Maricopa County Arizona Connected Vehicle Testbed

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Intelligent Transportation Systems – Wisconsin

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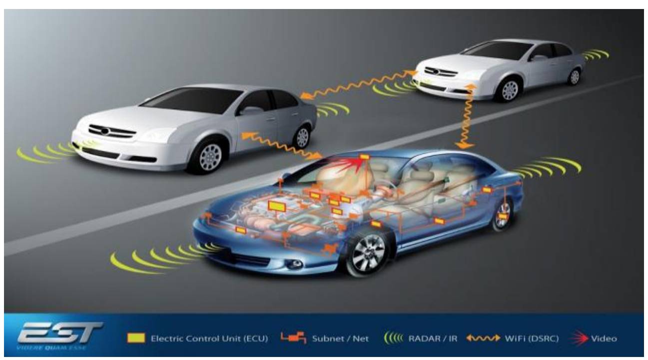
Connected Vehicles …

http://www.its.dot.gov/safety_pilot/index.htm



5.9 GHz DSRC vehicle-to-vehicle (v2v) and vehicle-to-infrastructure (v2i) communications

SAE J2735 Message Set: BSM, SPAT, MAP, SRM, SSM, RSA…

Applications:
SAFETY
MOBILITY
ENVIRONMENT

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Basic Building Blocks

Signal Phase and Timing Data (SPaT)
(10 Hz)

Basic Safety Message (BSM)
(10 Hz)

All message transmission is broadcast
WAVE Message (IEEE 1609)

MAP Data (1 Hz)
Digital Description of Roadway
(D. Kelley, 2012)

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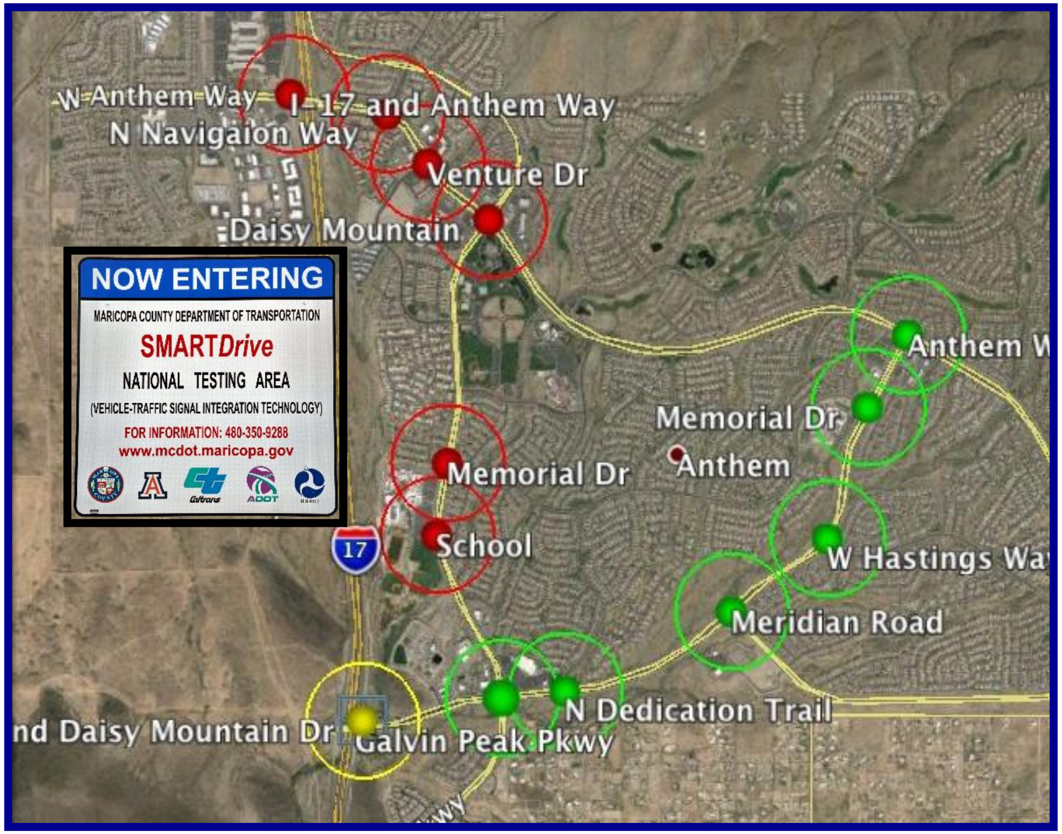
National Affiliated CV Test Beds

Maricopa County DOT SMARTDrive Program

- Several successful demos during last 3 years:
  - Inaugural SMARTDrive, April 26, 2012
  - AASHTO SCOR, December 3, 2013
  - APTA, March 20, 2014
  - FHWA Scanning Tour, July 22, 2014
  - TRB Sig. Com., May 19, 2015



Test Bed Traffic Info

Channel 182

Channel 172

NTCIP

SPaT

10 ASDs in:

- Valley Metro Bus
- Daisy Mountain Fire
- MC DOT REACT Vehicles
- Passenger Cars

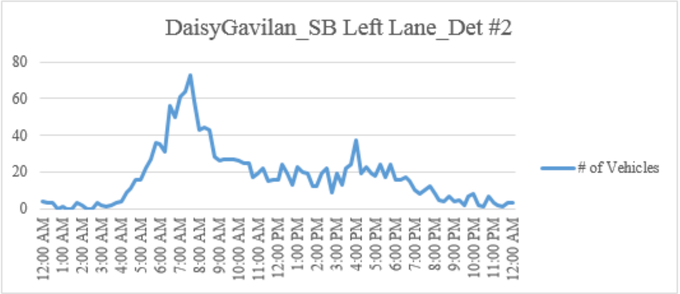
Fiber Optic Backbone Cabling System

Full Inductive Loop Detectorization

System Detectors

Stop bar Detectors

Traffic Demand



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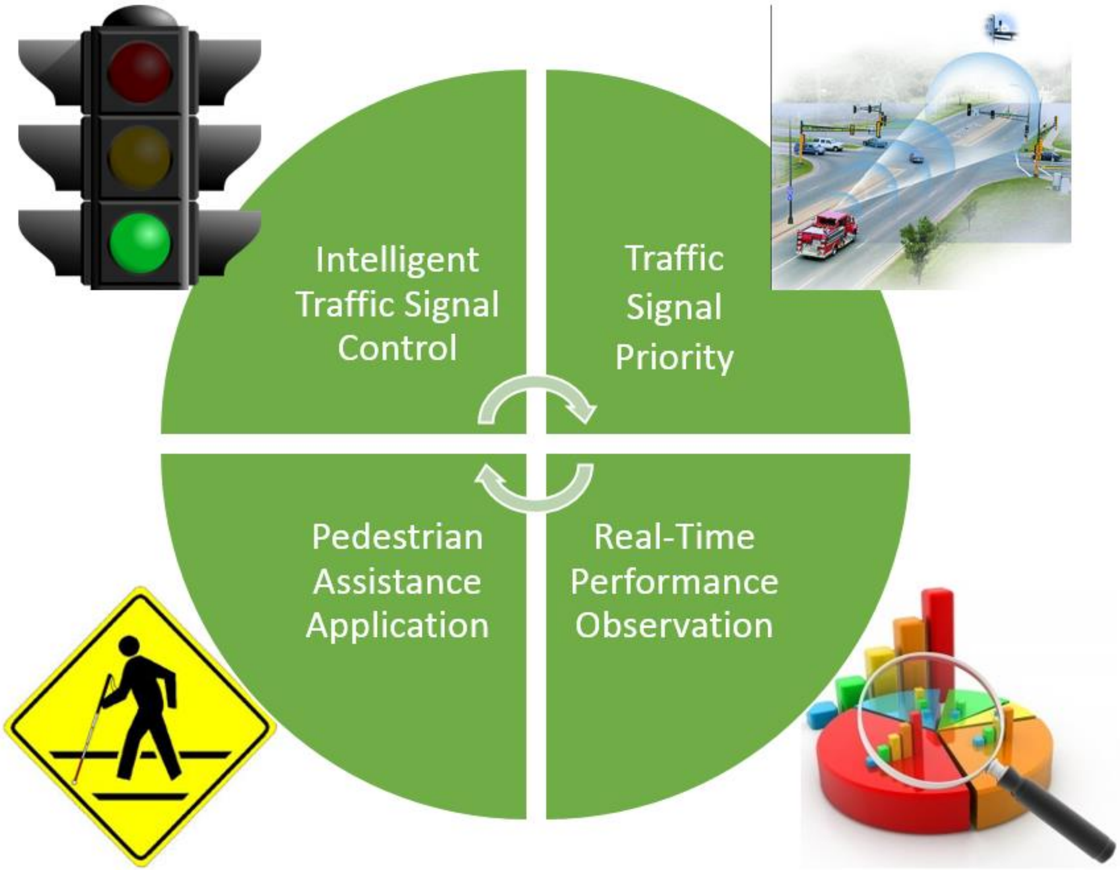
Multi-Modal Intelligent Traffic Signal Systems MMITSS

