THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Bringing Smart Transportation to Texans:

Ensuring the Benefits of A Connected & Autonomous Transportation System in Texas

Lisa Loftus-Otway & Paul Avery

TxDOT Research Project 0-6838

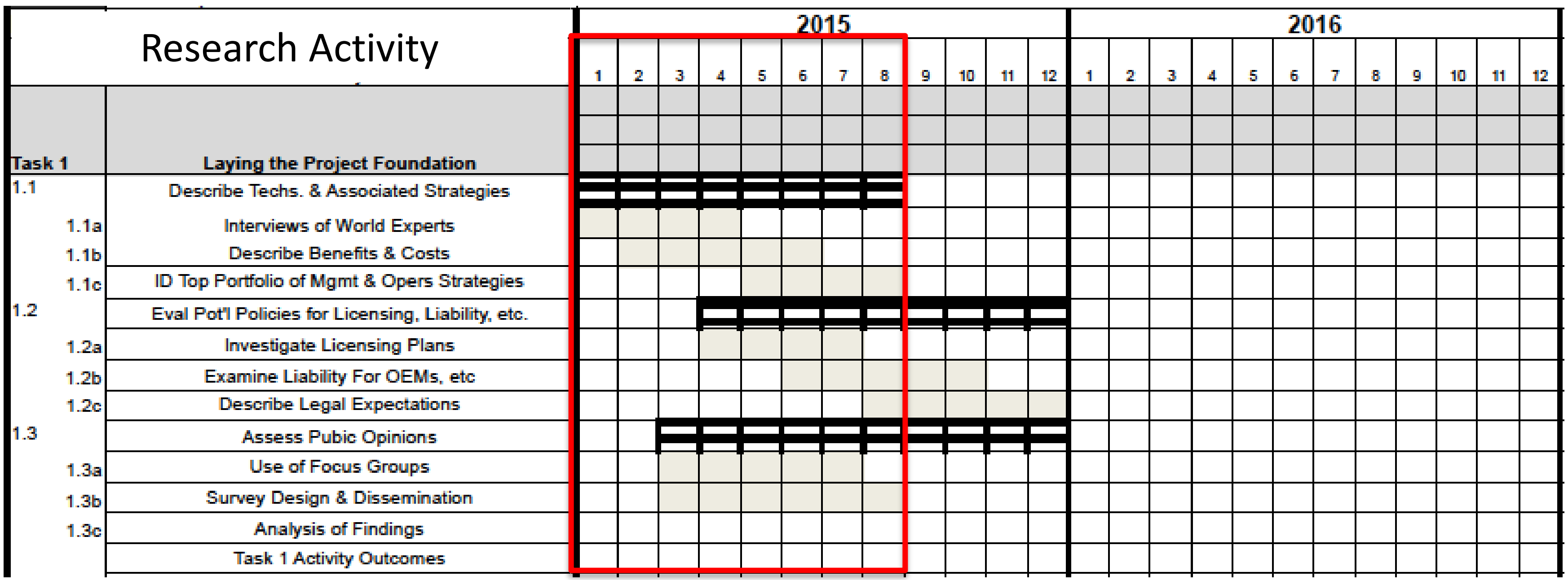
Research Team

- **Kara Kockelman – RS**
  - Dr. Kockelman is research supervisor and in charge of focus groups, survey data, demand modeling, & fleet simulation.
- **Steve Boyles**
  - Dr. Boyles is leading the effort for traffic simulation and modeling of autonomous vehicle traffic systems.
- **Christian Claudel**
  - Dr. Claudel is leading the design and prototype development of inexpensive traffic and road condition sensing platforms based on inertial measurement units.
- **Lisa Loftus-0tway & Wendy Wagner**
  - Ms. Lisa Loftus-Otway and Prof. Wagner co-lead the development of a legal review for the project which will develop recommendations for policy or legislative changes that may be needed.

Research Team

- **Jia Lia**
  - Dr. Li leads research activities on expert interview and benefit/cost analysis of transportation system management & operations strategies.
- **Dan Fagnant (University of Utah)**
  - Dr. Fagnant advises the research team and conducts background research on assessing potential benefits and costs across a variety of potential CAV strategies.
- **SwRI (Paul Avery, Cameron Mott, Darin Parish, Stephan Lemmer, Purser Sturgeon II)**
  - SwRI is leading the development of CAV demonstrations using industry-standard AV and CV hardware, and SwRI-developed software.
- **Duncan Stewart**
  - Dr. Stewart advises the team, especially the legal researchers, on the likely technology developments that will impact TxDOT policies and operations.

Schedule of Activities: Task 1



Schedule of Activities: Tasks 2 & 3

	Research Activity	2015												2016											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Task 2	**Data Analysis, Forecasting, Simulations, & Evaluation**																								
2.1	Simulate Network Dynamics Under Various CV+AV Settings																								
2.1a	Set Up Test Networks for Freeway Ops																								
2.1b	Set Up Test Networks for Simulating Arterial Ops																								
2.1c	Perform Simulations for Delays, etc																								
2.1d	Evaluate Benefits of Dynamic Micro-tolling																								
2.1e	Translate Vehicle Loading Using MOVES																								
2.1f	Prepare Subtask Report																								
2.2	Demand Modeling for CAV Benefits																								
2.2a	Obtain AUS & TX Inputs																								
2.2b	Apply Demand Models																								
2.2c	Apply Road Pricing Strategies																								
2.2d	Prepare Subtask Report																								
2.3	Overall Evaluation of Smart-Transport Strategies																								
2.3a	Defining the Performance Metrics																								
2.3b	Deliver Strategy Rankings																								
2.3c	Deliver Report Documenting Findings																								
	Task 2 Activity Outcomes																								
Task 3	**Demonstrations & Delivery**																								
3.1	Demonstrate DRSC-Instrumented V2I & V2V Driving on Freeways & Signalized Corridors																								
3.1a	Prepare Roadside & Vehicle Hardware																								
3.1b	Demonstrate V2I & V2V Communications																								
3.1c	Prepare Multiple Products																								

Task 1.2: Evaluate Potential Policies, Legislation & Standards

- Evaluate & recommend potential policies & legislation for a Texas CAV Licensing & Regulation System.
  - Investigate status & plans in U.S. & globally.
  - Examine liability issues for OEMs, owners, operators & network managers.
  - Describe issues surrounding privacy & data access.

