Benefits and Impacts of a Connected Vehicle Transit Signal Priority System

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System Overview

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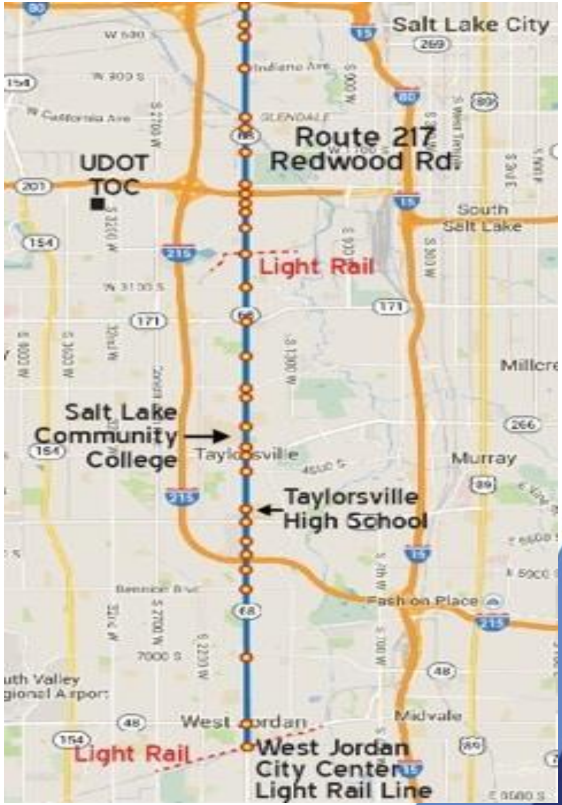
Utah CV DSRC Project

- 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



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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

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Transit Signal Priority Infrastructure

On Board Equipment

- DSRC OBU
- Linux On-board Processor (OBP)
- Antennas in/on bus roof

Roadside Equipment

- DSRC RSU (24)
- Ethernet cable to cabinet

Traffic Signals

- Signal Controllers
  - Econolite ASC/3 & Cobalt
  - Intelight MaxTime
- Beaglebone Linux Processor

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

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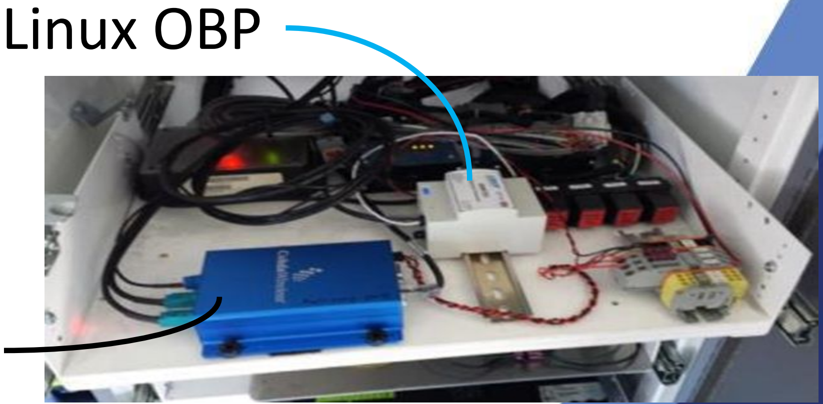
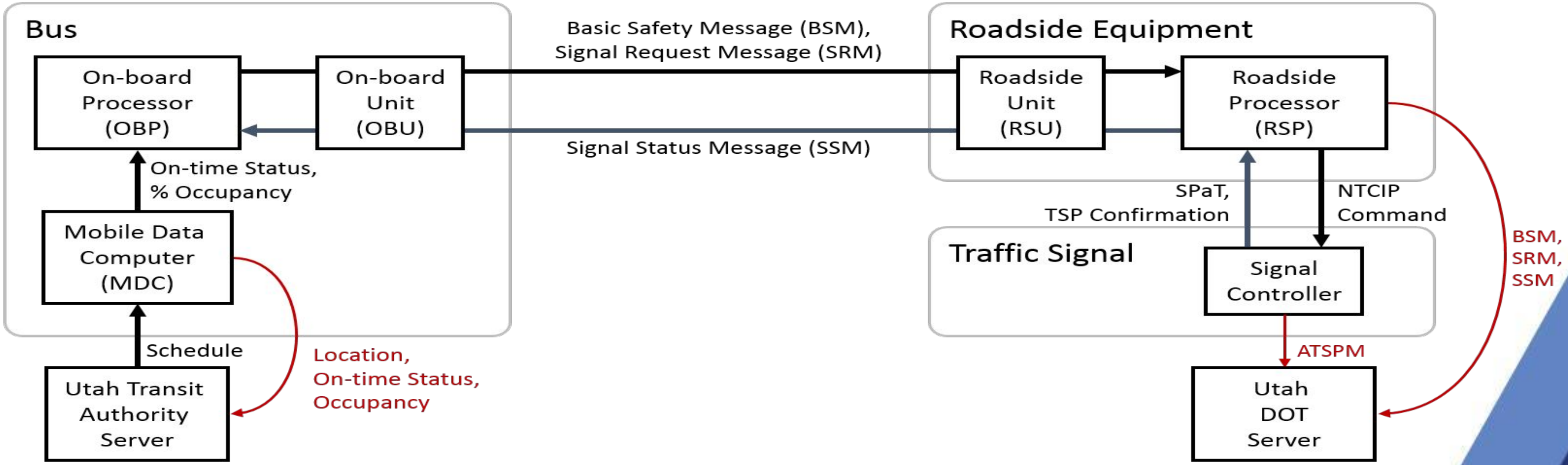
Transit Signal Priority Infrastructure

