Benefits and Impacts of a Connected Vehicle Transit Signal Priority System

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System Overview
Utah CV DSRC Project

• Establish DSRC corridor
  • Learn about the technology
  • Establish deployment experience
  • Evaluate hardware interoperability

• Connected Vehicle Application: Transit Signal Priority
  • Redwood Road
  • MMITSS Software (Utah Version)
  • Conditions: Lateness, % Occupancy
  • Goal: Increase transit reliability

• Meet the SPaT Challenge
Redwood Road Corridor

30 signalized intersections
- Full fiber optic connectivity
  - All signals connected to central system
    - Intelight MaxView
  - Running signal performance metrics
- Two brands of signal controller:
  - 4 - Econolite (Cobalt)
  - 26 – Intelight

RSUs installed on 24 intersections
- Four brands of DSRC RSU (initially)
  - Ultimately: Cohda / Lear

Software running on Beaglebone Linux Boards
## Transit Signal Priority Infrastructure

<table>
<thead>
<tr>
<th>On Board Equipment</th>
<th>Roadside Equipment</th>
<th>Traffic Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DSRC OBU</td>
<td>• DSRC RSU (24)</td>
<td>• Signal Controllers</td>
</tr>
<tr>
<td>• Linux On-board Processor (OBP)</td>
<td>• Ethernet cable to cabinet</td>
<td>• Econolite ASC/3 &amp; Cobalt</td>
</tr>
<tr>
<td>• Antennas in/on bus roof</td>
<td></td>
<td>• Intelight MaxTime</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Beaglebone Linux Processor</td>
</tr>
</tbody>
</table>

![On Board Equipment](image1.jpg)

![Roadside Equipment](image2.jpg)

![Traffic Signals](image3.jpg)
Transit Signal Priority Infrastructure

Roadside DSRC Installation

- Signal mast arm near pole
- Omni-directional antenna
  - Obstructions can impair signal
  - Needs line-of-sight
- Nominal range is 300 m – Actual range is longer
Transit Signal Priority Infrastructure

On-Board DSRC Installation

- OBU in bus electronics cabinet
  - Powered from bus system
- Linux OBP connects to transit “mobile data computer”
  - Is behind schedule? / What is occupancy?
- Antenna within rooftop shroud
CV TSP System Operations

Bus
- On-board Processor (OBP)
  - On-board Unit (OBU)
    - Basic Safety Message (BSM),
      Signal Request Message (SRM)
    - On-time Status, % Occupancy
  - Mobile Data Computer (MDC)
    - Schedule
  - Utah Transit Authority Server
    - Location, On-time Status, Occupancy

Roadside Equipment
- Roadside Unit (RSU)
  - Roadside Processor (RSP)
  - Signal Status Message (SSM)
  - SPaT, TSP Confirmation
  - NTCIP Command
- Traffic Signal
  - Signal Controller
    - ATSPM
  - Utah DOT Server
    - BSM, SRM, SSM
Transit Signal Priority Monitoring
TSP System Databases

**Basic Safety Message (BSM)**
- UTA Bus ID
- Latitude
- Longitude
- Speed
- Heading
- Received
- Intersection ID
- Timestamp

**Signal Request Message (SRM)**
- Intersection ID
- Lat/Long
- Timestamp
- Vehicle ID
- Request ID
- Request Status
- Latitude
- Longitude
- Heading
- Intersection ID
- Timestamp

**Signal Status Message (SSM)**
- Intersection ID
- Lat/Long
- Timestamp
- Vehicle ID
- Request ID
- Request Status
- Intersection ID
- Timestamp

**Geofence (MAP)**
- Approach ID
- Min X Coord
- Min Y Coord
- Max X Coord
- Max Y Coord

**UTA SIRI (Bus)**

**Bus Reliability**
- UTA Bus ID
- Timepoint ID
- Direction
- Scheduled Time
- Arrival Time
- On-time Status

**Bus Occupancy**
- UTA Bus ID
- Stop ID
- # On
- # Off
- Load
- Dwell Time

**Signal Controller Data (ATSPM)**
- TSP Input ON
- TSP Input OFF
- TSP Request Received
- TSP Request Cancel
- TSP Service: Early Green
- TSP Service: Green Extend
- Timestamp

https://udottraffic.utah.gov/atspm/
Transit Signal Priority Operation
How TSP Works: Signal Coordination
How TSP Works

**EARLY GREEN**

- Initial stop
- Time savings: ~10-15 seconds

**GREEN EXTEND**

- Initial stop
- Time savings: ~30-50 seconds

Only 10-15%
Available Transit Signal Priority

Redwood & 4700 S
- Busy intersection ➔ Moderate TSP

Redwood & 4800 S
- Minor intersection ➔ Generous TSP

Green Time ➔ Time Available for Transit Signal Priority ➔ Red Time
Available Transit Signal Priority

- Normal Intersection (10-20% of cycle)
- Busy Intersection (4-9% of cycle)
- Interchange or CFI (No TSP)

- Programmed Green Time (% of cycle)
- Potential Green Time Gain from TSP
TSP Optimization

Signal Performance

Bus Reliability

On-time Status:
Late = >5 minutes behind schedule

Occupancy:
Occupied = > 20% occupancy
(9 people)

Traffic Signal Programming

Available Green Time for TSP

Frequency of TSP Requests

Lateness Threshold
Minimum Occupancy

- Signal Performance
- Bus Reliability
- Available Green Time for TSP
- Frequency of TSP Requests
- Lateness Threshold
- Minimum Occupancy

On-time Status:
Late = >5 minutes behind schedule

Occupancy:
Occupied = > 20% occupancy
(9 people)
Results
Results:

Bus Trips with TSP

Does it hurt the signals?