Methods

1. Identify the primary changes expected for CAVs over next 3 decades and consider how these technological advances intersect with current Texas law. Legal research is focused on roadway design, maintenance, privacy, data security, liability, and licensing issues.

2. Texas law is compared against law in other states and countries with respect to implications for CAVs.

3. Alternative policy paths are identified for future based on literature, expert consultations, and policy experimentation already occurring.

Work Status

– Generated a research blueprint with general and detailed questions to ensure legal research addresses technical issues emerging from larger team.

– Substantial research conducted on status of Texas law with respect to CAV use.

– Substantial research conducted situating Texas law within other 50 states, EU, Canada, and Japan.

– From this research, policy alternatives are emerging for all main topics including data privacy, liability, and licensing.

Preliminary Results

1. Existing Texas law presents only a few impediments and/or constraints on use of CAVs.
2. A number of future "forks in the road" have been identified where legal confusion could occur. These forks can be addressed in the near-term with regulatory, legislative, and other types of clarifications based on State policy preferences.
3. Several alternative policy paths are available for Texas to consider with respect to data management, liability, and licensing. Some anticipatory policymaking may streamline the integration of CAV in the State; this intervention need not always entail legislation or regulatory action.

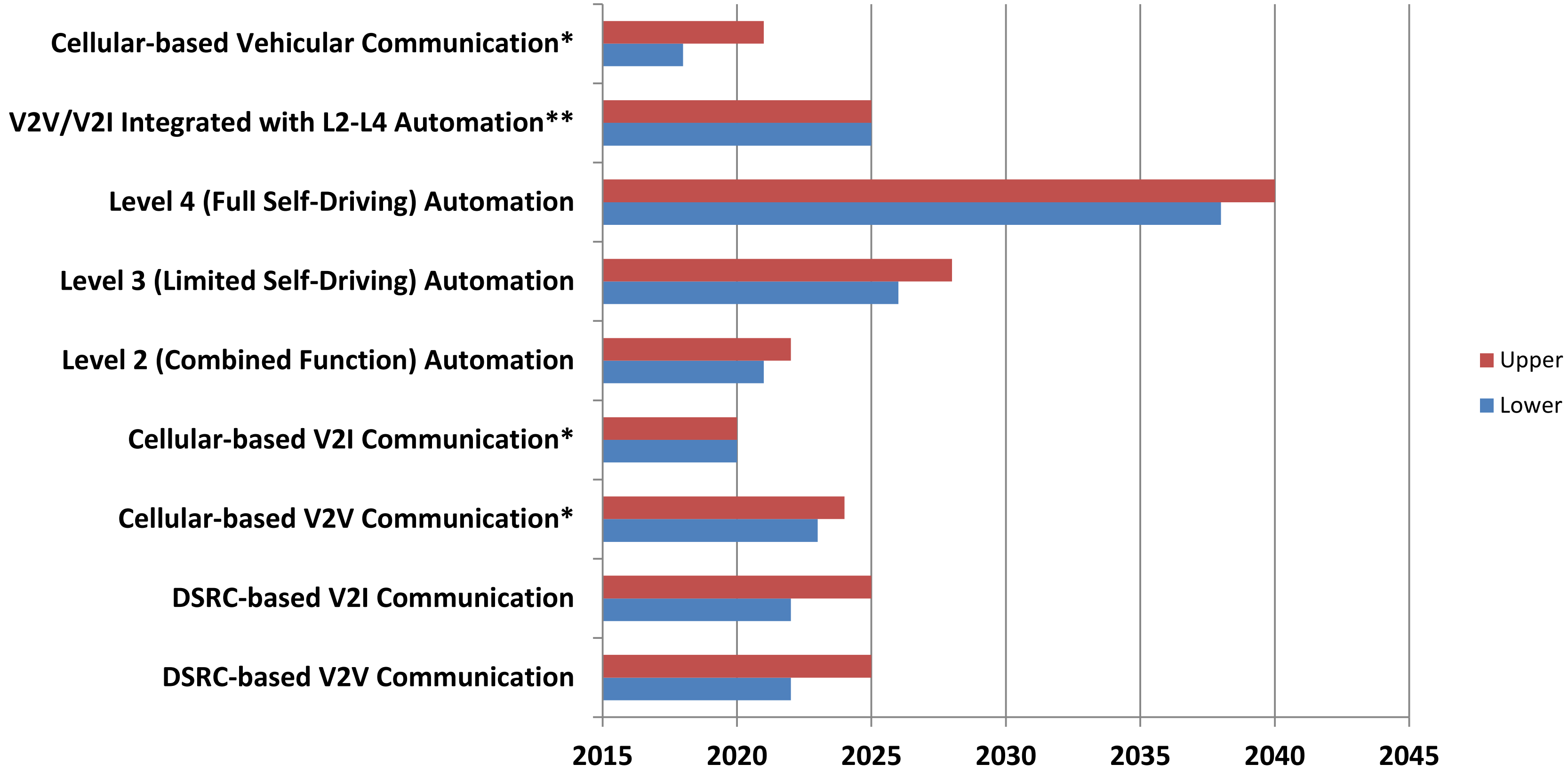
Task 1.2: Expert Survey & Interview

- Started in April 2015
  - Survey: April to June
  - Interview: June to July
  - Analysis: July
- 60+ Invited
- 11 Responses (both survey & interview) – Technology, ITS, Policy, Human Factor

	Respondent	Affiliate	Expertise Area
1	Chris Claudel	University of Texas at Austin	ITS, IMU Applications
2	Dan Fagnant	University of Utah	Safety & Policy
3	Eric Thorn	Southwest Research Institute	Smart Driving Technologies
4	Paul Avery	Southwest Research Institute	Smart Driving Technologies
5	Steve Shladover	PATH, University of California, Berkeley	Highway Automation
6	Meng Wang	TU Delft	CACC
7	Glenn Havinoviski	Iteris	ITS
8	Duncan Steward	University of Texas at Austin	Policy, Operations
9	Nichole Morris	University of Minnesota	CAV Human Factor & Safety
10	Jan Becker (phone)	Robert Bosch	Vehicle System Control
11	Richard Bishop	Bishop Consulting	CAVs & ITS

Expert Survey: Timeline Forecast

When do you think the ***technologies*** will be ***sufficiently developed*** for mainstream adoption?