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



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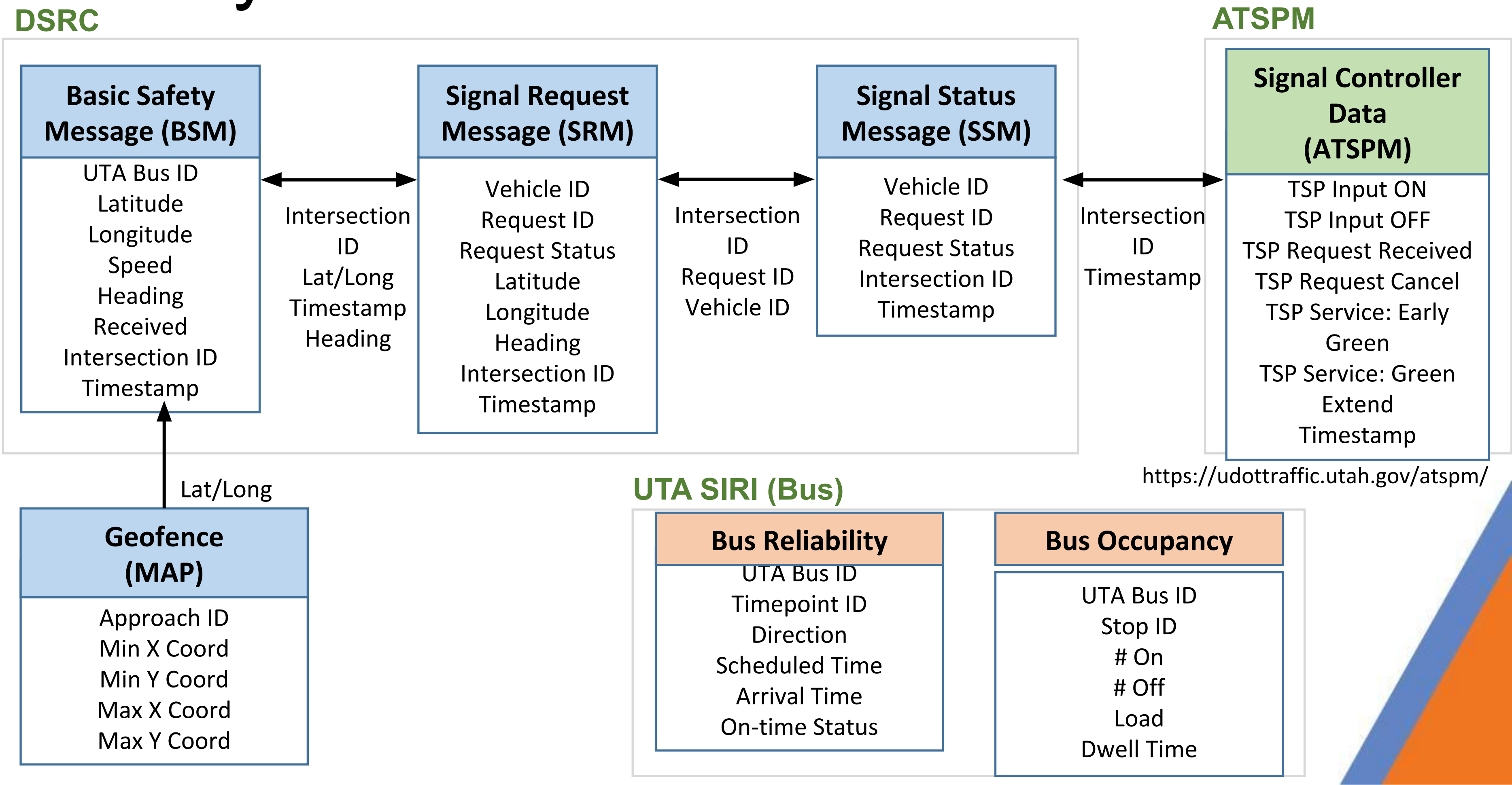
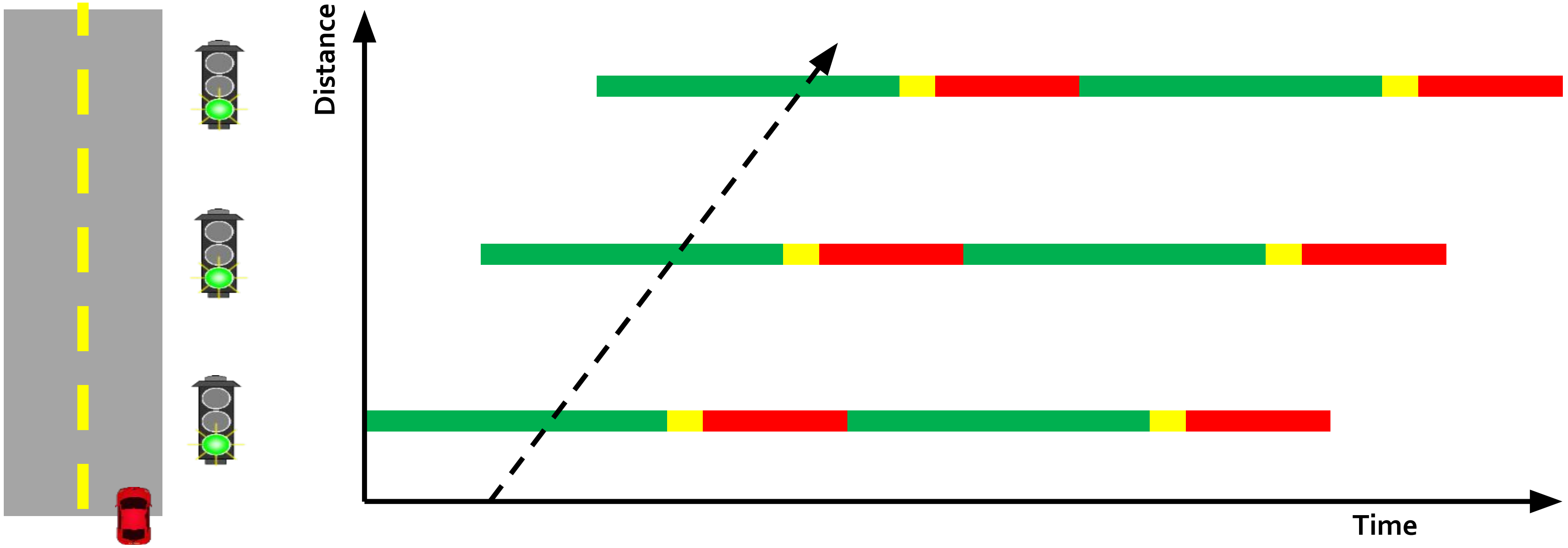
Transit Signal Priority Monitoring