- Technical
  - University of Arizona (Prime)
  - University of California Berkeley (PATH)
  - Savari
  - Econolite
- Sponsors - Pooled Fund Project
  - FHWA
  - Virginia DOT/UVA
  - Maricopa County DOT
  - Caltrans
  - Minnesota DOT
  - Florida DOT
  - Michigan DOT
  - …

4 Major Components in MMITSS



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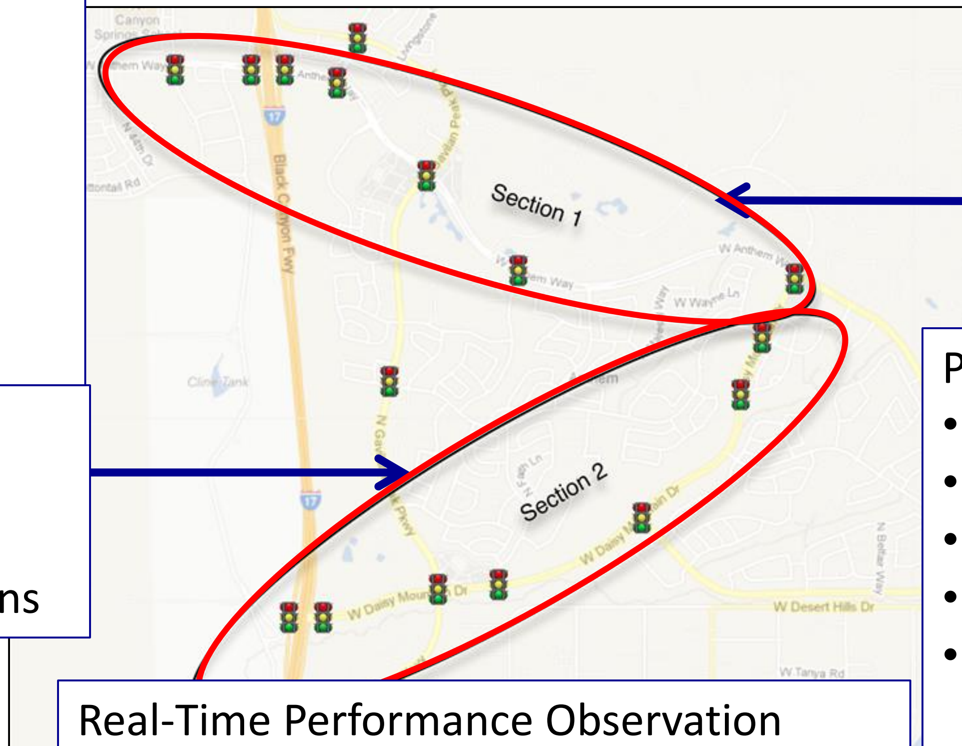
MMITSS Basic Concept

Priority Hierarchy
- Rail Crossings
- Emergency Vehicles
- Transit
  - BRT
  - Express
  - Local (Late)
- Pedestrians
- Vehicles
- Freight