Expert Survey: Technology Benefits

	Safety	Mobility	Driver Comfort	Environment	Social Equity
DSRC-Based V2V	4.4	2.6	2.1	2	1.4
DSRC-Based V2I	3.5	3	1.8	2.7	1.4
Cellular-Based V2V*	2	2.8	2.2	1.8	1.6
Cellular-Based V2I*	2	4.2	2.5	2.7	2
L2 Automation	3.8	1.7	3	1.8	1.4
L3 Automation	4.1	3.1	4	2.7	1.4
L4 Automation	4.6	4.4	4.9	3	2.1
Cellular-based Vehicular Communication*	2.2	2.8	3	2.2	1.3

Anticipated benefits of smart driving technologies (scale 1-5).

*In the first version of our survey we used the term "Cellular-based Vehicular Communication" to represent both Cellular-based V2V and V2I Communication. We later differentiated between the two, as was recommended by a few of the respondents.

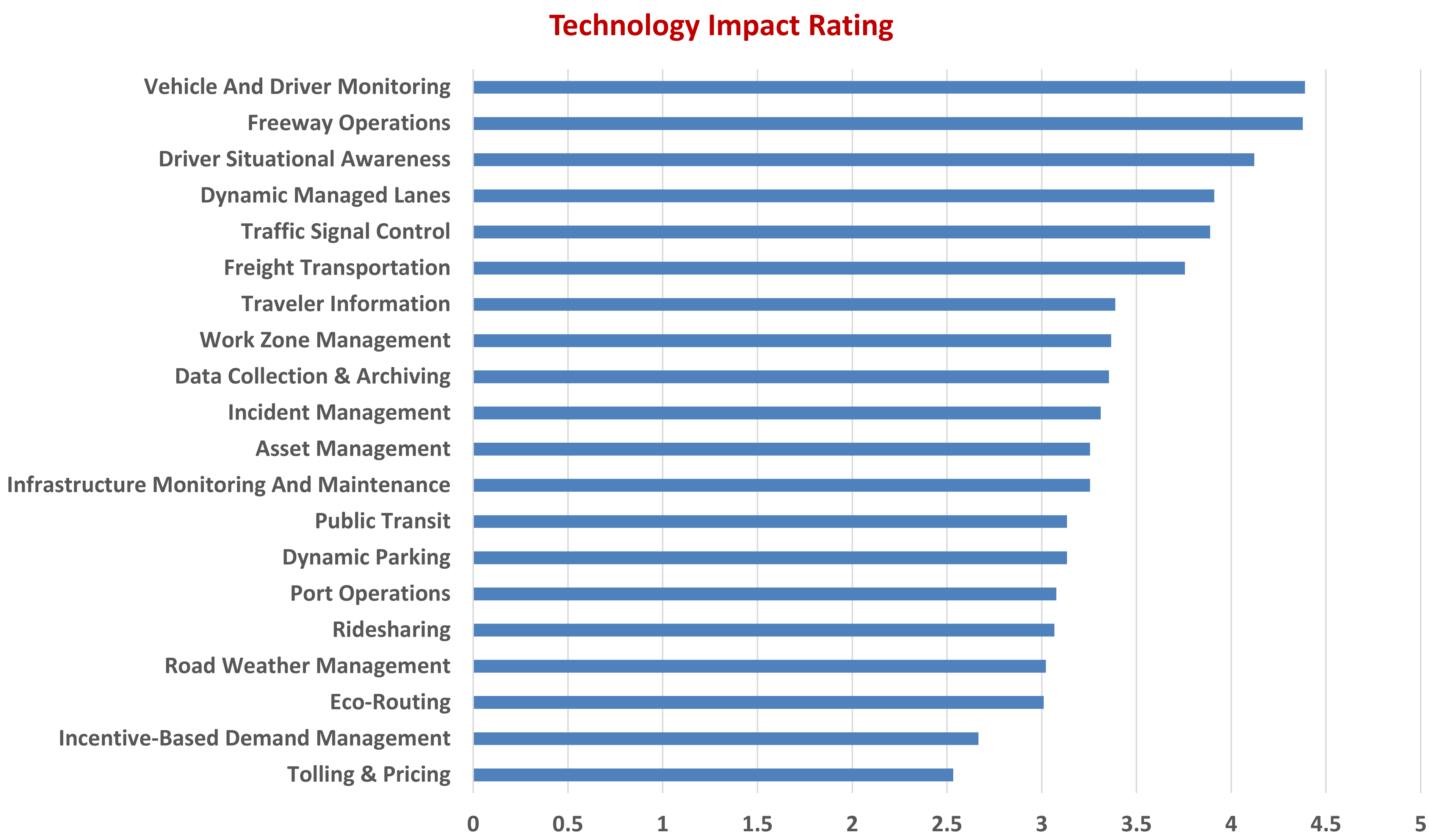
** This function was only present in the final two surveys distributed.

Expert Survey: Technology Barriers

	Cybersecurity	Reliability	Liability	Price	Infrastructure Preparedness	Policy & Regulation	Public Acceptance
DSRC-Based V2V	3.75	3.00	3.14	2.57	2.50	2.71	2.43
DSRC-Based V2I	3.75	2.86	2.00	3.00	4.13	2.71	2.14
Cellular-Based V2V	3.25	2.57	1.71	2.75	1.86	2.43	1.57
L2 Automation	2.375	3.38	3.43	3.13	1.57	2.00	2.25
L3 Automation	3.625	4.38	4.14	3.38	2.43	3.14	3.14
L4 Automation	3.75	4.00	3.43	3.75	2.29	3.14	3.00

Anticipated barriers of smart transportation technologies (scale 1-5).