TSP System Databases



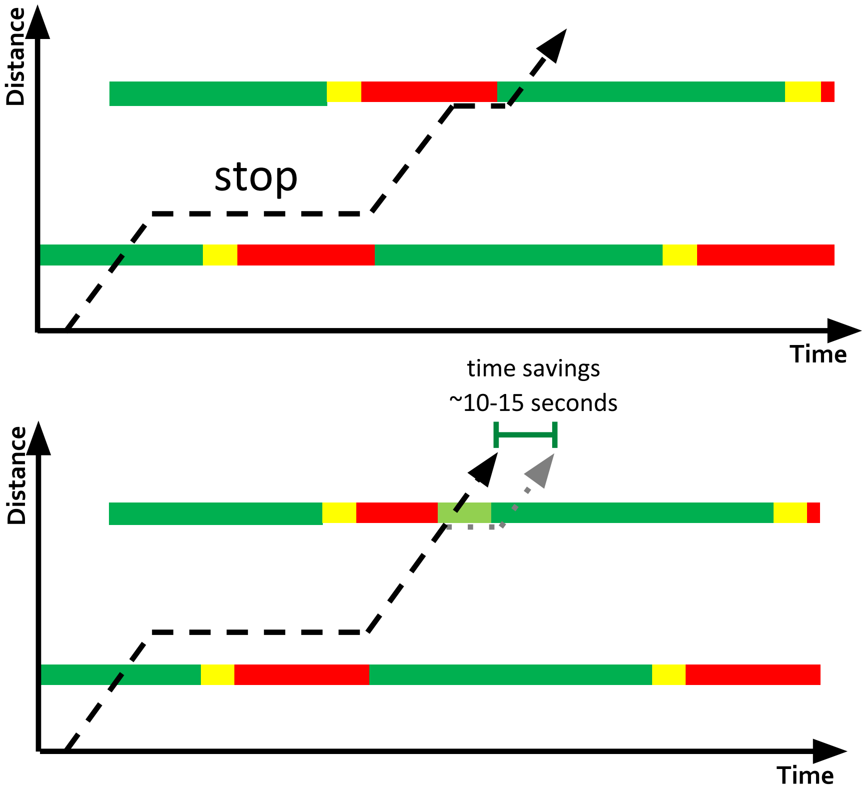
Transit Signal Priority Operation

How TSP Works: Signal Coordination



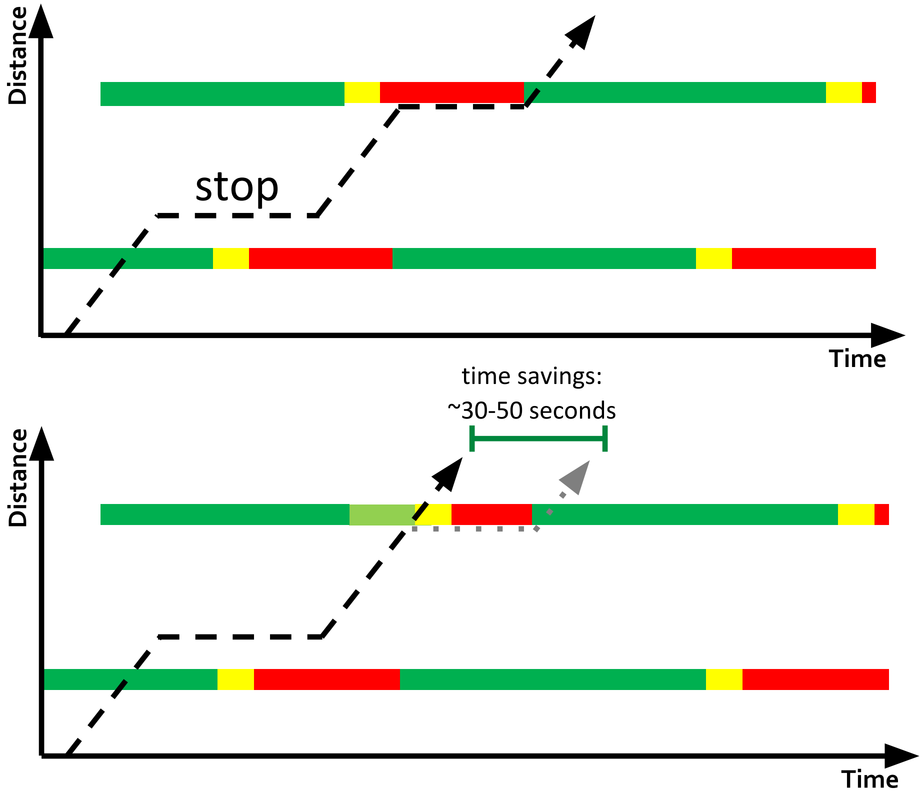
How TSP Works

EARLY GREEN

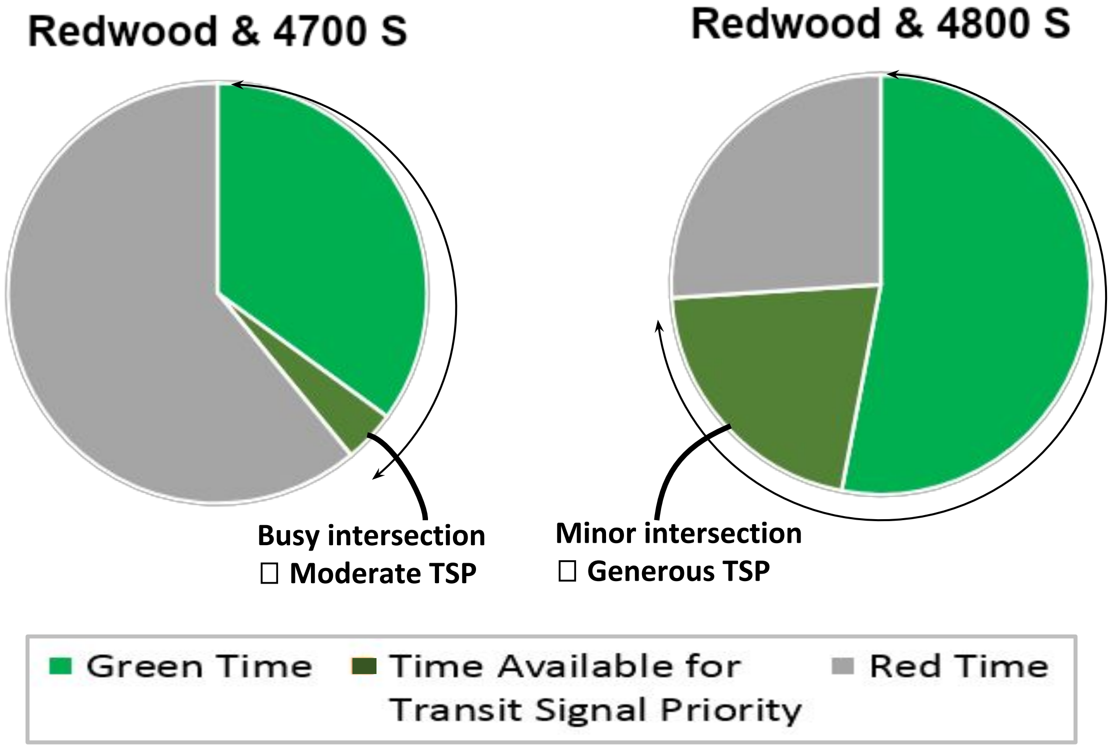


Only 10-15%

GREEN EXTEND



Available Transit Signal Priority