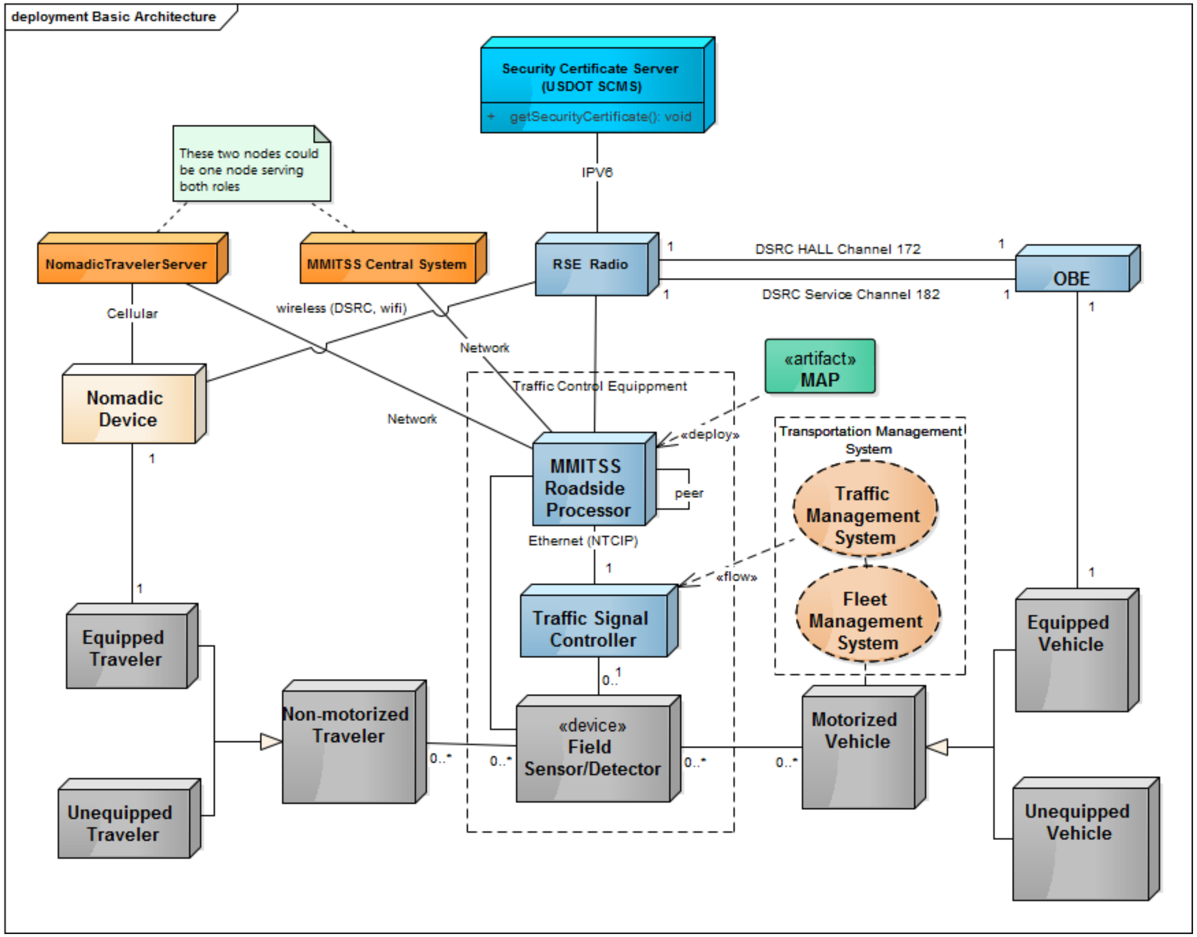
Section 1
- Priority for
  - Trucks

Section 2
- Priority for
  - Transit
  - Pedestrians

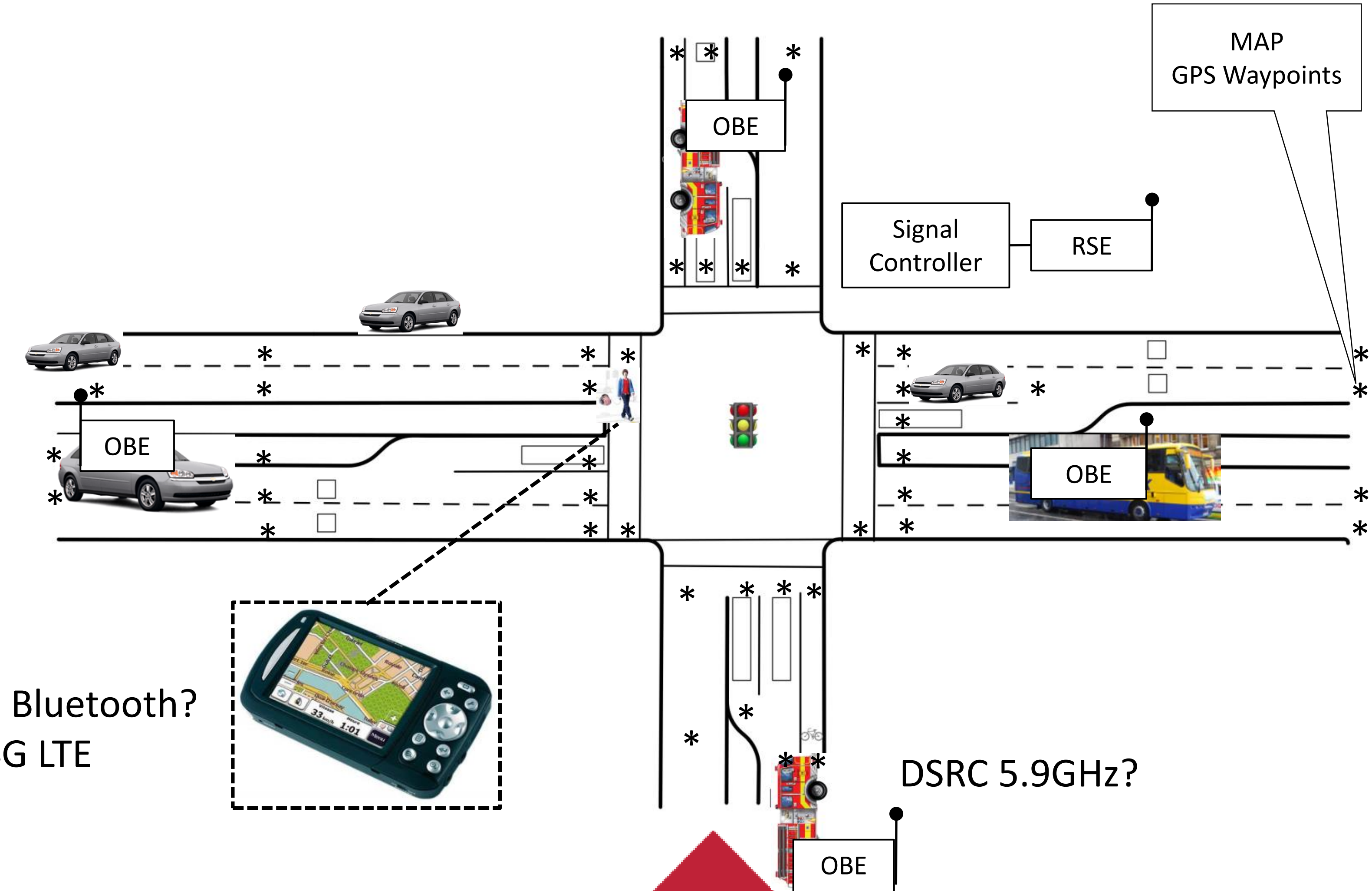
Priority Hierarchy
- Rail Crossings
- Emergency Vehicles
- Trucks/Freight
- Vehicles
- Transit
  - BRT
  - Express
  - Local (Late)
- Pedestrians

Real-Time Performance Observation
- Travel Time (by mode and movement)
- Delay (by mode and movement)
- Throughput (by mode and movement)
- Stops (by mode and movement)

MMITSS Architecture



Signal Control with Connected Vehicles



Wifi? Bluetooth?
3G, 4G LTE

DSRC 5.9GHz?

Messages (SAE J2735)

- Basic Safety Message (BSM)
  - Part I: temp id, location (GPS), speed, heading, steering angle, brakes, size
  - Part II: Safety extensions (path history, prediction, GPS correction), Vehicle status (wipers, lights, brakes, sensors, throttle, size, …)
- MAP (Geometric Description)
- SPaT (Signal Phase and Timing)
- Signal Request Message (SRM)
  - Request (preempt or priority id), inLane, outLane, vehicle type), time of service, end of service, transit status (ada, bike, occupancy, door), vehicle ID, BSM data, vehicle status (EV lights)
- Signal Status Message (SSM)
  - Signal status (preempt, priority, transition, flash), preempt or priority cause (vehicle)
- Priority Status Message (PSM – being proposed)
  - NTCIP 1211 Signal Request Table
    - Contains a table of all Active Requests received by the infrastructure Priority Request Server from Vehicles

Trajectory Awareness of Connected Vehicles

- Store vehicle trajectories
  - BSM: position(GPS, local), speed, heading
  - Frequency: 0.5s
- Construct MAP
- Locate vehicle on MAP: calculate vehicle states, phase, ETA
- Arrival Table: Input for phase allocation algorithm
- Reflect reality
  - Ensure vehicle privacy
  - Geo-fencing

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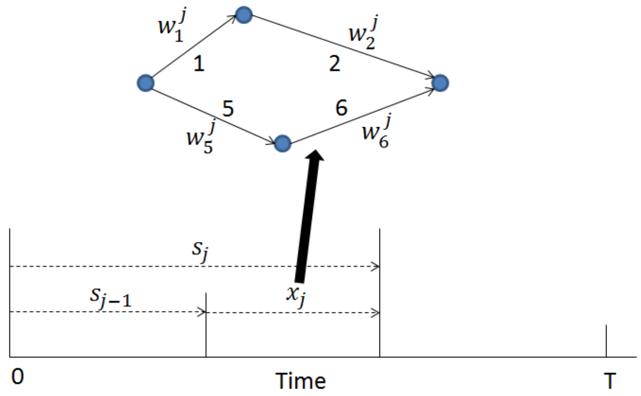
Intelligent Phase Allocation

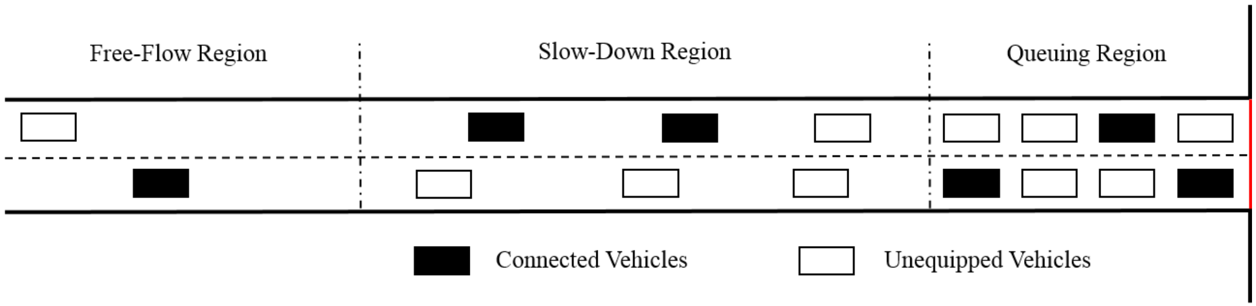
- Provide signal control for regular vehicles: Structure
- Extension of optimization of phases (COP) algorithm
  - Arrival data from CV as the input
  - Two-level optimization (Dynamic Programming)



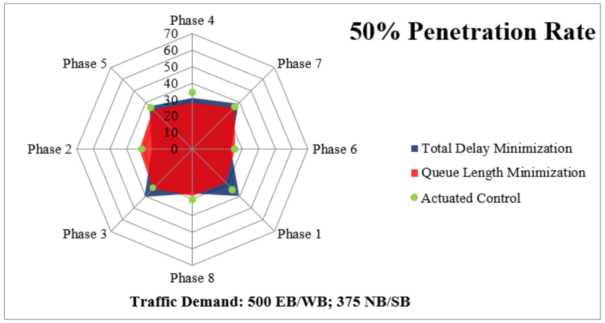
- Two control objectives: minimizing total delay, minimizing queue length

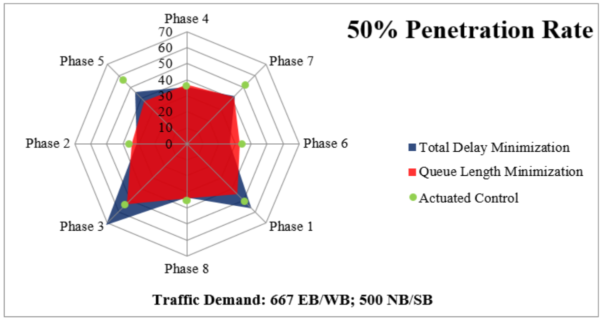
Intelligent Phase Allocation (Cont.)