Expert Survey: Impacts on Transportation System Management and Operations (TSM&O)



Expert Survey: Recommended Actions in Transition Phase

Public Agency

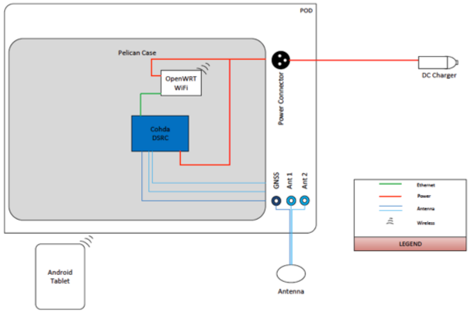
- Transition will be slow and painful unless infrastructure is segregated for automated and non-automated vehicles.
- Dedicated roads for AVs (certified truck, bus and other vehicles) with operation time.
- Keep investing in manual driving; don't look too far into the future at a government level of investment.
- DOT investment; research on identifying low added-cost infrastructure.
- Intersection collision warning & emergency braking.
- Provision of Real-time information & routing guidance.

Private Sector

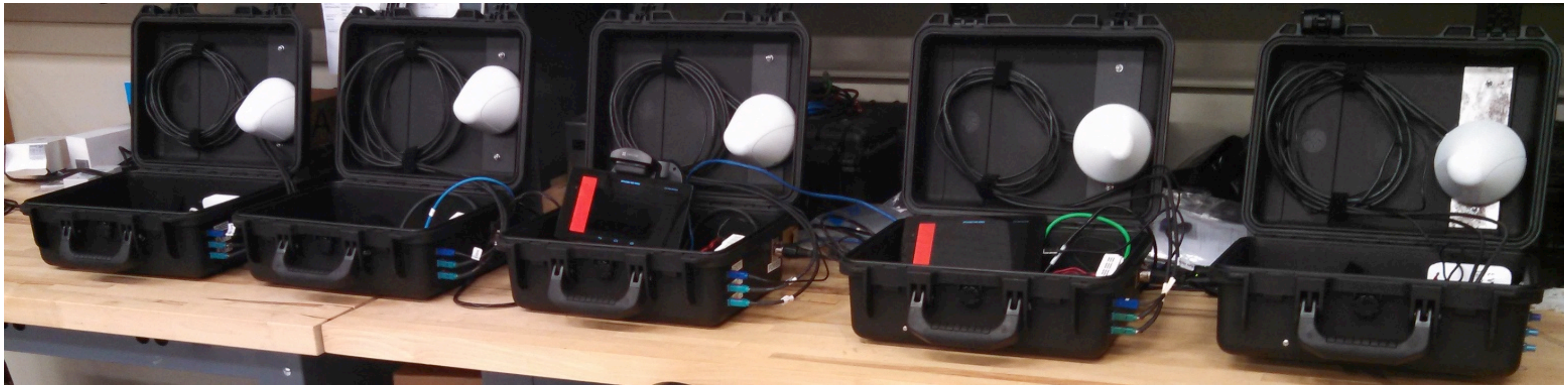
- Driverless taxi and rideshare.
- Central center for truck platooning/coordinating.

Task 3.1a Hardware Preparation

- SwRI Portable Onboard Device (POD)
  - 5 PODs have been assembled and tested at SwRI

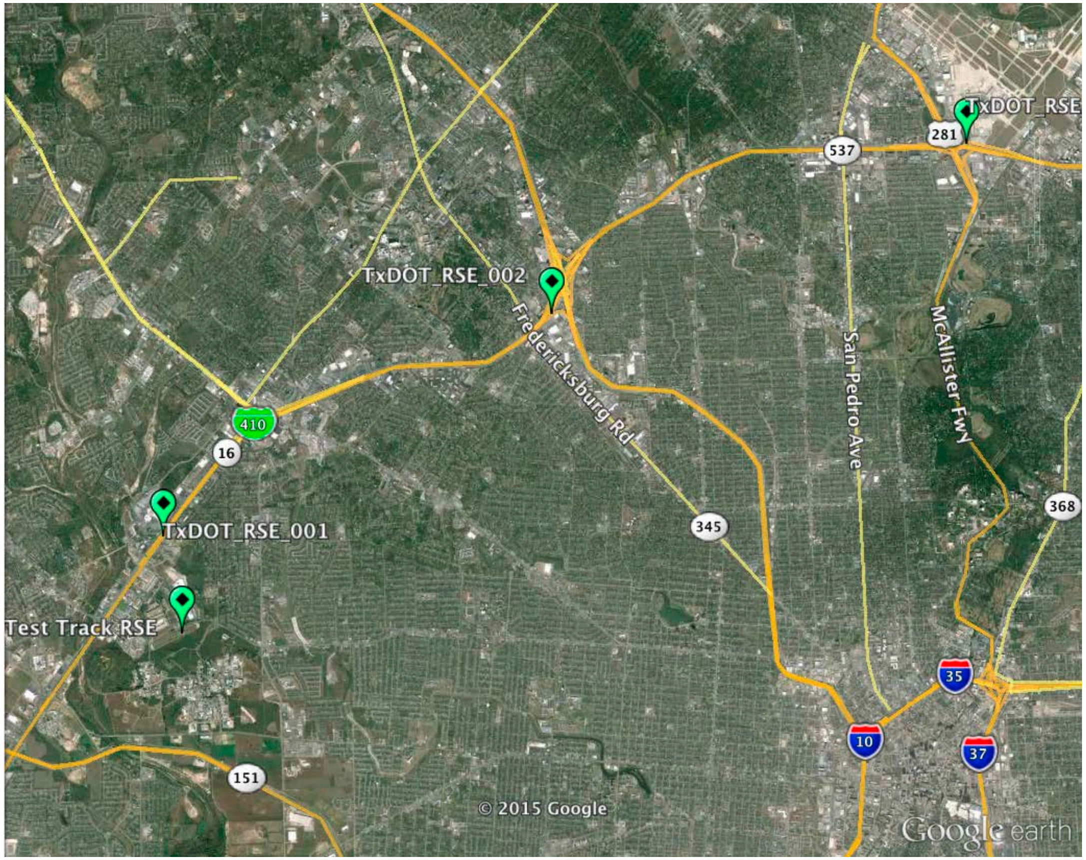


- ✓ Simple
- ✓ Modular design
- ✓ Self-contained
- ✓ 12V power source from vehicle
- ✓ Android tablet interface