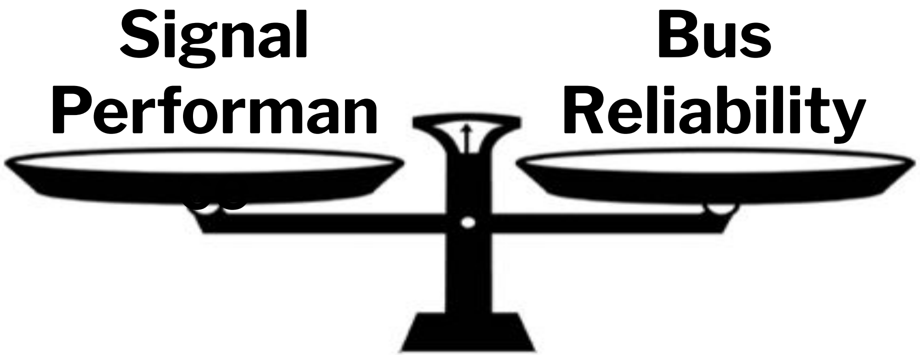


Available Transit Signal Priority

- 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

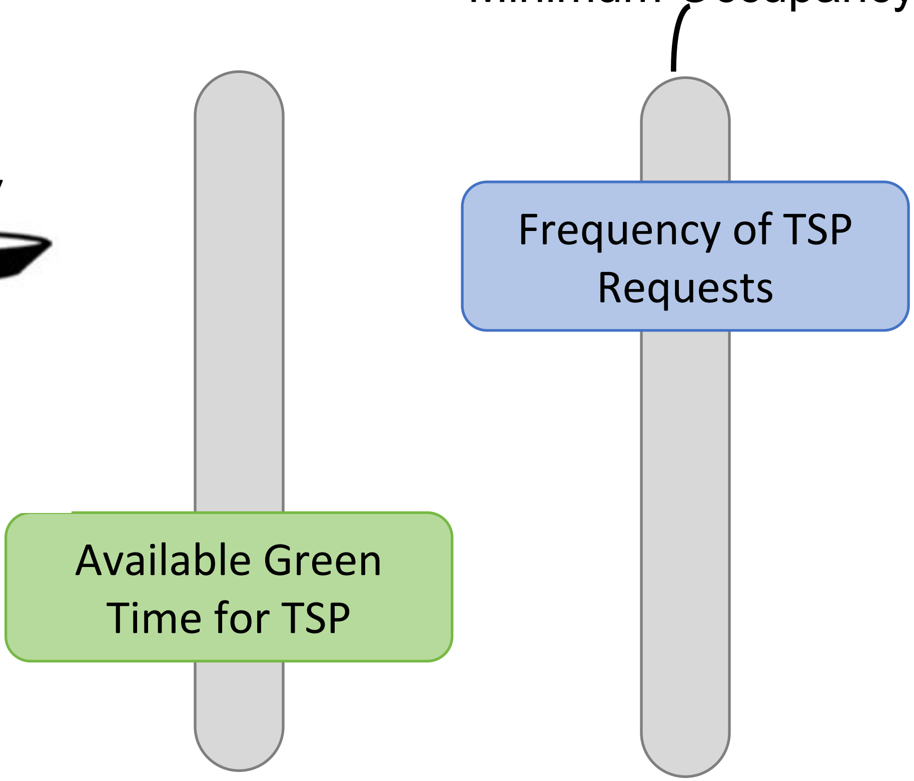


On-time Status:

Late = >5 minutes behind schedule

Occupancy:

Occupied = > 20% occupancy
(9 people)



