)
  - Travel time (Vehicle probe)
  - Bus dwell time & delay (20%) at intersection
  - Bus stop location (GIS from Metro Transit)
- Use AIMSUN Micro-Simulator

Simulation Model Development (con’t)

- Capacity Analysis

<table>
<thead>
<tr>
<th>Intersection</th>
<th>AM Peak</th>
<th>Off Peak</th>
<th>PM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hennepin</td>
<td>F</td>
<td>C</td>
<td>F</td>
</tr>
<tr>
<td>Lyndale</td>
<td>D</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Nicollet</td>
<td>E</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>Chicago</td>
<td>C</td>
<td>D</td>
<td>F</td>
</tr>
<tr>
<td>11th</td>
<td>B</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>Cedar</td>
<td>C</td>
<td>E</td>
<td>D</td>
</tr>
<tr>
<td>Minnehaha</td>
<td>B</td>
<td>E</td>
<td>B</td>
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</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>AM Peak</th>
<th>Off Peak</th>
<th>PM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hennepin</td>
<td>183.4</td>
<td>27.6</td>
<td>148.0</td>
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<tr>
<td>Lyndale</td>
<td>47.2</td>
<td>39.0</td>
<td>39.4</td>
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<tr>
<td>Nicollet</td>
<td>86.8</td>
<td>25.0</td>
<td>676.2</td>
</tr>
<tr>
<td>Chicago</td>
<td>33.8</td>
<td>49.5</td>
<td>202.5</td>
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<tr>
<td>11th</td>
<td>23.1</td>
<td>51.8</td>
<td>84.3</td>
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<tr>
<td>Cedar</td>
<td>25.9</td>
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<tr>
<td>Minnehaha</td>
<td>14.3</td>
<td>11.3</td>
<td>16.9</td>
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</table>
Network Modeling

Simulation Model Development (con’t)

Network Model Calibration

08:00 ~ 08:15AM EB
Reaction Time = 0.75s, Reaction Time at Stop = 0.8s

Detector Station (42 intersections)

Franklin Avenue Eastbound
Signal Priority Strategy

Signal Priority Request

u Nearside Bus Stop

Average bus travel time to stop $j$:

$$T_{aj} = \frac{d_{e,j}}{1.467 \times v_b} + T_{br} + T_{delay}$$

- $V_b$ is bus speed, in MPH.
- $d_{e,j}$ is the distance from the current bus location to bus stop $j$, in feet.
- $T_{br}$ is bus braking/stopping time.
- $T_{delay}$ is the traffic delay on bus route.
Signal Priority Request

**Far side Bus Stop**

Average bus travel time to intersection $i$:

$$T_{aw} = \frac{d_{wd}}{1.467 \times v_b} + T_{delay}$$

- $v_b$ is bus speed, in MPH.
- $d_{wd}$ is the distance from the current bus location to intersection $i$, in feet.
- $T_{delay}$ is the traffic delay on bus route.

![Signal Priority Request Diagram](image)

Bus Dwell Time Calculation

**Dwell Time Forecast at Bus Stop**

$$T^{\text{db}}_{dj} = \lambda(t) \times [t_k(j) - t_{k-1}(j)] \times T^{\text{boarding}}$$

- $T^{\text{db}}_{dj}$ is the dwell time for bus at stop $j$.
- $\lambda(t)$ is the passenger arrival rate at stop $j$.
- $t_k(j)$ is the arrival time of bus $k$ at stop $j$.
- $t_{k-1}(j)$ is the arrival time of bus $k-1$ at stop $j$.
- $T^{\text{boarding}}$ is the average boarding time per passenger.

![Bus Dwell Time Calculation Diagram](image)
Signal Priority Acknowledgement

- Request Time, TF (Time factor)
  - First come first serve
- Bus Schedule Adherence, LF (Lateness Factor)
  - LF=0 if bus is ahead of schedule
- Number of Passenger, PF (Passenger Factor)

Signal Priority Treatment: Green Extension

[Diagrams showing priority request and green extension for two plans (Plan 1 and Plan 2) with phases labeled 1 to 4 and a green extension highlighted in Plan 2.]
Signal Priority Treatment: Red Truncation

Signal Priority Treatment: Phase Insertion
Signal Priority Strategy Modeling

**GETRAM EXT API Interface**

**AIMSUN Traffic Simulator**

**Traffic Controller Model**
- Passenger arrival model at each stop
- Bus dwell time model at each stop
- Bus arrival/travel time estimation model
- Bus Signal Priority Controller
- Intersection signal phasing/timing model
- Signal priority, recovery, resynchronization model

**Bus Signal Priority Strategy**

**Signal Priority Control Flowchart**

1. Acquire bus(k) location, compare its distance to next stop(j) and intersection(i)
2. \[ \text{dist2NextStop} > \text{dist2NextInt} \] ?
   - Far side bus stop
   - Near side bus stop

3. Estimate time when bus will pass next signalized intersection
   \[ t_{\text{estimate}} = t_{\text{sim}} + \text{system response time} \]
   - Yes
   - No

4. Submit priority request using green extension or red truncation for intersection(i)
   \[ \text{dist2BusStop} < \text{system response distance} \]
   - Yes
   - No