Task 3.1a Hardware Preparation

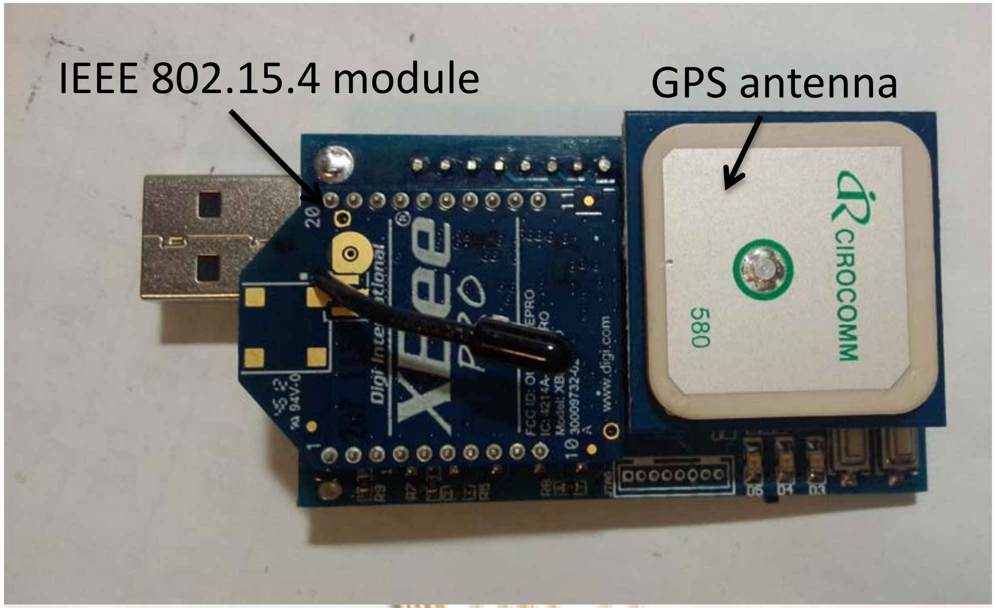
- 4 RSE devices are located in San Antonio
  - One on the SwRI campus, and
  - Three along IH-410 between Culebra road and SH-281
- RSE hardware issue affects reliability
  - Solution is to install a remote reset device. Will work with TxDOT in San Antonio to Schedule service

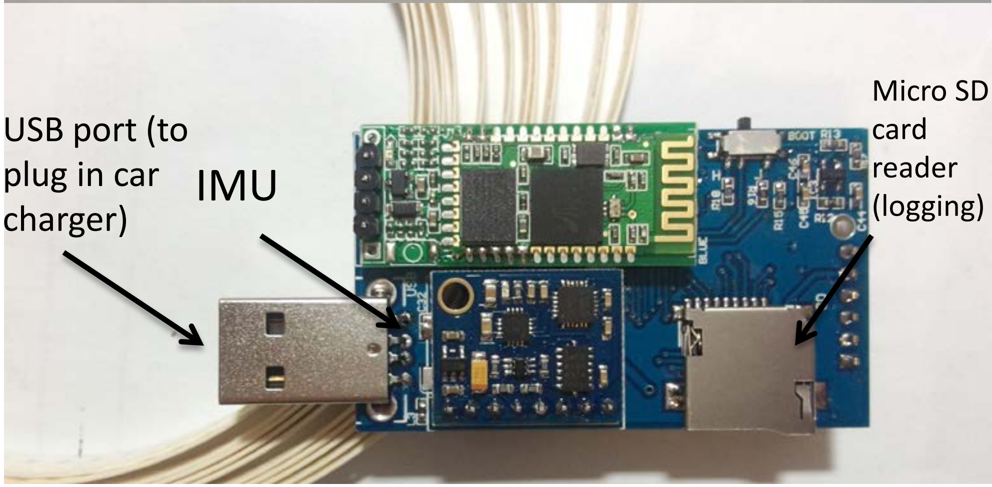


Task 3.1a Low cost IMU-based traffic sensing

- 20 custom-developed GPS-IMU with IEEE 802.15.4 transceiver boards for traffic sensing

- IMUs allow a better discrimination of the activities of the driver, to provide more contextualized traffic data