Results

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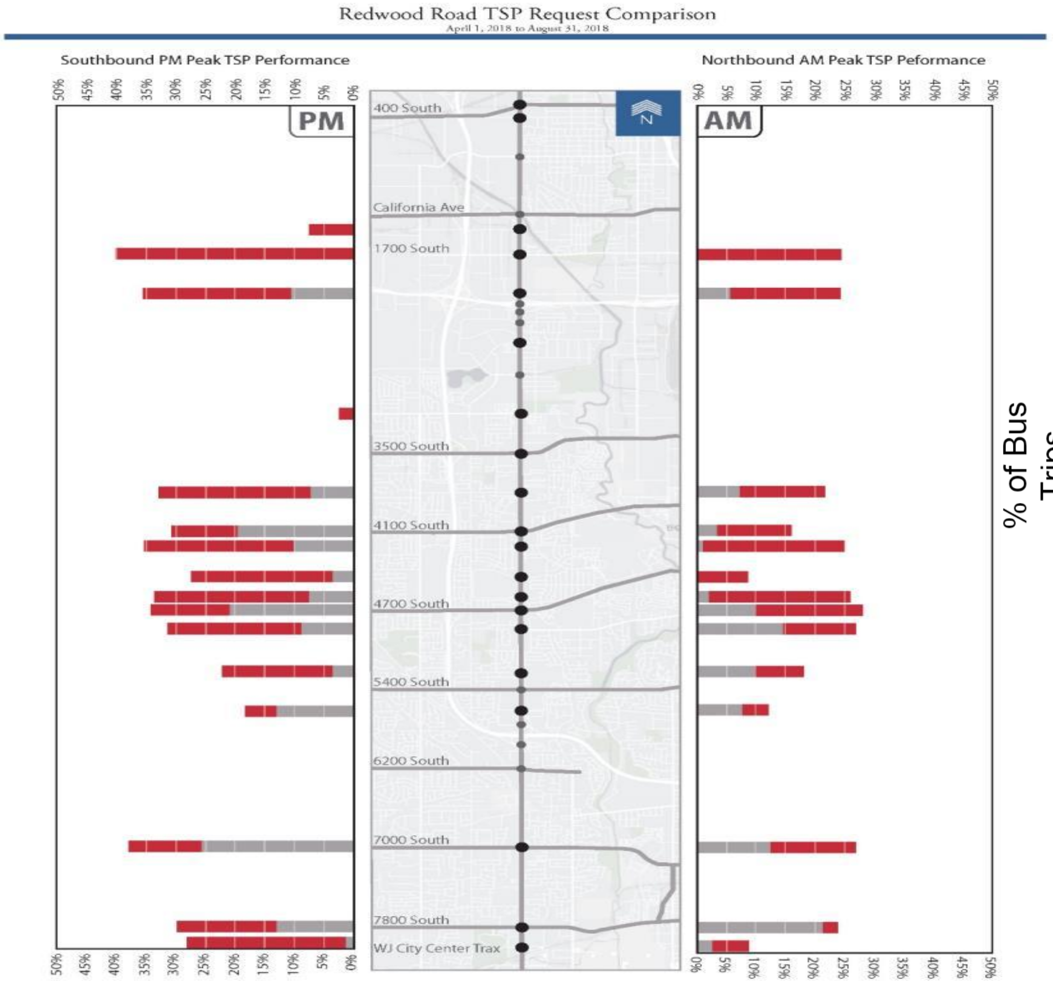
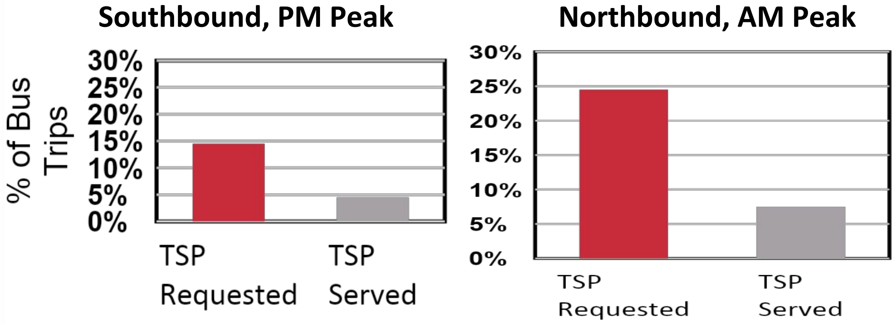


Results:
Bus Trips with TSP
Does it hurt the signals?