5. Exit extension phase and return back to phase \( p \), where \( p \) is the phase before extension

6. Resynchronize signal timing at next cycle

**University of Minnesota**

**ITS Institute**

**Minnesota Traffic Observatory (MTO)**
Bus Signal Priority
Phase I Simulation Study Results

- Bus travel time reduction
  - AM-Peak: 12-15%
  - PM-Peak: 4-11%

- Bus delay time reduction
  - AM-Peak: 16-20%
  - PM-Peak: 5-14%

Overall Network Measures

<table>
<thead>
<tr>
<th>Flow (1000 veh/h)</th>
<th>Speed MPH</th>
<th>AM Peak</th>
<th>PM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>15</td>
<td>9.4</td>
<td>9.4</td>
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<tr>
<td>15</td>
<td>20</td>
<td>9.3</td>
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</tr>
<tr>
<td>20</td>
<td>25</td>
<td>9.2</td>
<td>9.2</td>
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</table>

Network Flow and Speed

<table>
<thead>
<tr>
<th>Average Travel</th>
<th>Average Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0012</td>
<td>0.0012</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.0015</td>
</tr>
<tr>
<td>0.0018</td>
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</tbody>
</table>

Network Travel and Delay Time
### Bus Travel Time and Speed (AM Peak)

<table>
<thead>
<tr>
<th>AM Peak Bus Speed</th>
<th>AM Peak Bus Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Speed MPH</strong></td>
<td><strong>Travel Time</strong></td>
</tr>
<tr>
<td>No Priority</td>
<td>With Priority</td>
</tr>
<tr>
<td>9.1</td>
<td>9.7</td>
</tr>
<tr>
<td>10.4</td>
<td>10.7</td>
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<tr>
<td>8</td>
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<td>9</td>
<td>9.5</td>
</tr>
<tr>
<td>10</td>
<td>10.5</td>
</tr>
</tbody>
</table>

### Bus Travel Time and Speed (PM Peak)

<table>
<thead>
<tr>
<th>PM Peak Bus Speed</th>
<th>PM Peak Bus Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Speed MPH</strong></td>
<td><strong>Travel Time</strong></td>
</tr>
<tr>
<td>No Priority</td>
<td>With Priority</td>
</tr>
<tr>
<td>7.7</td>
<td>7.2</td>
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<tr>
<td>7</td>
<td>7.3</td>
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<td>6.5</td>
<td>6.8</td>
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<tr>
<td>7</td>
<td>7.5</td>
</tr>
<tr>
<td>8</td>
<td>8.5</td>
</tr>
</tbody>
</table>

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** Minnesota Traffic Observatory (MTO)  
University of Minnesota **
MOE Analysis of Major Intersections

- Hennepin – No significant change
- Lyndale – 10% decrease in delay & stops
- Nicollet – about 30% increase in travel time and 47% increase in delay
- Chicago – about 5% decrease in travel time & delay time
- Cedar - about 24% increase in travel time and 30% increase in delay

Video Clip

Without Priority

With Priority
Phase II Study Overview

- Develop wireless communication prototype using commercial off-the-shelf (COTS) product
- Implement & validate GPS/AVL and wireless communication based signal priority strategy
- Field testing and validation

Phase II Prototype Systems

Ref: NTCIP 1211 V01.37 Protocol
Signal Priority System Hardware

OBU
Controller Cabinet
RSU
GPS Receiver
NEMA Controller

AMD GX500
256 MB RAM

Signal Priority Embedded System

Embedded System
Radio Modem
Power Converter
Wireless Communications

Minneapolis Wi-Fi Network
5.9 GHz WAVE Radio

Minneapolis Wi-Fi

Implementation Start
November, 2006

Phase One
Anticipated Completion: June, 2007

Phase Two
Anticipated Completion: September, 2007

Phase Three
Anticipated Completion: October, 2007

Phase Four
Anticipated Completion: October, 2007

Phase Five
Anticipated Completion: November, 2007

Phase Six
Anticipated Completion: December, 2007

http://www.usiwireless.com/service/minneapolis/schedule.htm

30-40 nodes/sq mile
5.9 GHz Radio

Denso WAVE (Wireless Access in Vehicular Environment) Radio Module Prototype

- Bandwidth: 75 MHz (5.850 ~ 5.925 GHz)
- 5.89 GHz (IEEE 178, control channel)
- Channels: 10 MHz per channel (20 MHz optional)

5.9 GHz Radio

5.9 GHz DSRC Band Plan

- Shared Public Safety/Private
  - Control
  - Medium Range Service
  - Short Range Service
- Dedicated Public Safety
  - Veh-Veh
  - Intersections

US Spread Spectrum Allocation

US and Potential Mexican DSRC Allocation

Frequency (GHz)

IEEE DSRC Standard: http://www.ieee802.org
Bus Stop & Intersection Geo-Database

Bus route #2
Travel Pattern #1

Test Plan and Data Collection

- Equip a passenger vehicle for initial testing
- Wireless communication reliability and latency data collection and analysis
- Signal priority algorithm verification and validation
- Final testing and validation (one bus + one intersection)
Acknowledgement

- ITS Institute, University of Minnesota.
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- Priya Iyer, EE student.
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- Tony Juettner at Brown Traffic Products, Inc.

Thank You Very Much!