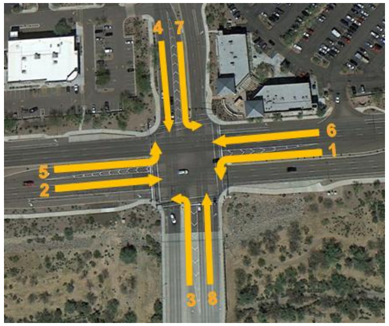
- Market penetration rate of connected vehicles (Goodall, 2013)
- Estimation of vehicle location and speed (EVLS) of unequipped vehicles



- Add detector data under low penetration rate case







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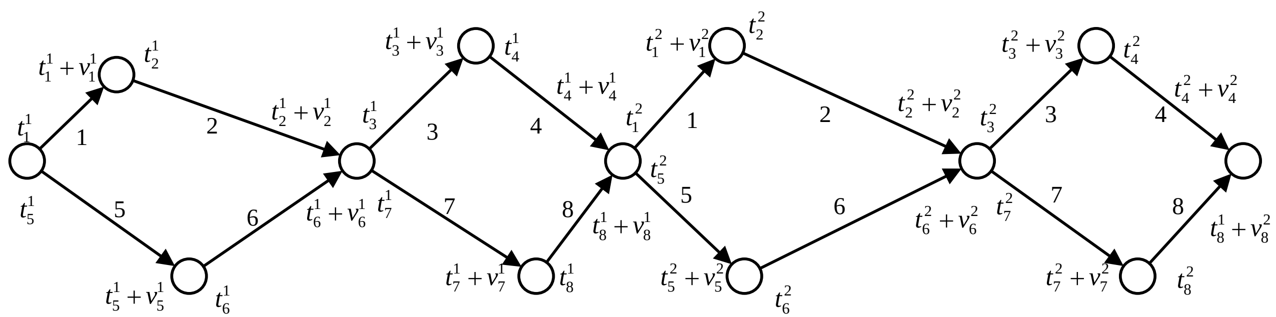
Signal Priority Control

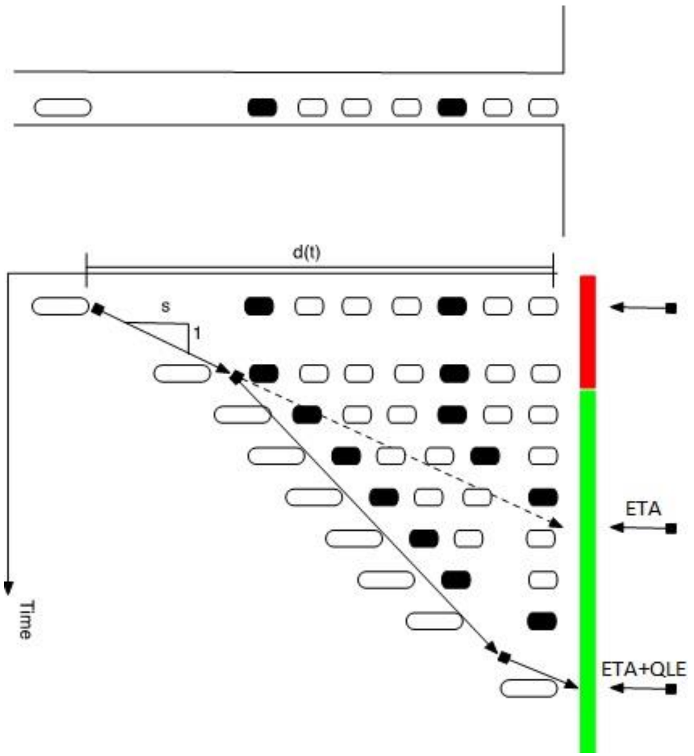
Priority control algorithm includes:

- A mixed integer linear programming (MILP) mode
  - Dual ring barrier signal controller logic
  - Precedence Diagram
- A signal implementation algorithm
  - Time-Phase Diagram



Signal Priority Request

- Priority vehicle broadcasts signal request message (SRM) that contains requested phase and estimated time of arrival (ETA)
- Different travel modes have their own specific characteristics that affect ETA
- Analyzing the DSRC range (300m)



Mathematical Formulation

Multi-Modal Delay | **Coordination Delay** | **Regular Vehicle Delay**

$$\min_{t,g,\theta,\mu} \quad \alpha\left(\sum_{m,j} w^m d_{j_m}\right) + \beta\left(\sum_{p,k} cd_{p,k}\right) + \gamma\left(\frac{\sum_{p,i} N_i . rd_{i,p(i)}}{\sum_i N_i}\right)$$

α, β, γ	are the weights assigned to priority vehicles, coordination, and regular vehicle
w^m	is the weight assigned to mode *m*
d_{j_m}	is the delay of *j*th request from mode *m*
$cd_{p,k}$	is coordination delay for coordinated phase *p* in cycle *k*
$rd_{i,p(i)}$	is the regular vehicle delay for the vehicle that arrives at time *i* for phase *p*
t_p^k	is starting time of phase *p* in cycle *k*
g_p^k	is green time of *p* in cycle *k*
$\theta_{j,p}^m \in \{0,1\}$	whether request *j of* mode *m* is served in cycle *k* or not

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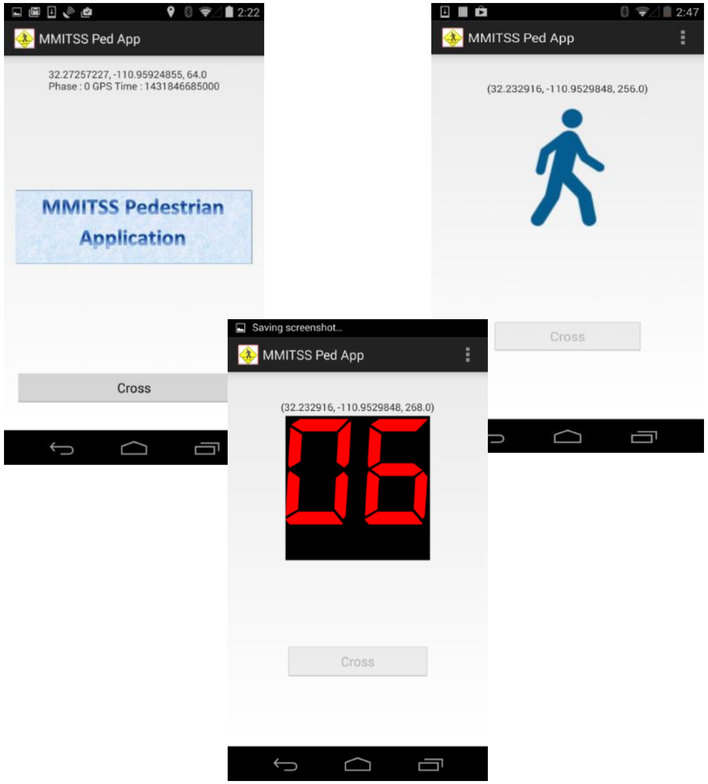
Pedestrian Crossing

- The TRB Traffic Signal System Committee
- TRB Accessibility Committee
- TRB Pedestrian Committees
- SAAVI (Southern Arizona Association for the Visually Impaired)
- Selected group



Performance Observation and Monitoring

- Collect Basic Safety Message Data
  - ✓ Detailed Spatial and Temporal information
  - ✓ High resolution vehicle Trajectories
  - ✓ By mode, by movement analysis
- Process Trajectories to compute observed

Performance Metric	Abbreviation	Unit	Data Source
Travel Time	TT	Second	MRP_EquippedVehicleTrajectoryAware
Delay	D	Second	MRP_EquippedVehicleTrajectoryAware
Travel Time Variability	TTV	Second	MRP_EquippedVehicleTrajectoryAware
Delay Variability	DV	Second	MRP_EquippedVehicleTrajectoryAware
Queue Length	QL	Meter/number of vehicles	MRP_EquippedVehicleTrajectoryAware
Number of Stops	NS		MRP_EquippedVehicleTrajectoryAware
Volume	V		MRP_TrafficControllerInterface
Occupancy	O	%	MRP_TrafficControllerInterface
Market Penetration Rate	MPR	%	MRP_EquippedVehicleTrajectoryAware & MRP_TrafficControllerInterface