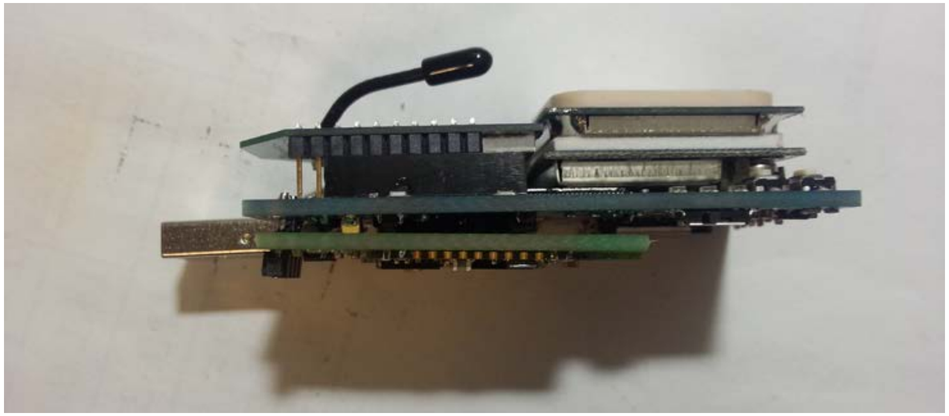




Task 3.1a Low cost IMU-based traffic sensing

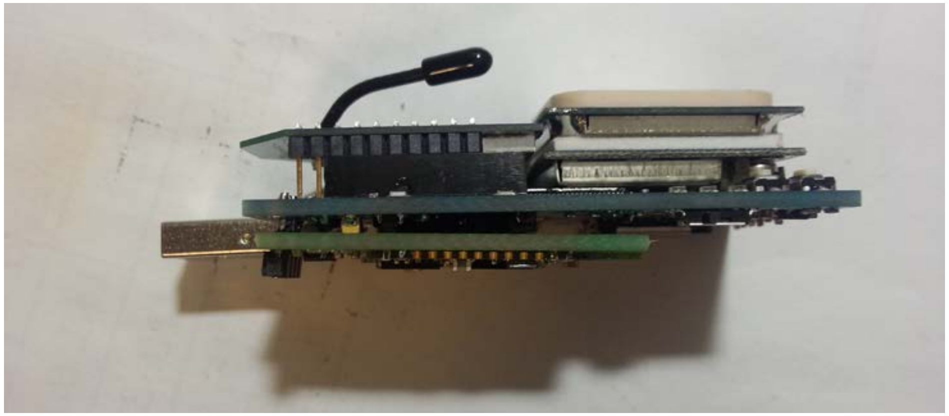
- First prototypes used for enhancing GPS position accuracy (through GPS-IMU fusion)

- In addition to generating traffic data, these devices can be used to monitor road condition (in collaboration with SwRI)



Task 3.1a Low cost IMU-based traffic sensing

- Second generation of prototypes (200 devices) will have no 802.15.4 transceiver, and will connect directly to a Bluetooth enabled smartphone to relay the data to a computer server
- Participating users will have a specific smartphone app to visualize the measurement data in real time

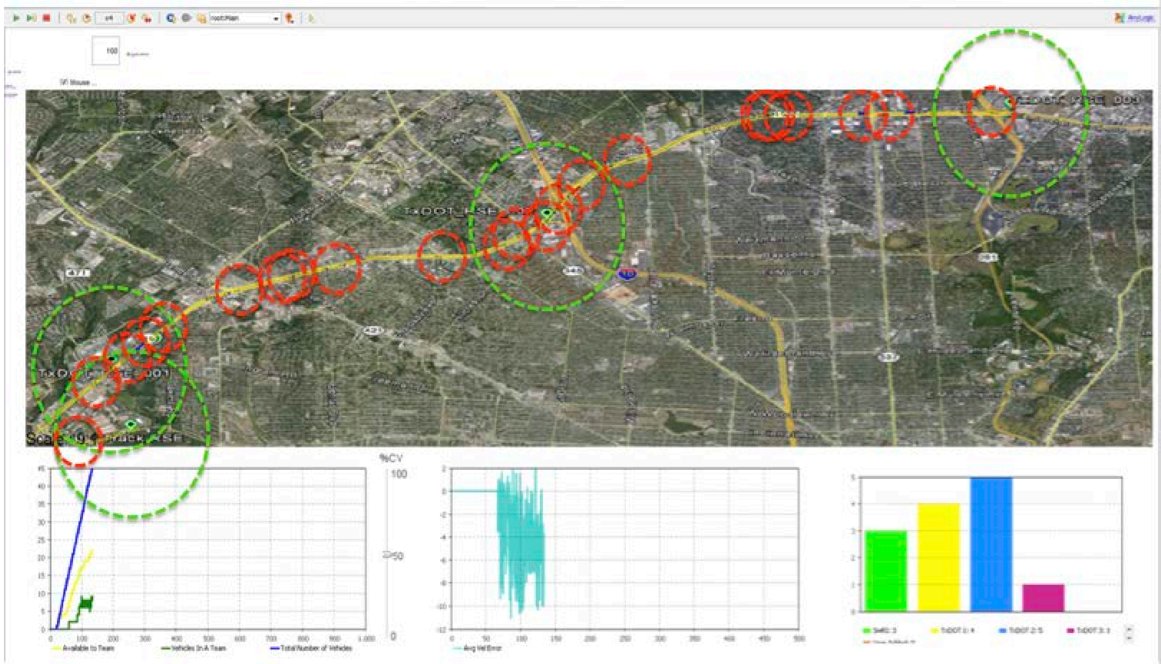


Task 3.1b List of Demonstrations

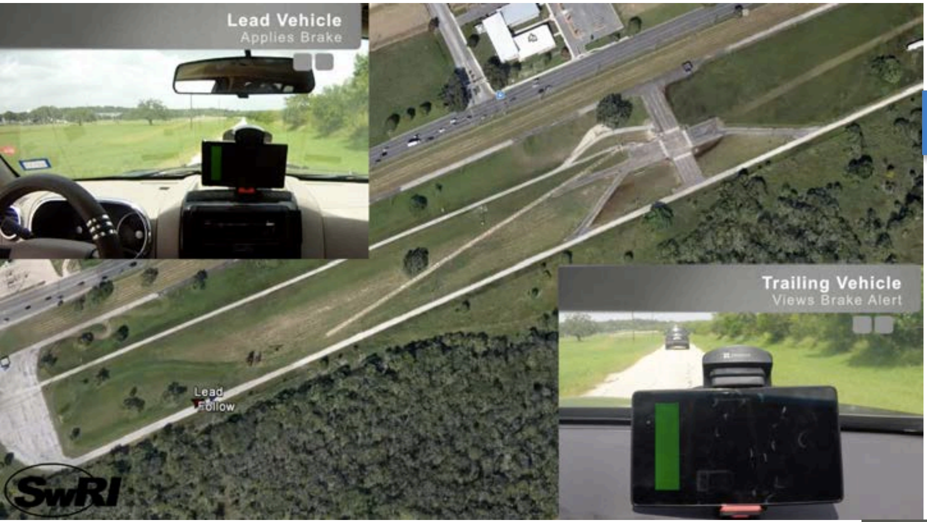
- Connected Vehicle Message Propagation (CVMP)
- Emergency Braking (EB)
- Road Condition Monitoring (RCM)
- Static Wrong-way Driver Detection (s-WWD)
- Dynamic Wrong-way Driving Detection(d-WWD)
- Emergency Vehicle Alert (EVA)