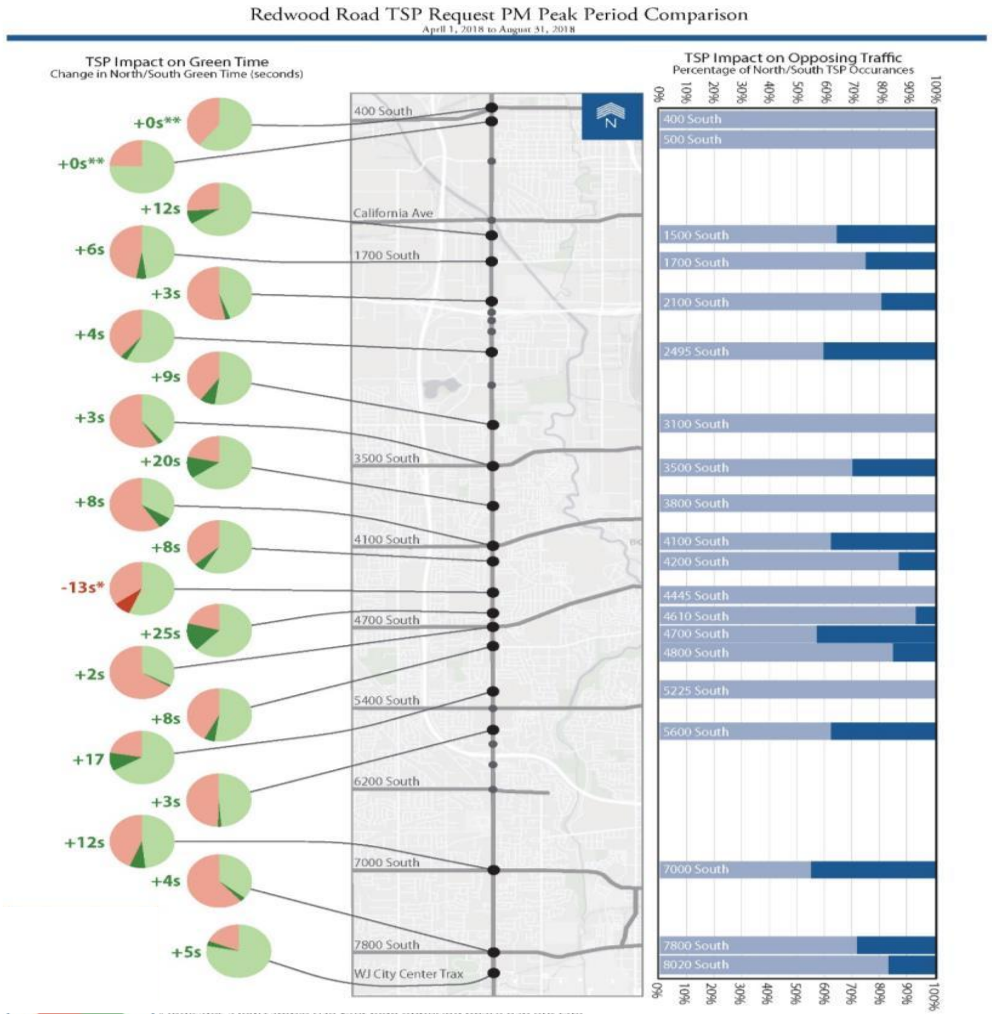
Average TSP Requests & Services



- **% Bus Trips with TSP Requests**