- Performance Measures Used for
  - Monitoring and Assessment
  - Section Level Control

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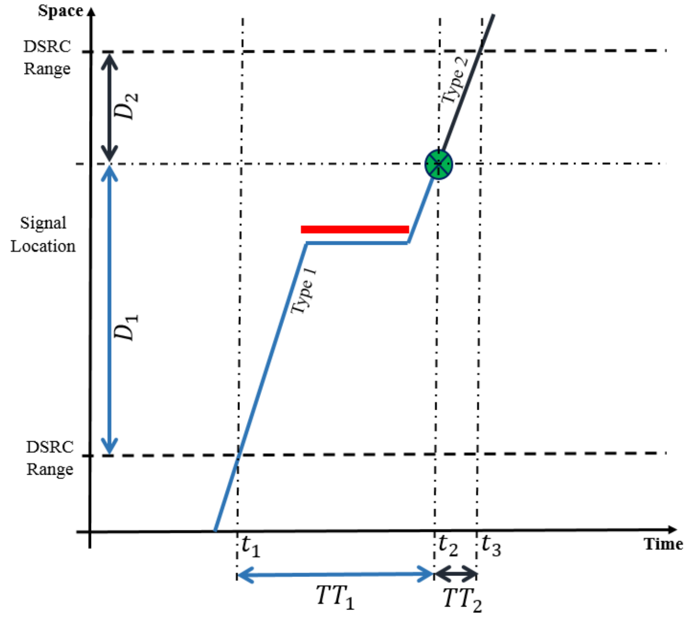
Partial Trajectories to Preserve the Privacy

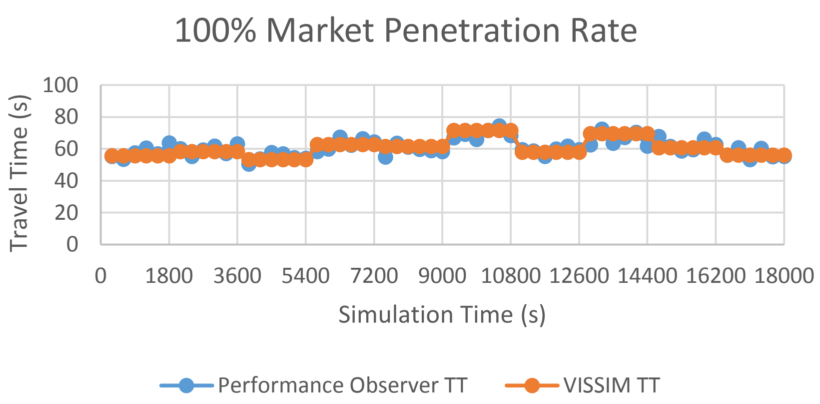


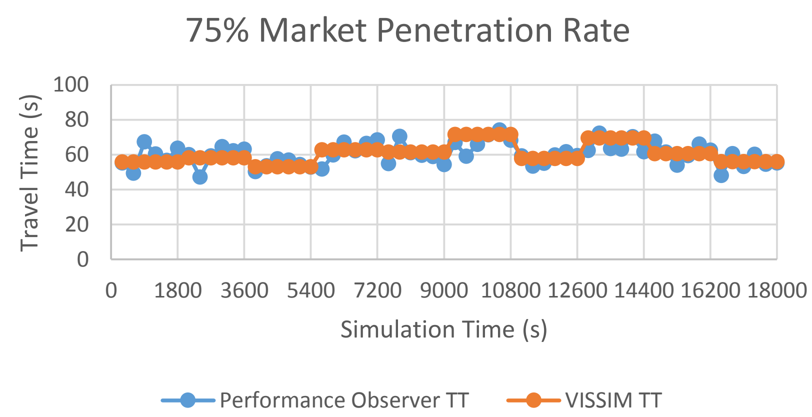
$$Probability\ of\ changing\ ID = p = \frac{Travel\ Time\ of\ vehicle_j}{300}$$

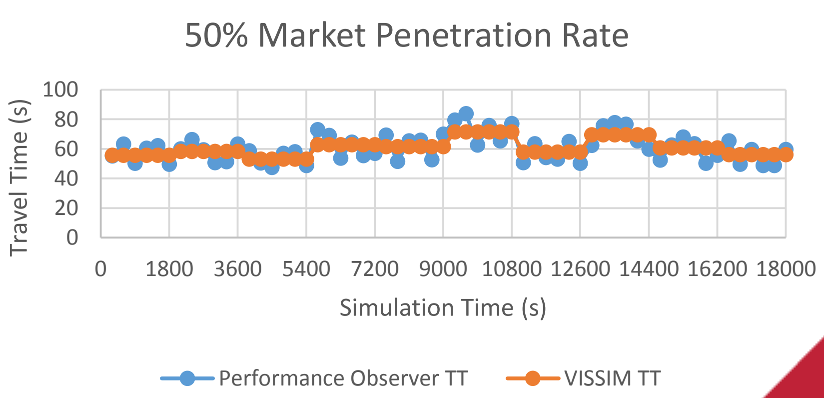
$$ETT = \left[\sum_{i=1}^{n} \frac{TT^i}{D^i} + \sum_{j=1}^{m_1} \frac{TT_1^j}{D_1^j} + \sum_{j=1}^{m_2} \frac{TT_2^j}{D_2^j}\right] \times \left[\sum_{i=1}^{n} D^i + \sum_{j=1}^{m_1} D_1^j + \sum_{j=1}^{m_2} D_2^j\right] / [n + m_1 + m_2]$$

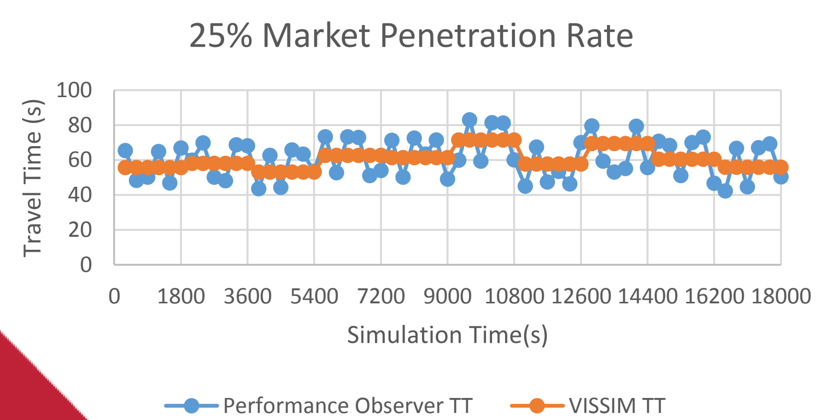
Simulated Travel Time Estimation

- ✓Daisy Mountain and Memorial Drive
- ✓Travel Time Data accumulated every 5 Minutes for Northbound Through Movement









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Research and Development Steps

- Algorithm concept definition and application development
- Simulation testing on **calibrated** models in lab environment
  - ✓ Traffic Signal Data
  - ✓ Traffic Demand and Input
  - ✓ DSRC Range
- Field testing at the intersection of Mountain and Speedway in Tucson, AZ

- Arizona Connected Vehicle Test Bed implementation

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VISSIM Simulation Environment

Arizona CV Test Bed

- Hardware-in-the-loop Simulation (HILS)
- Software-in-the-loop Simulation (SILS)
- Drivermodel.dll API
  - ✓ Coordinates transformation: local -> GPS (Farrell and Barth, 1999)
  - ✓ Pack J2735 BSM/SRM messages (ASN1 encoder/decoder)
  - ✓ Send through UDP socket
- GPS Error Modeling
- OBE Message Distributor
- Docker