Connected Vehicle Message Propagation

- Enhanced an existing micro-simulation
  - Scaled geography
  - Green circles are RSE locations
  - Red circles are CV vehicles
- Will use this to simulate message propagation strategies – then transfer to PODs for testing and verification

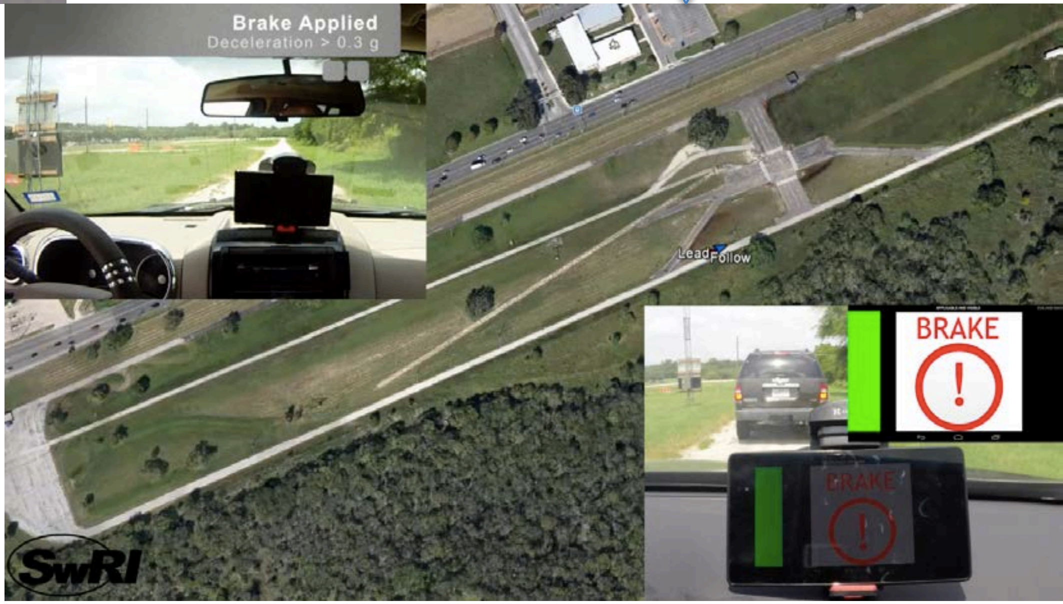


Emergency Braking



Normal Vehicle Following

Emergency Braking Event



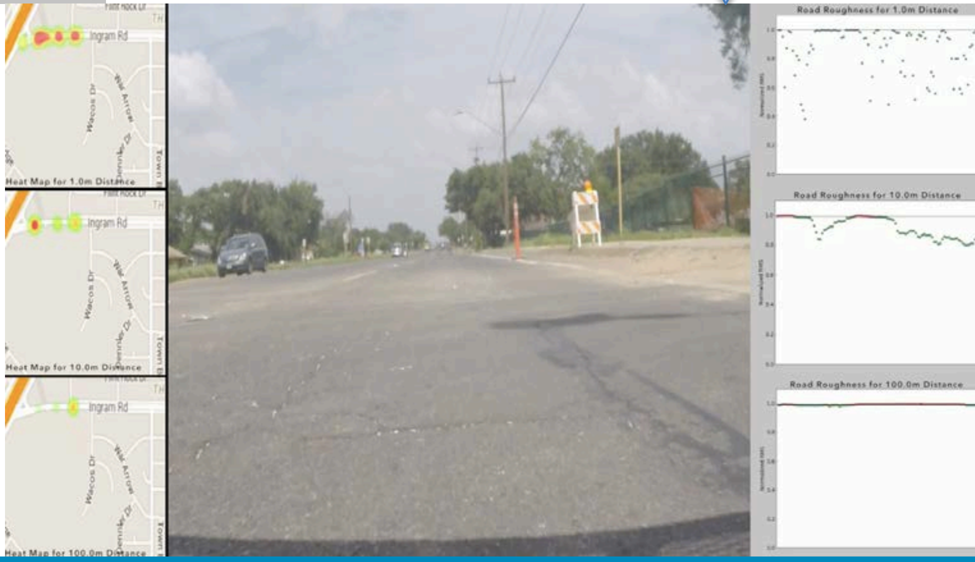
- ✓ Vehicle-to-vehicle communication using DSRC
- ✓ Outfit vehicles with SwRI PODs
- ✓ Demonstrate up to 5 vehicles with PODS, and SwRI autonomous vehicles

video

Road Condition Monitoring

Smooth Road

Rough Road



- IMU data analysis using:
  - SwRI MARTI autonomous vehicle
  - Modified Acura
- Visual integration with Google Earth via kml
- IMU data can be used to determine location and relative severity of “pothole” vs “rough road”
- Planned data collection using:
  - SwRI autonomous HMMWV 1165
  - SwRI autonomous Freightliner

video

Static Wrong-way Driver Detection

- SwRI can simulate a vehicle entering the wrong direction using our San Antonio test track.
  - SwRI's RSE receives vehicle BSMs
  - A road segment on the track is "defined" as a one-direction segment
  - A vehicle equipped with a SwRI POD or other DSRC device broadcasts its BSM while driving the "wrong direction" within the road segment
  - RSE broadcasts Roadside Service Announcement (RSA) to targeted vehicle in addition to other vehicles in vicinity
  - Visual display is integrated with Google Earth