- **% Bus Trips with TSP Serviced**

Results: Signal Performance

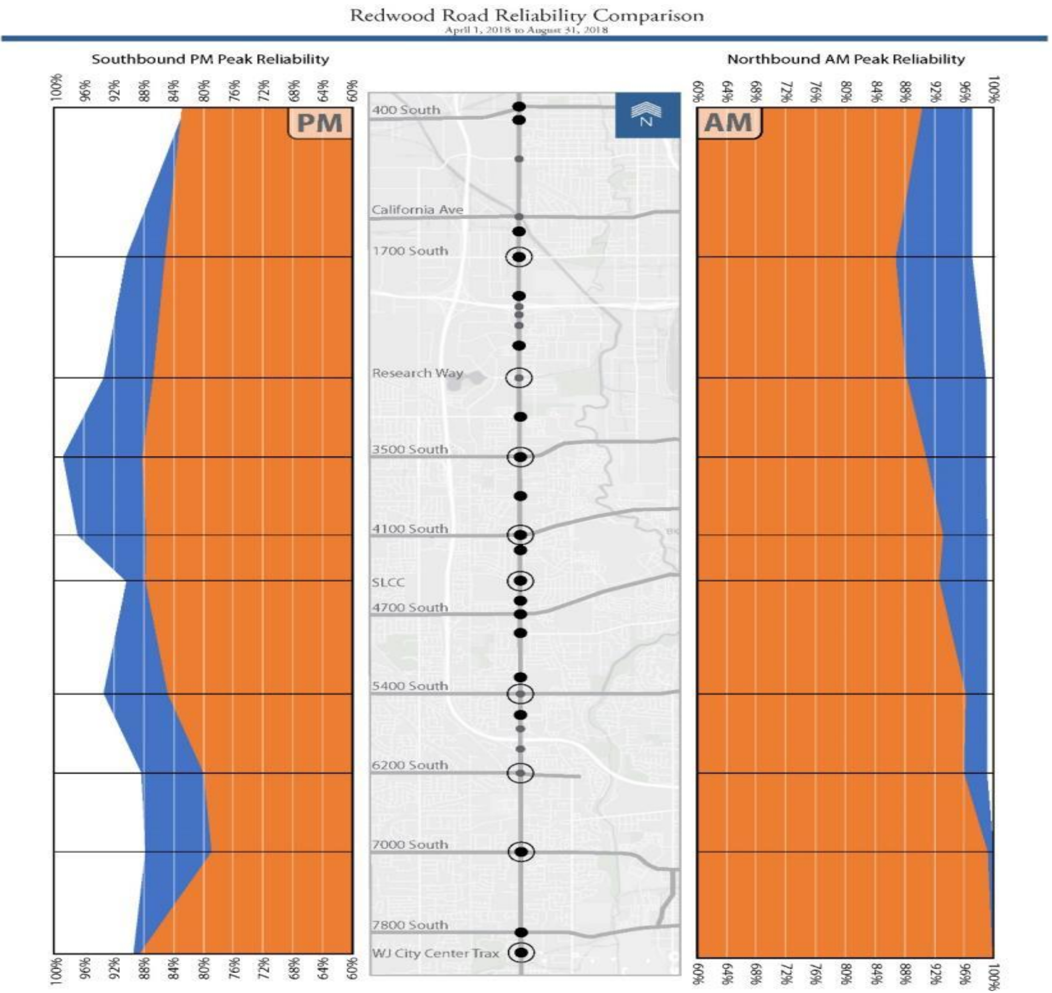
Does it hurt the signals?