Average TSP Requests & Services

Southbound, PM Peak

Northbound, AM Peak

- % Bus Trips with TSP Requests
- % Bus Trips with TSP Serviced
Results:

Signal Performance

Does it hurt the signals?

- Primary Movement Green Time
- Primary Movement Red Time
- Gain in Green or Red Time with TSP

% of TSP Services without a negative impact on other phases
% of TSP Services with a negative impact on other phases

* Indicates a low sample size &/or high opposing phase gap out rate.
** No TSP served.
Results:
Bus Reliability

Does it benefit the bus?

Average Reliability

Southbound, PM Peak
Northbound, AM Peak

Note: A bus is “reliable” if it is less than 5 minutes late
## Results: Bus Schedule Reliability

<table>
<thead>
<tr>
<th>Average Reliability</th>
<th>Southbound PM Peak</th>
<th>Northbound AM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No TSP</td>
<td>TSP</td>
</tr>
<tr>
<td>Along Route</td>
<td>85%</td>
<td>91%</td>
</tr>
<tr>
<td>End of Route</td>
<td>89%</td>
<td>89%</td>
</tr>
</tbody>
</table>
Study Results to be Published

- “Demonstrating Transit Schedule Benefits with a DSRC-Based Connected Vehicle System”
- Transportation Research Record
- TRB 2019 Conference
Additional Analysis Underway

- Evaluate the Sensitivity of “Lateness Threshold”
  - 5-minutes vs 3-minutes vs 2-minutes
  - Occupancy criteria removed
  - Help balance signal performance vs bus reliability
Benefits, Impacts, Considerations
Benefit vs Cost

• Direct Benefits:
  • Bus is on time more often
  • Riders can depend on the bus schedule
  • Possible fuel savings with fewer delays at signals

• Indirect Benefits:
  • More people will ride if the bus is dependable
  • System is useable for many other things

• How Do You Quantify the “Dependability” Benefits?

• Project Costs:
  • $1.02 million (as of Dec 2017)
    • 55% software / 12% hardware / 33% engineering & learning

• But – Deployment costs are coming down . . .
UVX CV TSP Deployment

- Provo-Orem BRT Project (UVX)
  - 10.5-mile corridor
  - DSRC on 47 Intersections
  - DSRC on 25 Buses
  - Budget: $365,000
    - Nominally: $5k per unit
  - Operational December 3, 2018

- Effectiveness Study Underway
CV Snow Plow Pre-emption Project

- Snow Plow Pre-emption Project
  - Salt Lake Valley – 5 corridors
  - 55 Additional DSRC Intersections
  - 46 Snow Plows
  - Pre-emption when actually plowing
    - Connection to ForceAmerica system
    - Based on spreader operations
  - Budget: $473,000
    - Nominally $4.7k per unit installed
  - Operational March 2019

- Study on Effectiveness
  - Winter ‘19-’20
More DSRC CV Deployment Coming

• Additional Transit Signal Priority Routes
  • State Street, Utah Co. (2020)
  • State Street SL County (2020)
  • Two to three additional TSP Corridors in 2021
  • Extension of 3300 South MAX BRT Corridor with TSP

• Additional Snow Plow Pre-emption Routes
  • Snow Plow Pre-emption on UVX Route (2019)
  • Two more Snow Plow Pre-emption Corridors (2020)

• Additional Applications
  • Curve Speed Warning Application (20 locations)
  • Road Weather Warning Application (20 locations)
  • 2000 other vehicles equipped over next 4 years
Benefits and Impacts

• Improved Transit Reliability

• Improved Snow Plow Efficiency and Safety
  • Neither proven yet . . .

• Connected Vehicle Technology (DSRC) is:
  • Functional and Available
  • Able to bring measurable benefits
  • Scalable to more locations and applications

• UDOT is Planning More Deployment
A Tangential Comment...
Why DSRC?

Connected Vehicle – per public understanding

Cellular 4G technology
Vehicle telematics:
  - Navigation, Infotainment, Corporate connection (i.e. GM On-Star)
Vehicle to the cloud (corporate) – not connected to other cars
Relatively slow
Why DSRC?

**Connected Vehicle – per DOT use case**

- Direct communication – no “base station” involved
- Ad-hoc, decentralized communication
- TEA-21 (1998) required that a system be developed
- 5.9GHz spectrum allocation by FCC
- Short range
- Free public spectrum
- Privacy by design
- Low latency
Connected Vehicle V2X Options

**DSRC**
- Meets TEA-21 rqmts
- Developed and evolved to meet specific needs
- 802.11 standards (like WiFi)
- Tested, proven, available
- Widespread deployment consensus
- Future Path to IEEE NGV

LTDOT
Keeping Utah Moving
Connected Vehicle V2X Options

**DSRC**
- Meets TEA-21 rqmts
- Meets needs
- Tested, proven
- Deployed
- Future Path: IEEE NGV

**C-V2X**
- Cellular 4G-LTE technology (not “5G”)
- No independent testing (despite claims)
- No wide-scale testing or deployment
- Not commercially available
- Not interoperable with DSRC
- Has no legal spectrum
- No added benefits
Connected Vehicle V2X Options

**DSRC**
- Meets TEA-21 rqmts
- Meets needs
- Tested, proven
- Deployed
- Future Path: IEEE NGV

**C-V2X**
- Cellular 4G-LTE tech
- 3GPP Rel 14 /15
- No independent testing
- No wide-scale deployment
- Not available
- No spectrum
- No added benefits
- Not interoperable

**Cellular 5G technology**
- Generic use: IoT
- NR-V2X
- 3GPP Rel 16 (pending)
- Will not interoperate or co-exist with C-V2X
- Still an idea