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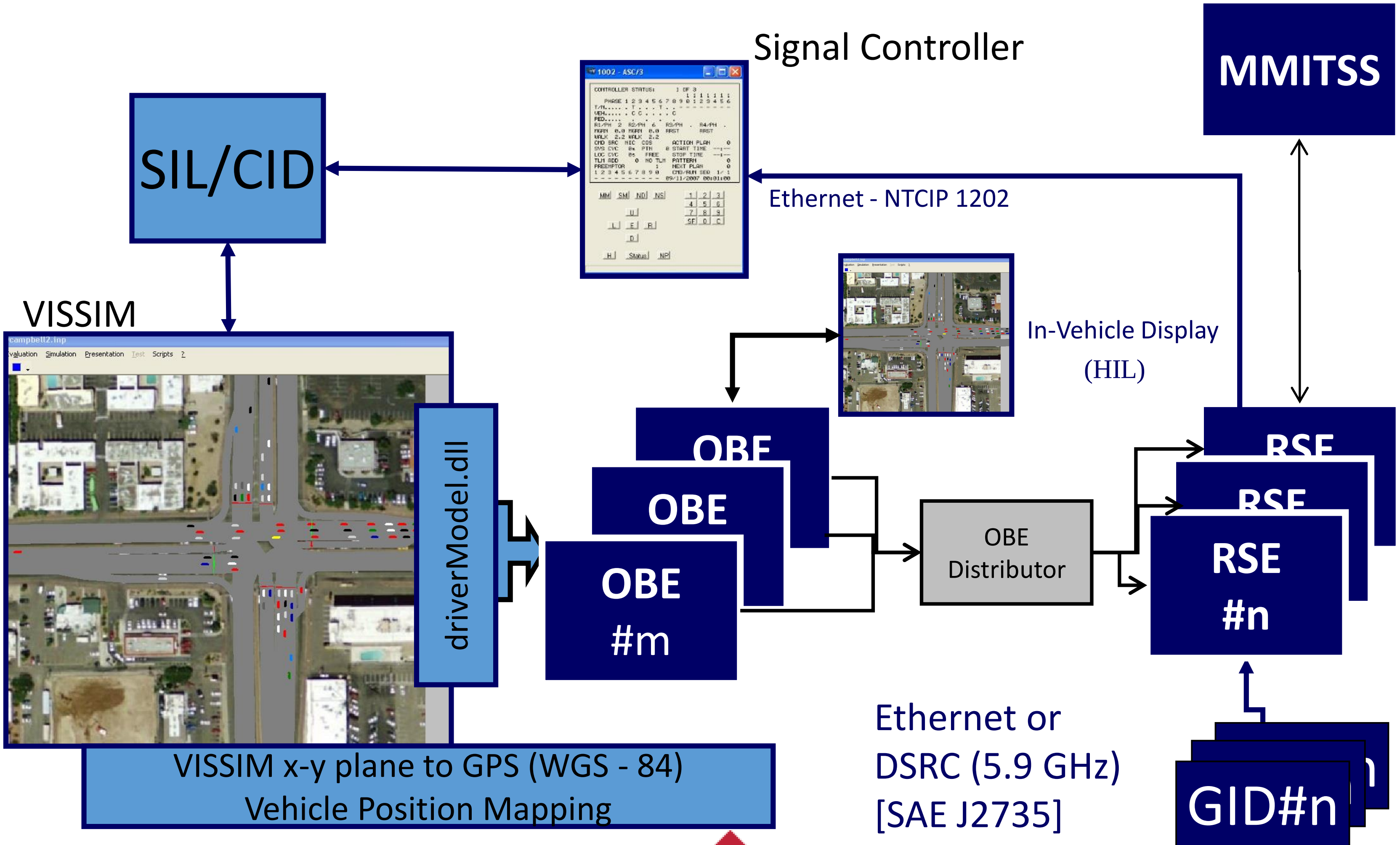
Simulation Platform Architecture



GPS Error Modeling

- GPS Error in real world,
  but doesn't exist in simulation
- Data collection: 2 hours of 1Hz GPS data

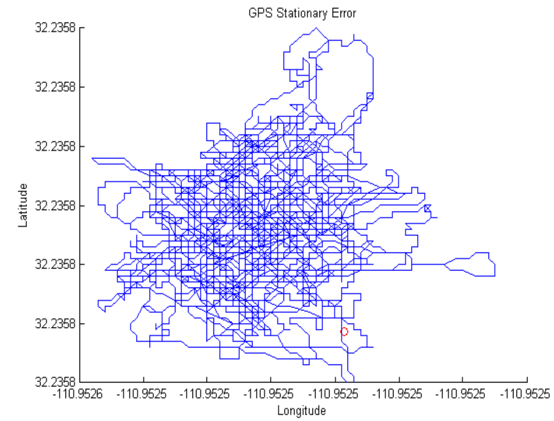
- Univariate Autoregressive Integrated Moving Average (ARIMA)
- $x_t = \emptyset_1 x_{t-1} + \emptyset_2 x_{t-2} + \cdots + \emptyset_p\, x_{t-p} + a_t + \theta_1 a_{t-1} + \cdots + \theta_q a_{t-q}$

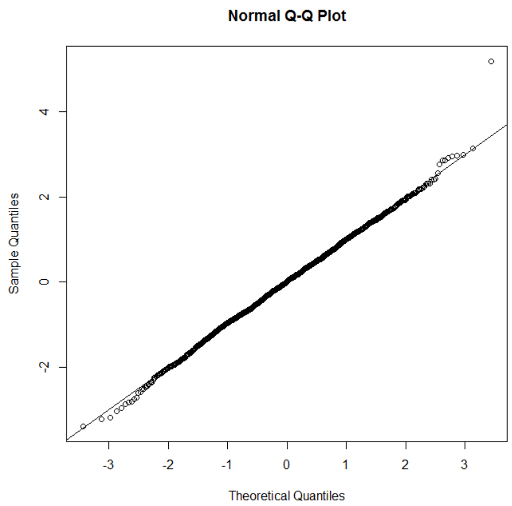
  x_t: Observed Value of time t.

  a_t: IID noise term, assumed to be normally distributed

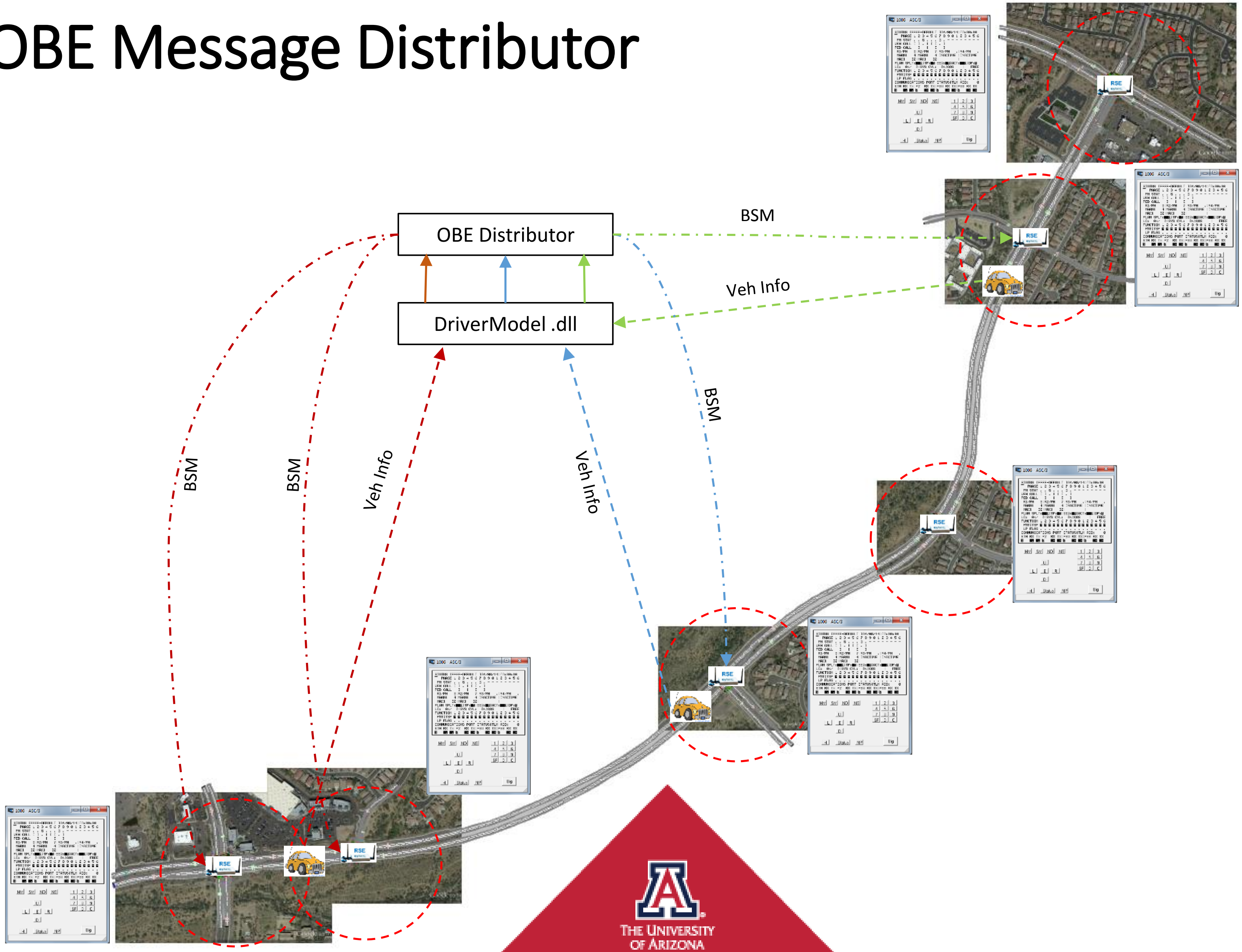
  $\emptyset_i$: Autoregressive parameters