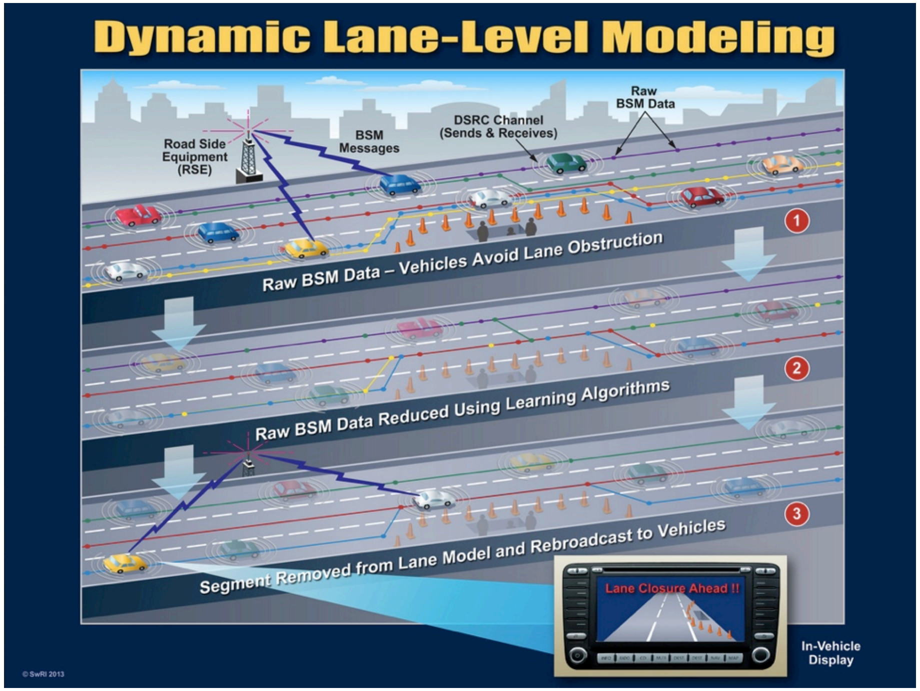
WWD Vehicle Display

RWD Vehicle Display

video

Dynamic Wrong-way Driver Detection

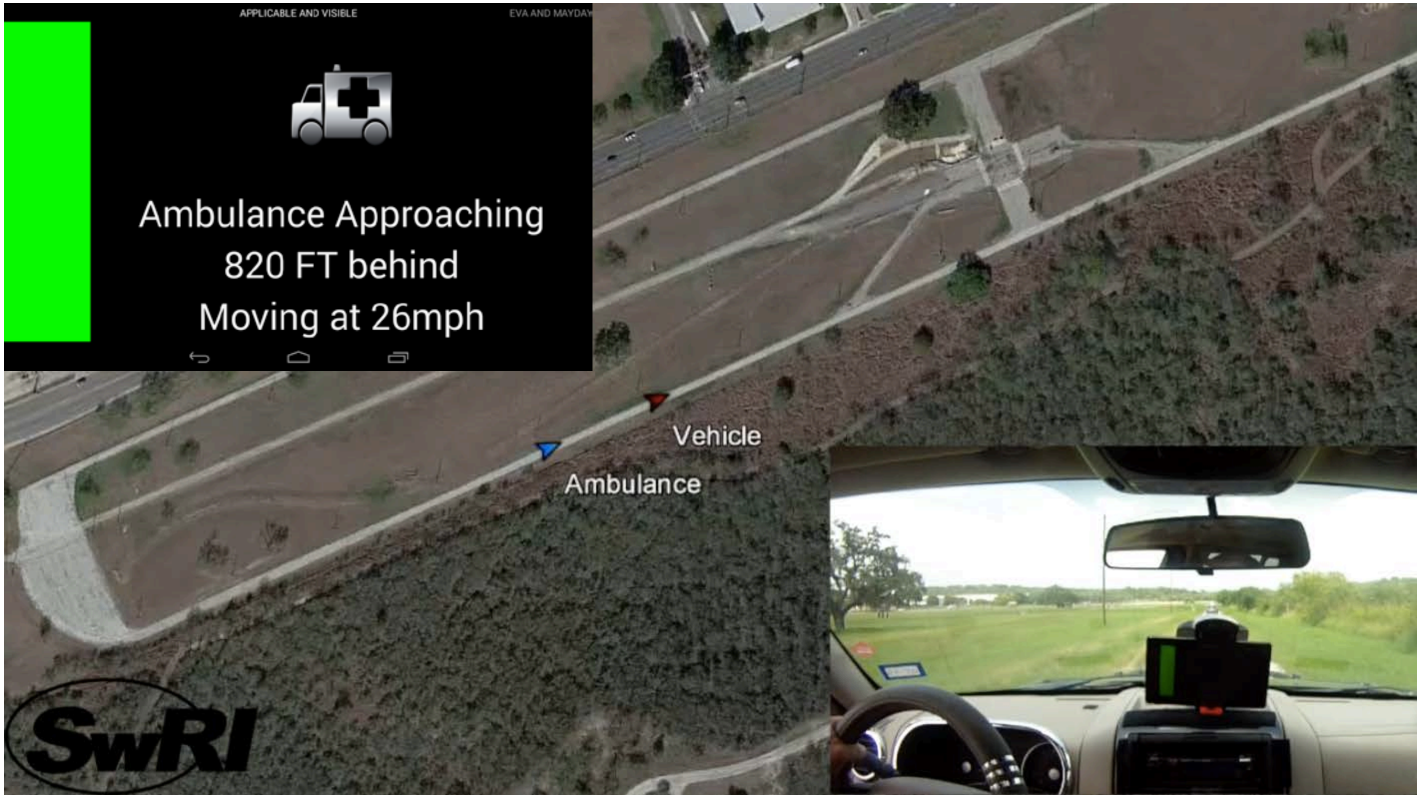
- An alternate method for WWD detection
  - An RSE “learns” the roadway through analysis of vehicle BSMs passing through its range
  - Lane geometry and direction can be determined
  - Once learned, a vehicle traveling in the opposite direction would be identified as a WWD
  - Alert other vehicles in the communication range of the RSE



Emergency Vehicle Alert (EVA)

- ✓ All five SwRI PODs can send and receive EVA messages
  - ✓ Each POD can be individually configured as an emergency vehicle for:
    - ✓ Ambulance
    - ✓ Police
    - ✓ Fire
  - ✓ Receiving POD determines from BSM the location, direction, and speed of the emergency vehicle

Vehicle Display for EVA



video

Thank You!

Questions or Suggestions?