- **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.

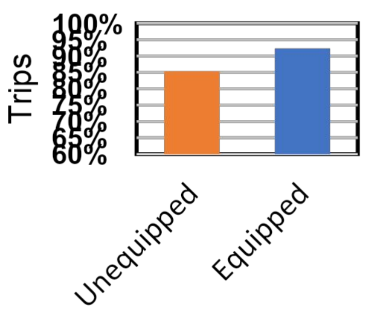


Results: Bus Reliability

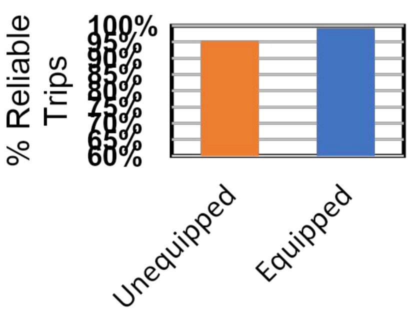
Does it benefit the bus?

Average Reliability

Southbound, PM Peak



Northbound, AM Peak



Note: A bus is "reliable" if it is less than 5 minutes late

Unequipped Bus Reliability

Equipped Bus Reliability

UTA Timepoint

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Results: Bus Schedule Reliability

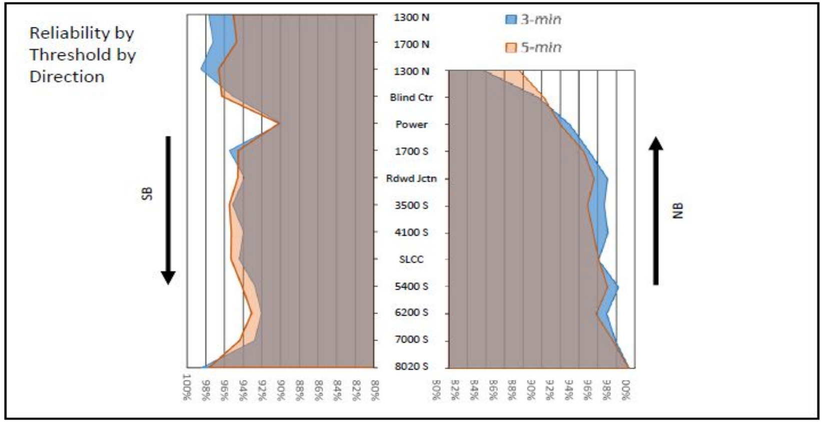
Average Reliability	Southbound PM Peak			Northbound AM Peak		
	No TSP	TSP	Benefit	No TSP	TSP	Benefit
Along Route	85%	91%	***+6%***	93%	99%	***+6%***
End of Route	89%	89%	***0%***	90%	97%	***+7%***

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



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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 . . .

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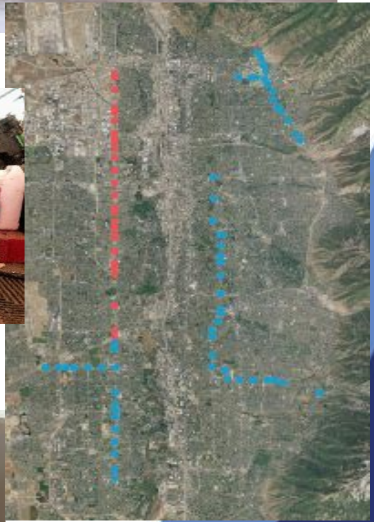
UVX CV TSP Deployment

- 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

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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

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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

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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

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Why DSRC?

Connected Vehicle – per DOT use case

Cellular 4G technology

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

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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")
Built on 3GPP Release 14 (2017) and 15 (2018)
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

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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 deploymt
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

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