  θ_i: Moving average parameters
- ARIMA (2,0,2)
- Residual Normality Test
  - p-value:0.618



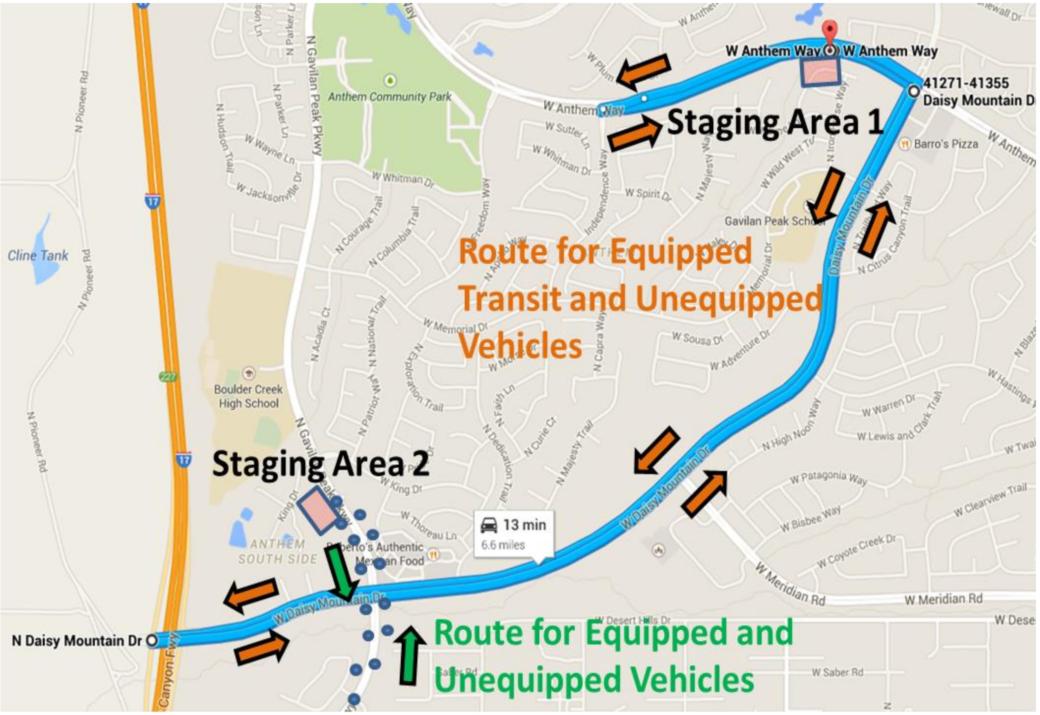


OBE Message Distributor



Field Testing Scenarios_Impact Assessment

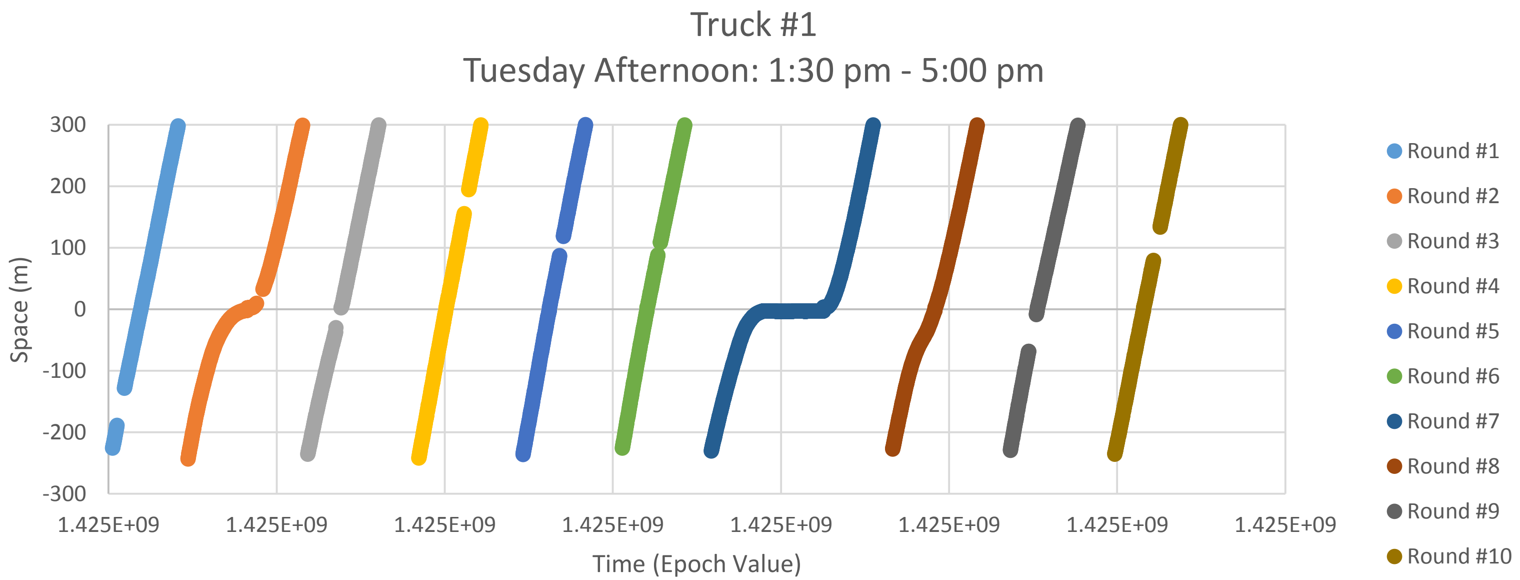
- March 2nd-5th, 2015
- 2 trucks with priority in northbound/southbound
- 2 buses with priority in eastbound/westbound
- 6 regular vehicles
- 10 rounds of testing



Source: Leidos Field Test Plan

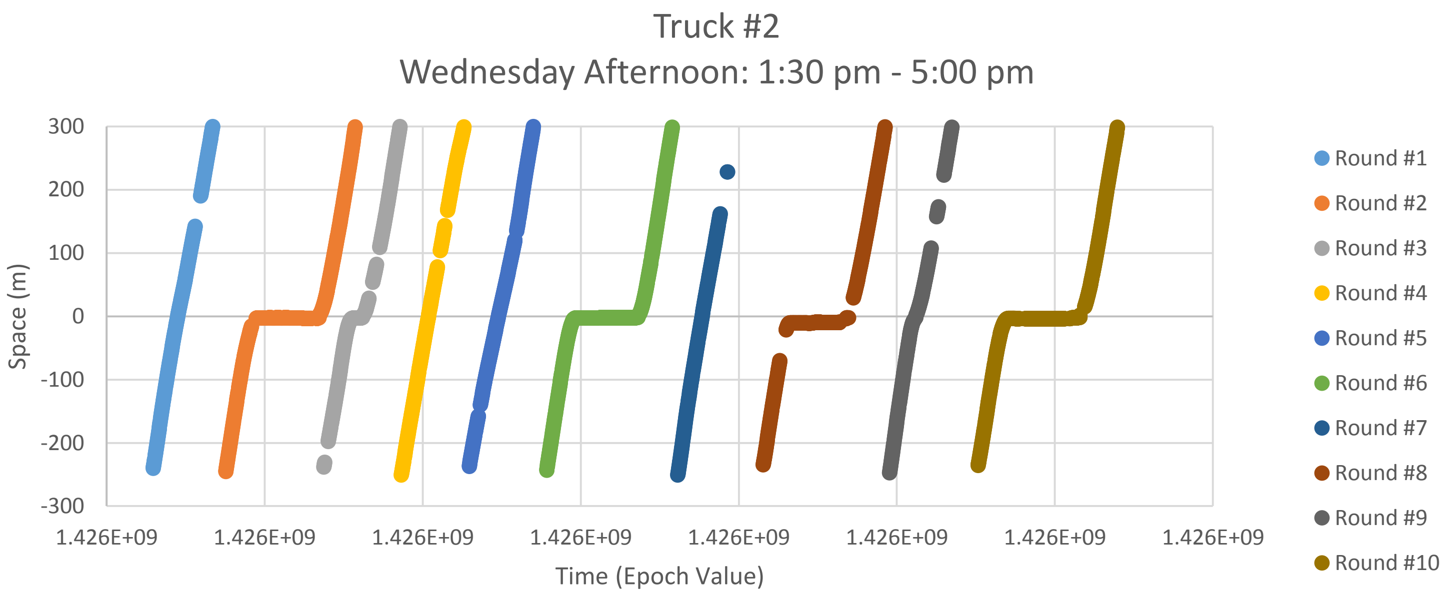
Time-Space Diagram with MMITSS

- Daisy Mountain and Gavilan Peak Northbound Movement
- Number of Stops: 1, Number of Queue Encounters: 2
- Using BSMs sent from Truck#1



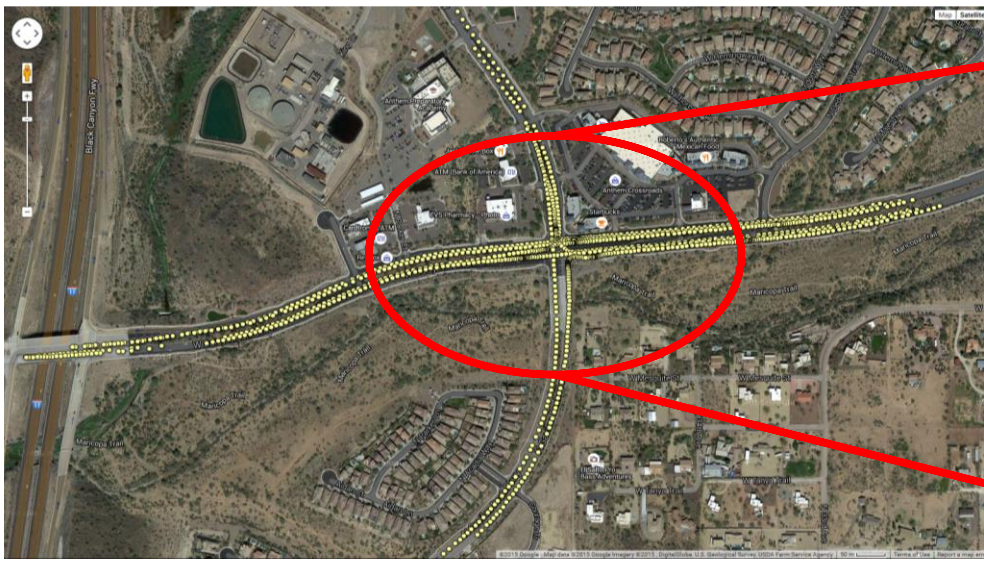
Time-Space Diagram without MMITSS

- Daisy Mountain and Gavilan Peak Northbound Movement
- Number of Stops: 5, Number of Queue Encounters:1
- Using BSMs sent from Truck #2



DSRC Range vs. Geo Fencing Sections (MAP Nodes)

- Limitation of Map: WAVE Message Requirement (<1Kb)
  - Reducing Number of Lane Nodes
  - Reducing Number of Lanes on Egress Approaches



True DSRC Range Based on collected BSMs

Geo Fence Area Based on Extension of Map Nodes

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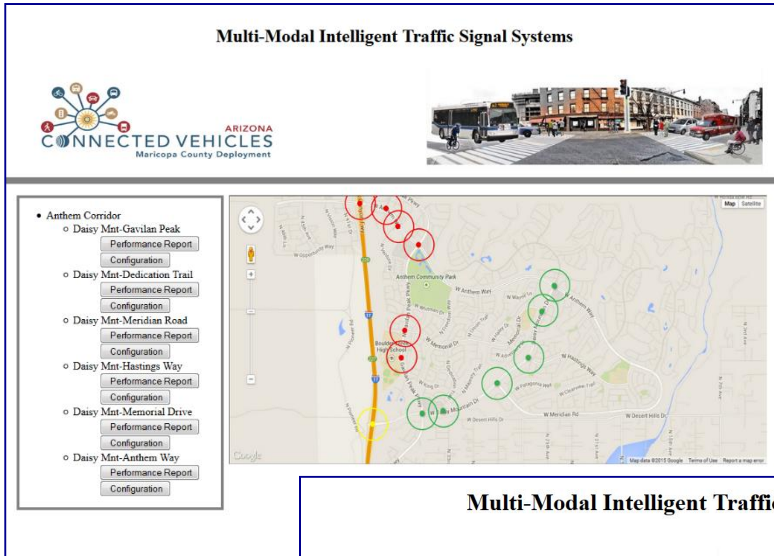
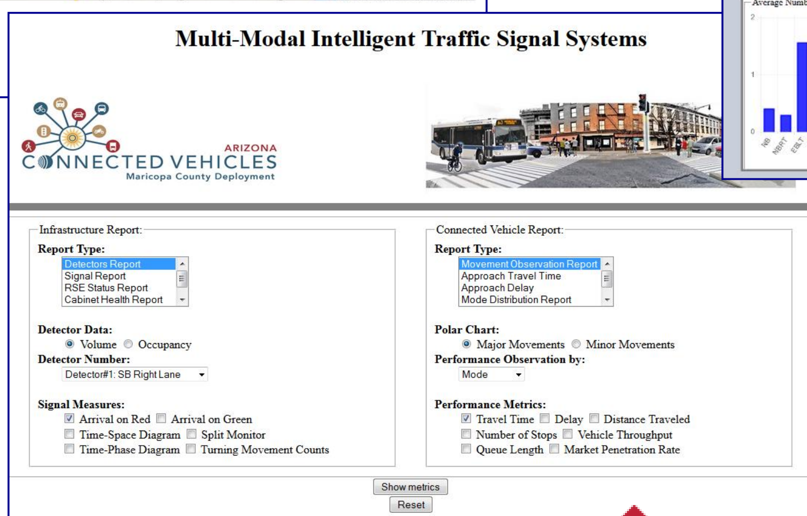
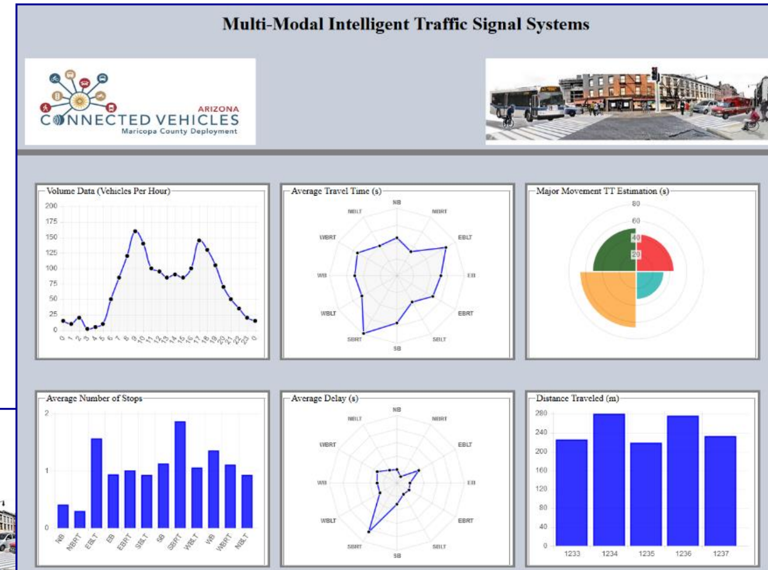
Performance Web Application (Cont.)







Conclusion

- Maricopa County DOT is a great partner in the Arizona Connected Vehicle Test Bed for CV research and development.
- A platform to support the design, development, implementation, and testing of CV applications including:
  - Intelligent Traffic Signal Control Application
  - Signal Priority Application
  - Pedestrian Assistance Application
  - Real-time Performance Observation Application
- Using latest standards in wireless communication and messaging
- Real-Time analysis of performance metrics by mode by movement

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Questions?

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